

**INCH-POUND**

**MIL-HDBK-5H  
1 December 1998**

# **DEPARTMENT OF DEFENSE HANDBOOK**

## **METALLIC MATERIALS AND ELEMENTS FOR AEROSPACE VEHICLE STRUCTURES**



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**1 October 2001**

## **FOREWORD**

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4. This document contains design information on the strength properties of metallic materials and elements for aerospace vehicle structures. All information and data contained in this handbook have been coordinated with the Air Force, Army, Navy, Federal Aviation Administration, and industry prior to publication, and are being maintained as a joint effort of the Department of Defense and the Federal Aviation Administration.
5. The electronic copy of the Handbook is technically consistent with the paper-copy Handbook; however, minor differences exist in format; e.g., table or figure position. Depending on monitor size and resolution setting, more data may be viewed without on-screen magnification. The figures were converted to electronic format using one of several methods. For example, digitization or recomputation methods were used on most of the engineering figures like typical stress-strain and effect of temperature, etc. Scanning was used to capture informational figures such as those found in Chapters 1 and 9, as well as most of the S/N curves and the majority of graphics in Chapters 4 through 7. These electronic figures were also used to generate the paper copy figures to maintain equivalency between the paper copy and electronic copy. In all cases, the electronic figures have been compared to the paper copy figures to ensure the electronic figure was technically equivalent. Appendix E provides a detailed listing of all the figures in the Handbook, along with a description of each figure's format.

EXPLANATION OF NUMERICAL CODE

For chapters containing materials properties, a deci-numeric system is used to identify sections of text, tables, and illustrations. This system is explained in the examples shown below. Variations of this deci-numerical system are also used in Chapters 1, 8, and 9.

|                                                                                                                                                         |           |
|---------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| Example A                                                                                                                                               | 2.4.2.1.1 |
| General material category (in this case, steel)                                                                                                         |           |
| A logical breakdown of the base material by family characteristics<br>(in this case, intermediate alloy steels); or for element properties              |           |
| Particular alloy to which all data are pertinent. If zero, section contains comments<br>on the family characteristics                                   |           |
| If zero, section contains comments specific to the alloy; if it is an integer, the<br>number identifies a specific temper or condition (heat treatment) |           |
| Type of graphical data presented on a given figure<br>(see following description)                                                                       |           |

|                                                            |           |
|------------------------------------------------------------|-----------|
| Example B                                                  | 3.2.3.1.X |
| Aluminum                                                   |           |
| 2000 Series Wrought Alloy                                  |           |
| 2024 Alloy                                                 |           |
| T3, T351, T3510, T3511, T4, and T42 Tempers                |           |
| Specific Property as Follows                               |           |
| Tensile properties (ultimate and yield strength)           | 1         |
| Compressive yield and shear ultimate strengths             | 2         |
| Bearing properties (ultimate and yield strength)           | 3         |
| Modulus of elasticity, shear modulus                       | 4         |
| Elongation, total strain at failure, and reduction of area | 5         |
| Stress-strain curves, tangent-modulus curves               | 6         |
| Creep                                                      | 7         |
| Fatigue                                                    | 8         |
| Fatigue-Crack Propagation                                  | 9         |
| Fracture Toughness                                         | 10        |

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## CHAPTER 1

### GENERAL

#### 1.1 PURPOSE AND USE OF DOCUMENT

**1.1.1 INTRODUCTION** — Since many aerospace companies manufacture both commercial and military products, the standardization of metallic materials design data, which are acceptable to Government procuring or certification agencies is very beneficial to those manufacturers as well as governmental agencies. Although the design requirements for military and commercial products may differ greatly, the required design values for the strength of materials and elements and other needed material characteristics are often identical. Therefore, this publication provides standardized design values and related design information for metallic materials and structural elements used in aerospace structures. The data contained herein, or from approved items in the minutes of MIL-HDBK-5 coordination meetings, are acceptable to the Air Force, the Navy, the Army, and the Federal Aviation Administration. Approval by the procuring or certifying agency must be obtained for the use of design values for products not contained herein.

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**1.1.2 SCOPE OF HANDBOOK** — This Handbook is primarily intended to provide a source of design mechanical and physical properties, and joint allowables. Material property and joint data obtained from tests by material and fastener producers, government agencies, and members of the airframe industry are submitted to MIL-HDBK-5 for review and analysis. Results of these analyses are submitted to the membership during semi-annual coordination meetings for approval and, when approved, published in this Handbook.

This Handbook also contains some useful basic formulas for structural element analysis. However, structural design and analysis are beyond the scope of this Handbook.



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References for data and various test methods are listed at the end of each chapter. The reference number corresponds to the applicable paragraph of the chapter cited. Such references are intended to provide sources of additional information, but should not necessarily be considered as containing data suitable for design purposes.

The content of this Handbook is arranged as follows:

| <b>Chapter(s)</b> | <b>Subjects</b>                                                                                                                  |
|-------------------|----------------------------------------------------------------------------------------------------------------------------------|
| 1                 | Nomenclature, Systems of Units, Formulas, Material Property Definitions, Failure Analysis, Column Analysis, Thin-Walled Sections |
| 2-7               | Material Properties                                                                                                              |
| 8                 | Joint Allowables                                                                                                                 |
| 9                 | Data Requirements, Statistical Analysis Procedures                                                                               |

## **1.2 NOMENCLATURE**

**1.2.1 SYMBOLS AND DEFINITIONS** — The various symbols used throughout the Handbook to describe properties of materials, grain directions, test conditions, dimensions, and statistical analysis terminology are included in Appendix A.

**1.2.2 INTERNATIONAL SYSTEM OF UNITS (SI)** — Design properties and joint allowables contained in this Handbook are given in customary units of U.S. measure to ensure compatibility with government and industry material specifications and current aerospace design practice. Appendix A.4 may be used to assist in the conversion of these units to Standard International (SI) units when desired.

## **1.3 COMMONLY USED FORMULAS**

**1.3.1 GENERAL** — Formulas provided in the following sections are listed for reference purposes. Sign conventions generally accepted in their use are that quantities associated with tension action (loads, stresses, strains, etc., are usually considered as positive and quantities associated with compressive action are considered as negative. When compressive action is of primary interest, it is sometimes convenient to identify associated properties with a positive sign. Formulas for all statistical computations relating to allowables development are presented in Chapter 9.

### **1.3.2 SIMPLE UNIT STRESSES** —

|                                                                                                                                                                |            |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| $f_t = P / A$ (tension)                                                                                                                                        | [1.3.2(a)] |
| $f_c = P / A$ (compression)                                                                                                                                    | [1.3.2(b)] |
| $f_b = My / I = M / Z$                                                                                                                                         | [1.3.2(c)] |
| $f_s = S / A$ (average direct shear stress)                                                                                                                    | [1.3.2(d)] |
| $f_x = SQ / Ib$ (longitudinal or transverse shear stress)                                                                                                      | [1.3.2(e)] |
| $f_x = Ty / I_p$ (shear stress in round tubes due to torsion)                                                                                                  | [1.3.2(f)] |
| $f_s = (T/2At)$ (shear stress due to torsion in thin-walled structures of closed section. Note that A is the area enclosed by the median line of the section.) | [1.3.2(g)] |
| $f_A = Bf_H ; f_T = Bf_L$                                                                                                                                      | [1.3.2(h)] |

**1.3.3 COMBINED STRESSES (SEE SECTION 1.5.3.5) —**

$$f_A = f_c + f_b \text{ (compression and bending)} \quad [1.3.3(a)]$$

$$f_{s\max} = \left[ f_s^2 + (f_n/2)^2 \right]^{1/2} \text{ (compression, bending, and torsion)} \quad [1.3.3(b)]$$

$$f_{n\max} = f_n/2 + f_{s\max} \quad [1.3.3(c)]$$

**1.3.4 DEFLECTIONS (AXIAL) —**

$$e = \delta / L \text{ (unit deformation or strain)} \quad [1.3.4(a)]$$

$$E = f/e \text{ (This equation applied when E is obtained from the same tests in which f and e are measured.)} \quad [1.3.4(b)]$$

$$\delta = eL = (f / E)L \quad [1.3.4(c)]$$

$$= PL / (AE) \text{ (This equation applies when the deflection is to be calculated using a known value of E.)} \quad [1.3.4(d)]$$

**1.3.5 DEFLECTIONS (BENDING) —**

$$di/dx = M / (EI) \text{ (Change of slope per unit length of a beam; radians per unit length)} \quad [1.3.5(a)]$$

$$i_2 = i_1 + \int_{x_1}^{x_2} [M/(EI)] dx \text{ — Slope at Point 2. (This integral denotes the area under the curve of M/EI plotted against x, between the limits of } x_1 \text{ and } x_2.) \quad [1.3.5(b)]$$

$$y_2 = y_1 + i(x_2 - x_1) + \int_{x_1}^{x_2} (M / EI)(x_2 - x) dx \text{ — Deflection at Point 2.} \quad [1.3.5(c)]$$

(This integral denotes the area under the curve having an ordinate equal to M/EI multiplied by the corresponding distances to Point 2, plotted against x, between the limits of  $x_1$  and  $x_2$ .)

$$y_2 = y_1 + \int_{x_1}^{x_2} i dx \text{ — Deflection at Point 2. (This integral denotes the area under the curve of } x_1(i) \text{ plotted against x, between the limits of } x_1 \text{ and } x_2.) \quad [1.3.5(d)]$$

**1.3.6 DEFLECTIONS (TORSION) —**

$$d\phi / dx = T / (GJ) \text{ (Change of angular deflection or twist per unit length of a member, radians per unit length.)} \quad [1.3.6(a)]$$

$$\Phi = \int_{x_1}^{x_2} [T / (GJ)] dx \text{ — Total twist over a length from } x_1 \text{ to } x_2. \text{ (This integral denotes the area under the curve of } T/GJ \text{ plotted against x, between the limits of } x_1 \text{ and } x_2.) \quad [1.3.6(b)]$$

$$\Phi = TL/(GJ) \text{ (Used when torque } T/GJ \text{ is constant over length L.)} \quad [1.3.6(c)]$$

**1.3.7 BIAXIAL ELASTIC DEFORMATION —**

$\mu = e_T/e_L$  (Unit lateral deformation/unit axial deformation.) This identifies Poisson's ratio in uniaxial loading. [1.3.7(a)]

$Ee_x = f_x - \mu f_y$  [1.3.7(b)]

$Ee_y = f_y - \mu f_x$  [1.3.7(c)]

$E_{\text{biaxial}} = E(1 - \mu B)$  —  $B$  = biaxial elastic modulus. [1.3.7(d)]

**1.3.8 BASIC COLUMN FORMULAS —**

$F_c = \pi^2 E_t (L' / \rho)^2$  where  $L' = L / \sqrt{c}$  — conservative using tangent modulus [1.3.8(a)]

$F_c = \pi^2 E (L' / \rho)^2$  — standard Euler formula [1.3.8(b)]

**1.4 BASIC PRINCIPLES**

**1.4.1 GENERAL** — It is assumed that users of this Handbook are familiar with the principles of strength of materials. A brief summary of that subject is presented in the following paragraphs to emphasize principles of importance regarding the use of allowables for various metallic materials.

Requirements for adequate test data have been established to ensure a high degree of reliability for allowables published in this Handbook. Statistical analysis methods, provided in Chapter 9, are standardized and approved by all government regulatory agencies as well as MIL-HDBK-5 members from industry.

**1.4.1.1 Basis** — Primary static design properties are provided for the following conditions:

|                       |                         |
|-----------------------|-------------------------|
| Tension . . . . .     | $F_{tu}$ and $F_{ty}$   |
| Compression . . . . . | $F_{cy}$                |
| Shear . . . . .       | $F_{su}$                |
| Bearing . . . . .     | $F_{bru}$ and $F_{bry}$ |

These design properties are presented as A- and B- or S-basis room temperature values for each alloy. Design properties for other temperatures, when determined in accordance with Section 1.4.1.3, are regarded as having the same basis as the corresponding room temperature values.

Elongation and reduction of area design properties listed in room temperature property tables represent procurement specification minimum requirements, and are designated as S-values. Elongation and reduction of area at other temperatures, as well as moduli, physical properties, creep properties, fatigue properties and fracture toughness properties are all typical values unless another basis is specifically indicated.

Use of B-Values — The use of B-basis design properties is permitted in design by the Air Force, the Army, the Navy, and the Federal Aviation Administration, subject to certain limitations specified by each agency. Reference should be made to specific requirements of the applicable agency before using B-values in design.

**1.4.1.2 Statistically Calculated Values** — Statistically calculated values are  $S$  (since 1975),  $T_{99}$  and  $T_{90}$ .  $S$ , the minimum properties guaranteed in the material specification, are calculated using the same requirements and procedure as AMS and is explained in Chapter 9.  $T_{99}$  and  $T_{90}$  are the local tolerance bounds, and are defined and may be computed using the data requirements and statistical procedures explained in Chapter 9.

**1.4.1.3 Ratioed Values** — A ratioed design property is one that is determined through its relationship with an established design value. This may be a tensile stress in a different grain direction from the established design property grain direction, or it may be another stress property, e.g., compression, shear or bearing. It may also be the same stress property at a different temperature. Refer to Chapter 9 for specific data requirements and data analysis procedures.

Derived properties are presented in two manners. Room temperature derived properties are presented in tabular form with their baseline design properties. Other than room temperature derived properties are presented in graphical form as percentages of the room temperature value. Percentage values apply to all forms and thicknesses shown in the room temperature design property table for the heat treatment condition indicated therein unless restrictions are otherwise indicated. Percentage curves usually represent short time exposures to temperature (thirty minutes) followed by testing at the same strain rate as used for the room temperature tests. When data are adequate, percentage curves are shown for other exposure times and are appropriately labeled.

**1.4.2 STRESS** — The term “stress” as used in this Handbook implies a force per unit area and is a measure of the intensity of the force acting on a definite plane passing through a given point (see Equations 1.3.2(a) and 1.3.2(b)). The stress distribution may or may not be uniform, depending on the nature of the loading condition. For example, tensile stresses identified by Equation 1.3.2(a) are considered to be uniform. The bending stress determined from Equation 1.3.2(c) refers to the stress at a specified distance perpendicular to the normal axis. The shear stress acting over the cross section of a member subjected to bending is not uniform. (Equation 1.3.2(d) gives the average shear stress.)

**1.4.3 STRAIN** — Strain is the change in length per unit length in a member or portion of a member. As in the case of stress, the strain distribution may or may not be uniform in a complex structural element, depending on the nature of the loading condition. Strains usually are present also in directions other than the directions of applied loads.

**1.4.3.1 Poisson’s Ratio Effect** — A normal strain is that which is associated with a normal stress; a normal strain occurs in the direction in which its associated normal stress acts. Normal strains that result from an increase in length are designated as positive (+) and those that result in a decrease in length are designated as negative (-).

Under the condition of uniaxial loading, strain varies directly with stress. The ratio of stress to strain has a constant value ( $E$ ) within the elastic range of the material, but decreases when the proportional limit is exceeded (plastic range). Axial strain is always accompanied by lateral strains of opposite sign in the two directions mutually perpendicular to the axial strain. Under these conditions, the absolute value of a ratio of lateral strain to axial strain is defined as Poisson’s ratio. For stresses within the elastic range, this ratio is approximately constant. For stresses exceeding the proportional limit, this ratio is a function of the axial strain and is then referred to as the lateral contraction ratio. Information on the variation of Poisson’s ratio with strain and with testing direction is available in Reference 1.4.3.1.

Under multiaxial loading conditions, strains resulting from the application of each directional load are additive. Strains must be calculated for each of the principal directions taking into account each of the principal stresses and Poisson’s ratio (see Equations 1.3.7.2 and 1.3.7.3 for biaxial loading).

**1.4.3.2 Shear Strain** — When an element of uniform thickness is subjected to pure shear, each side of the element will be displaced in opposite directions. Shear strain is computed by dividing this total displacement by the right angle distance separating the two sides.

**1.4.3.3 Strain Rate** — Strain rate is a function of loading rate. Test results are dependent upon strain rate, and the ASTM testing procedures specify appropriate strain rates. Design properties in this Handbook were developed from test data obtained from coupons tested at the stated strain rate or up to a value of 0.01 in./in./min, the standard maximum static rate for tensile testing materials per specification ASTM E 8.

**1.4.3.4 Elongation and Reduction of Area** — Elongation and reduction of area are measured in accordance with specification ASTM E 8.

**1.4.4 TENSILE PROPERTIES** — When a metallic specimen is tested in tension using standard procedures of ASTM E 8, it is customary to plot results as a “stress-strain diagram.” Typical tensile stress-strain diagrams are characterized in Figure 1.4.4. Such diagrams, drawn to scale, are provided in appropriate chapters of this Handbook. The general format of such diagrams is to provide a strain scale nondimensionally (in./in.) and a stress scale in 1000 lb/in. (ksi). Properties required for design and structural analysis are discussed in Sections 1.4.4.1 to 1.4.4.6.

**1.4.4.1 Modulus of Elasticity (E)** — Referring to Figure 1.4.4, it is noted that the initial part of stress-strain curves are straight lines. This indicates a constant ratio between stress and strain. Numerical values of such ratios are defined as the modulus of elasticity, and denoted by the letter E. This value applies up to the proportional limit stress at which point the initial slope of the stress-strain curve then decreases. Modulus of elasticity has the same units as stress. See Equation 1.3.4 (b).

Other moduli of design importance are tangent modulus,  $E_t$ , and secant modulus,  $E_s$ . Both of these moduli are functions of strain. Tangent modulus is the instantaneous slope of the stress-strain curve at any selected value of strain. Secant modulus is defined as the ratio of total stress to total strain at any selected value of strain. Both of these moduli are used in structural element designs. Except for materials such as those described with discontinuous behaviors, such as the upper stress-strain curve in Figure 1.4.4, tangent modulus is the lowest value of modulus at any state of strain beyond the proportional limit. Similarly, secant modulus is the highest value of modulus beyond the proportional limit.

Clad aluminum alloys may have two separate modulus of elasticity values, as indicated in the typical stress-strain curve shown in Figure 1.4.4. The initial slope, or primary modulus, denotes a response of both the low-strength cladding and higher-strength core elastic behaviors. This value applies only up to the proportional limit of the cladding. For example, the primary modulus of 2024-T3 clad sheet applies only up to about 6 ksi. Similarly, the primary modulus of 7075-T6 clad sheet applies only up to approximately 12 ksi. A typical use of primary moduli is for low amplitude, high frequency fatigue. Primary moduli are not applicable at higher stress levels. Above the proportional limits of cladding materials, a short transition range occurs while the cladding is developing plastic behavior. The material then exhibits a secondary elastic modulus up to the proportional limit of the core material. This secondary modulus is the slope of the second straight line portion of the stress-strain curve. In some cases, the cladding is so little different from the core material that a single elastic modulus value is used.

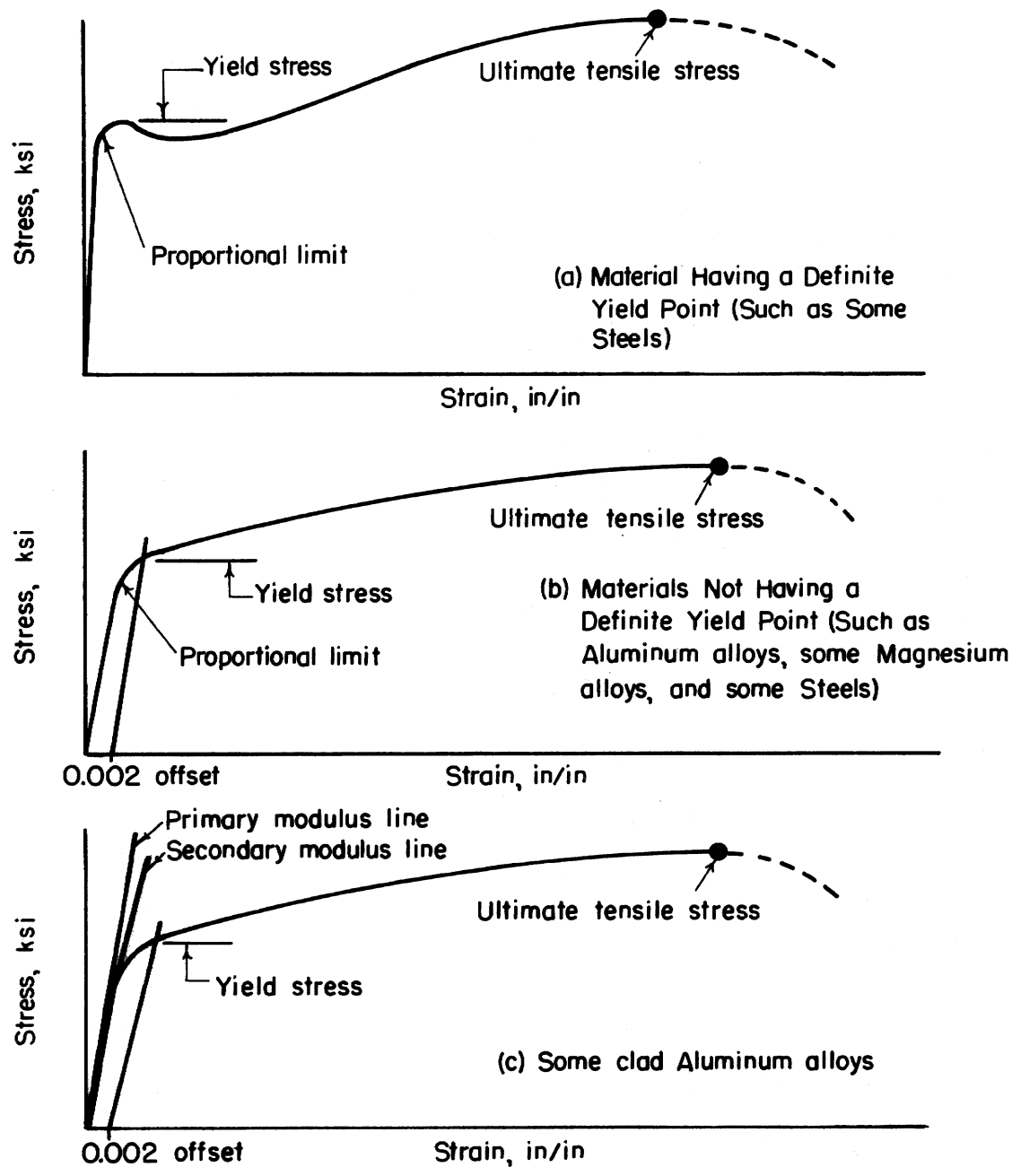


Figure 1.4.4. Typical tensile stress-strain diagrams.

**1.4.4.2 Tensile Proportional Limit Stress ( $F_{tp}$ )** — The tensile proportional limit is the maximum stress for which strain remains proportional to stress. Since it is practically impossible to determine precisely this point on a stress-strain curve, it is customary to assign a small value of plastic strain to identify the corresponding stress as the proportional limit. In this Handbook, the tension and compression proportional limit stress corresponds to a plastic strain of 0.0001 in./in.

**1.4.4.3 Tensile Yield Stress (TYS or  $F_{ty}$ )** — Stress-strain diagrams for some ferrous alloys exhibit a sharp break at a stress below the tensile ultimate strength. At this critical stress, the material elongates considerably with no apparent change in stress. See the upper stress-strain curve in Figure 1.4.4. The stress at which this occurs is referred to as the yield point. Most nonferrous metallic alloys and most high strength steels do not exhibit this sharp break, but yield in a monotonic manner. This condition is also illustrated in Figure 1.4.4. Permanent deformation may be detrimental, and the industry adopted 0.002 in./in. plastic strain as an arbitrary limit that is considered acceptable by all regulatory agencies. For tension and compression, the corresponding stress at this offset strain is defined as the yield stress (see Figure 1.4.4). This value of plastic axial strain is 0.002 in./in. and the corresponding stress is defined as the yield stress. For practical purposes, yield stress can be determined from a stress-strain diagram by extending a line parallel to the elastic modulus line and offset from the origin by an amount of 0.002 in./in. strain. The yield stress is determined as the intersection of the offset line with the stress-strain curve.

**1.4.4.4 Tensile Ultimate Stress (TUS or  $F_{ty}$ )** — Figure 1.4.4 shows how the tensile ultimate stress is determined from a stress-strain diagram. It is simply the maximum stress attained. It should be noted that all stresses are based on the original cross-sectional dimensions of a test specimen, without regard to the lateral contraction due to Poisson's ratio effects. That is, all strains used herein are termed engineering strains as opposed to true strains which take into account actual cross sectional dimensions. Ultimate tensile stress is commonly used as a criterion of the strength of the material for structural design, but it should be recognized that other strength properties may often be more important.

**1.4.4.5 Elongation (e)** — An additional property that is determined from tensile tests is elongation. This is a measure of ductility. Elongation, also stated as total elongation, is defined as the permanent increase in gage length, measured after fracture of a tensile specimen. It is commonly expressed as a percentage of the original gage length. Elongation is usually measured over a gage length of 2 inches for rectangular tensile test specimens and in 4D (inches) for round test specimens. Welded test specimens are exceptions. Refer to the applicable material specification for applicable specified gage lengths. Although elongation is widely used as an indicator of ductility, this property can be significantly affected by testing variables, such as thickness, strain rate, and gage length of test specimens. See Section 1.4.1.1 for data basis.

**1.4.4.6 Reduction of Area (RA)** — Another property determined from tensile tests is reduction of area, which is also a measure of ductility. Reduction of area is the difference, expressed as a percentage of the original cross sectional area, between the original cross section and the minimum cross sectional area adjacent to the fracture zone of a tested specimen. This property is less affected by testing variables than elongation, but is more difficult to compute on thin section test specimens. See Section 1.4.1.1 for data basis.

**1.4.5 COMPRESSIVE PROPERTIES** — Results of compression tests completed in accordance with ASTM E 9 are plotted as stress-strain curves similar to those shown for tension in Figure 1.4.4. Preceding remarks concerning tensile properties of materials, except for ultimate stress and elongation, also apply to compressive properties. Moduli are slightly greater in compression for most of the commonly used structural metallic alloys. Special considerations concerning the ultimate compressive stress are described in the following section. An evaluation of techniques for obtaining compressive strength properties of thin sheet materials is outlined in Reference 1.4.5.

**1.4.5.1 Compressive Ultimate Stress ( $F_{cu}$ )** — Since the actual failure mode for the highest tension and compression stress is shear, the maximum compression stress is limited to  $F_{tu}$ . The driver for all the analysis of all structure loaded in compression is the slope of the compression stress strain curve, the tangent modulus.

**1.4.5.2 Compressive Yield Stress (CYS or  $F_{cy}$ )** — Compressive yield stress is measured in a manner identical to that done for tensile yield strength. It is defined as the stress corresponding to 0.002 in./in. plastic strain.

**1.4.6 SHEAR PROPERTIES** — Results of torsion tests on round tubes or round solid sections are plotted as torsion stress-strain diagrams. The shear modulus of elasticity is considered a basic shear property. Other properties, such as the proportional limit stress and shear ultimate stress, cannot be treated as basic shear properties because of “form factor” effects. The theoretical ratio between shear and tensile stress for homogeneous, isotropic materials is 0.577. Reference 1.4.6 contains additional information on this subject.

**1.4.6.1 Modulus of Rigidity (G)** — This property is the initial slope of the shear stress-strain curve. It is also referred to as the modulus of elasticity in shear. The relation between this property and the modulus of elasticity in tension is expressed for homogeneous isotropic materials by the following equation:

$$G = \frac{E}{2(1 + \mu)} \quad [1.4.6.1]$$

**1.4.6.2 Proportional Limit Stress in Shear ( $F_{sp}$ )** — This property is of particular interest in connection with formulas which are based on considerations of linear elasticity, as it represents the limiting value of shear stress for which such formulas are applicable. This property cannot be determined directly from torsion tests.

**1.4.6.3 Yield and Ultimate Stresses in Shear ( $F_{sy}$  or  $F_{sy}$ ) and ( $F_{su}$  or  $F_{su}$ )** — These properties, as usually obtained from ASTM test procedures tests, are not strictly basic properties, as they will depend on the shape of the test specimen. In such cases, they should be treated as moduli and should not be combined with the same properties obtained from other specimen configuration tests.

Design values reported for shear ultimate stress ( $F_{su}$ ) in room temperature property tables for aluminum and magnesium thin sheet alloys are based on “punch” shear type tests except when noted. Heavy section test data are based on “pin” tests. Thin aluminum products may be tested to ASTM B 831, which is a slotted shear test (this test is used for other alloys; however, the standard doesn’t specifically cover materials other than aluminum). Thicker aluminums use ASTM B 769, otherwise known as the Amsler shear test. These two tests only provide ultimate strength. Shear data for other alloys are obtained from pin tests, except where product thicknesses are insufficient.

**1.4.7 BEARING PROPERTIES** — Bearing stress limits are of value in the design of mechanically fastened joints and lugs. Only yield and ultimate stresses are obtained from bearing tests. Bearing stress is computed from test data by dividing the load applied to the pin, which bears against the edge of the hole, by the bearing area. Bearing area is the product of the pin diameter and the sheet or plate thickness.

A bearing test requires the use of special cleaning procedures as specified in ASTM E 238. Results are identified as “dry-pin” values. The same tests performed without application of ASTM E 238 cleaning procedures are referred to as “wet pin” tests. Results from such tests can show bearing stresses at least 10 percent lower than those obtained from “dry pin” tests. See Reference 1.4.7 for additional information.



Additionally, ASTM E 238 requires the use of hardened pins that have diameters within 0.001 of the hole diameter. As the clearance increases to 0.001 and greater, the bearing yield and failure stress tends to decrease.

In the definition of bearing values,  $t$  is sheet or plate thickness,  $D$  is the pin diameter, and  $e$  is the edge distance measured from the center of the hole to the adjacent edge of the material being tested in the direction of applied load.

**1.4.7.1 Bearing Yield and Ultimate Stresses (BYS or  $F_{bry}$ ) and (BUS or  $F_{bru}$ )** — BUS is the maximum stress withstood by a bearing specimen. BYS is computed from a bearing stress-deformation curve by drawing a line parallel to the initial slope at an offset of 0.02 times the pin diameter.

Tabulated design properties for bearing yield stress ( $F_{bry}$ ) and bearing ultimate stress ( $F_{bru}$ ) are provided throughout the Handbook for edge margins of  $e/D = 1.5$  and  $2.0$ . Bearing values for  $e/D$  of  $1.5$  are not intended for designs of  $e/D < 1.5$ . Bearing values for  $e/D < 1.5$  must be substantiated by adequate tests, subject to the approval of the procuring or certificating regulatory agency. For edge margins between  $1.5$  and  $2.0$ , linear interpolation of properties may be used.

Bearing design properties are applicable to  $t/D$  ratios from  $0.25$  to  $0.50$ . Bearing design values for conditions of  $t/D < 0.25$  or  $t/D > 0.50$  must be substantiated by tests. The percentage curves showing temperature effects on bearing stress may be used with both  $e/D$  properties of  $1.5$  and  $2.0$ .

Due to differences in results obtained between dry-pin and wet-pin tests, designers are encouraged to consider the use of a reduction factor with published bearing stresses for use in design.

**1.4.8 TEMPERATURE EFFECTS** — Temperature effects require additional considerations for static, fatigue and fracture toughness properties. In addition, this subject introduces concerns for time-dependent creep properties.

**1.4.8.1 Low Temperature** — Temperatures below room temperature generally cause an increase in strength properties of metallic alloys. Ductility, fracture toughness, and elongation usually decrease. For specific information, see the applicable chapter and references noted therein.

**1.4.8.2 Elevated Temperature** — Temperatures above room temperature usually cause a decrease in the strength properties of metallic alloys. This decrease is dependent on many factors, such as temperature and the time of exposure which may degrade the heat treatment condition, or cause a metallurgical change. Ductility may increase or decrease with increasing temperature depending on the same variables. Because of this dependence of strength and ductility at elevated temperatures on many variables, it is emphasized that the elevated temperature properties obtained from this Handbook be applied for only those conditions of exposure stated herein.

The effect of temperature on static mechanical properties is shown by a series of graphs of property (as percentages of the room temperature allowable property) versus temperature. Data used to construct these graphs were obtained from tests conducted over a limited range of strain rates. Caution should be exercised in using these static property curves at very high temperatures, particularly if the strain rate intended in design is much less than that stated with the graphs. The reason for this concern is that at very low strain rates or under sustained loads, plastic deformation or creep deformation may occur to the detriment of the intended structural use.

**1.4.8.2.1 Creep and Stress-Rupture Properties** — Creep is defined as a time-dependent deformation of a material while under an applied load. It is usually regarded as an elevated temperature phenomenon, although some materials creep at room temperature. If permitted to continue indefinitely, creep terminates in rupture. Since creep in service is usually typified by complex conditions of loading and temperature, the number of possible stress-temperature-time profiles is infinite. For economic reasons, creep data for general design use are usually obtained under conditions of constant uniaxial loading and constant temperature in accordance with Reference 1.4.8.2.1(a). Creep data are sometimes obtained under conditions of cyclic uniaxial loading and constant temperature, or constant uniaxial loading and variable temperatures. Section 9.3.6 provides a limited amount of creep data analysis procedures. It is recognized that, when significant creep appears likely to occur, it may be necessary to test under simulated service conditions because of difficulties posed in attempting to extrapolate from simple to complex stress-temperature-time conditions.

Creep damage is cumulative similar to plastic strain resulting from multiple static loadings. This damage may involve significant effects on the temper of heat treated materials, including annealing, and the initiation and growth of cracks or subsurface voids within a material. Such effects are often recognized as reductions in short time strength properties or ductility, or both.

**1.4.8.2.2 Creep-Rupture Curve** — Results of tests conducted under constant loading and constant temperature are usually plotted as strain versus time up to rupture. A typical plot of this nature is shown in Figure 1.4.8.2.2. Strain includes both the instantaneous deformation due to load application and the plastic strain due to creep. Other definitions and terminology are provided in Section 9.3.6.2.

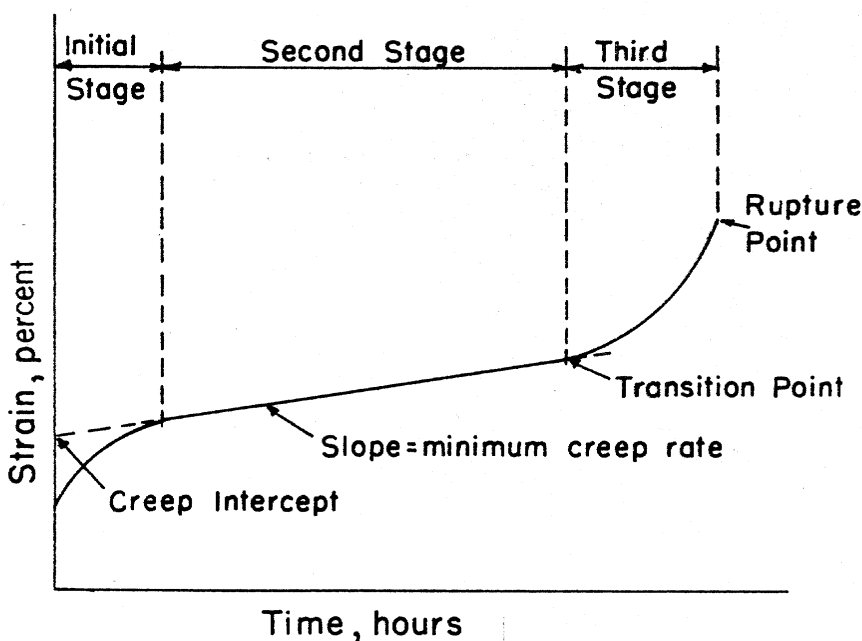


**Figure 1.4.8.2.2. Typical creep-rupture curve.**

**1.4.8.2.3 Creep or Stress-Rupture Presentations** — Results of creep or stress-rupture tests conducted over a range of stresses and temperatures are presented as curves of stress versus the logarithm of time to rupture. Each curve represents an average, best-fit description of measured behavior. Modification of such curves into design use are the responsibility of the design community since material applications and regulatory requirements may differ. Refer to Section 9.3.6 for data reduction and presentation methods and References 1.4.8.2.1(b) and (c).

**1.4.9 FATIGUE PROPERTIES** — Repeated loads are one of the major considerations for design of both commercial and military aircraft structures. Static loading, preceded by cyclic loads of lesser magnitudes, may result in mechanical behaviors ( $F_{tu}$ ,  $F_{ty}$ , etc.) lower than those published in room temperature allowables tables. Such reductions are functions of the material and cyclic loading conditions. A fatigue allowables development philosophy is not presented in this Handbook. However, basic laboratory test data are useful for materials selection. Such data are therefore provided in the appropriate materials sections.

In the past, common methods of obtaining and reporting fatigue data included results obtained from axial loading tests, plate bending tests, rotating bending tests, and torsion tests. Rotating bending tests apply completely reversed (tension-compression) stresses to round cross section specimens. Tests of this type are now seldom conducted for aerospace use and have therefore been dropped from importance in this Handbook. For similar reasons, flexural fatigue data also have been dropped. No significant amount of torsional fatigue data have ever been made available. Axial loading tests, the only type retained in this Handbook, consist of completely reversed loading conditions (mean stress equals zero) and those in which the mean stress was varied to create different stress (or strain) ratios ( $R$  = minimum stress or strain divided by maximum stress or strain). Refer to Reference 1.4.9(a) for load control fatigue testing guidelines and Reference 1.4.9(b) for strain control fatigue testing guidelines.

**1.4.9.1 Terminology** — A number of symbols and definitions are commonly used to describe fatigue test conditions, test results and data analysis techniques. The most important of these are described in Section 9.3.4.2.

**1.4.9.2 Graphical Display of Fatigue Data** — Results of axial fatigue tests are reported on S-N and  $\epsilon$  - N diagrams. Figure 1.4.9.2(a) shows a family of axial load S-N curves. Data for each curve represents a separate R-value.

S-N and  $\epsilon$  - N diagrams are shown in this Handbook with the raw test data plotted for each stress or strain ratio or, in some cases, for a single value of mean stress. A best-fit curve is drawn through the data at each condition. Rationale used to develop best-fit curves and the characterization of all such curves in a single diagram is explained in Section 9.3.4. For load control test data, individual curves are usually based on an equivalent stress which consolidates data for all stress ratios into a single curve. Refer to Figure 1.4.9.2(b). For strain control test data, an equivalent strain consolidation method is used.

Elevated temperature fatigue test data are treated in the same manner as room temperature data, as long as creep is not a significant factor and room temperature analysis methods can be applied. In the limited number of cases where creep strain data have been recorded as a part of an elevated temperature fatigue test series, S-N (or  $\epsilon$  - N) plots are constructed for specific creep strain levels. This is provided in addition to the customary plot of maximum stress (or strain) versus cycles to failure.

The above information may not apply directly to the design of structures for several reasons. First, Handbook information may not take into account specific stress concentrations unique to any given structural design. Design considerations usually include stress concentrations caused by reentrant corners, notches, holes, joints, rough surfaces, structural damage, and other conditions. Localized high stresses induced during the fabrication of some parts have a much greater influence on fatigue properties than on static properties.

These factors significantly reduce fatigue life below that which is predictable by estimating smooth specimen fatigue performance with estimated stresses due to fabrication. Fabricated parts have been found to fail at less than 50,000 cycles of loading when the nominal stress was far below that which could be repeated many millions of times using a smooth machined test specimen.

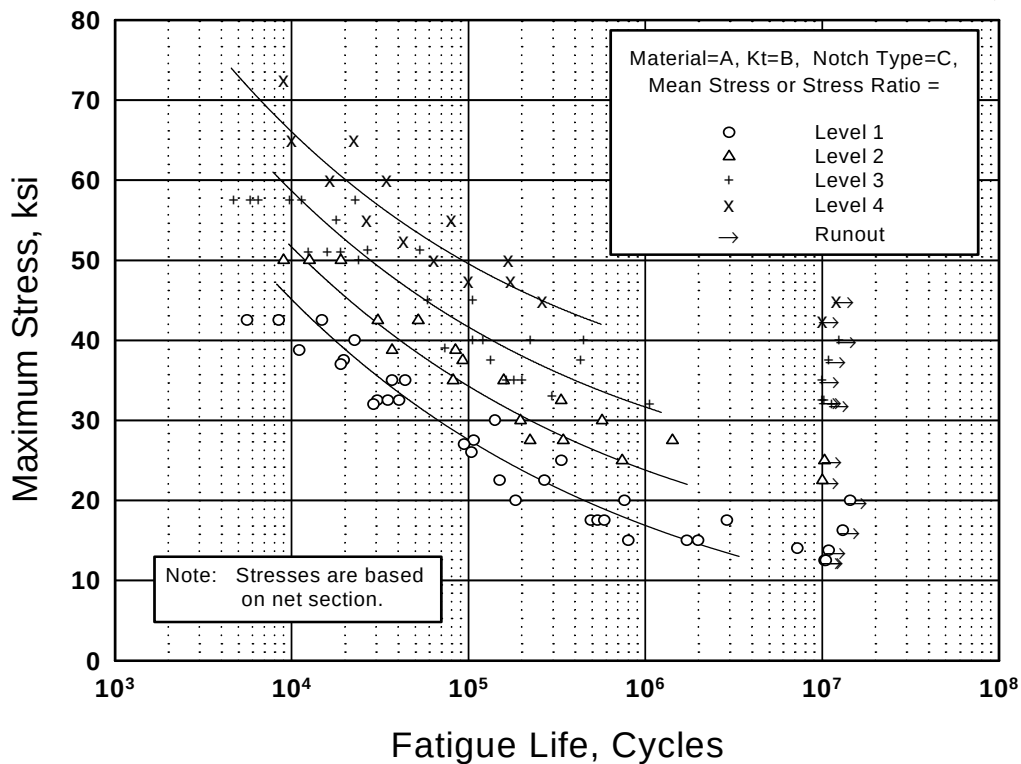


Figure 1.4.9.2(a). Best fit S/N curve diagram for a material at various stress ratios.

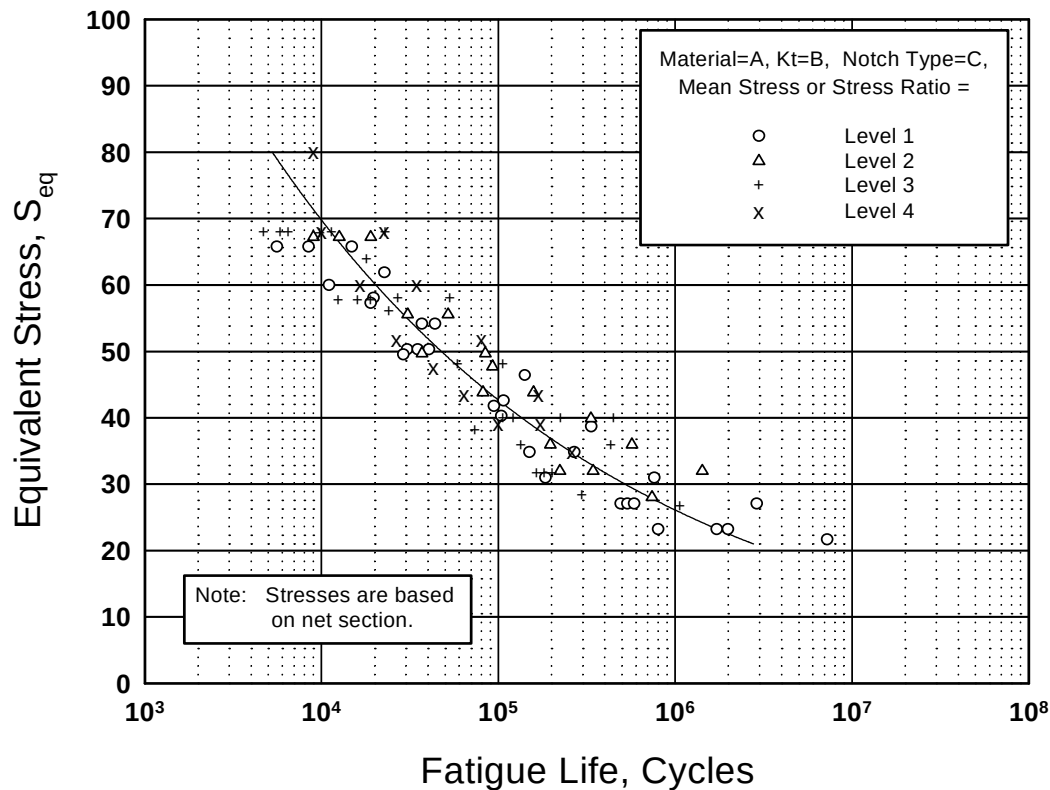


Figure 1.4.9.2(b). Consolidated fatigue data for a material using the equivalent stress parameter.

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**1 October 2001**

Notched fatigue specimen test data are shown in various Handbook figures to provide an understanding of deleterious effects relative to results for smooth specimens. All of the mean fatigue curves published in this Handbook, including both the notched fatigue and smooth specimen fatigue curves, require modification into allowables for design use. Such factors may impose a penalty on cyclic life or upon stress. This is a responsibility for the design community. Specific reductions vary between users of such information, and depend on the criticality of application, sources of uncertainty in the analysis, and requirements of the certifying activity. References 1.4.9.2(a) and (b) contain more specific information on fatigue testing procedures, organization of test results, influences of various factors, and design considerations.

**1.4.10 METALLURGICAL INSTABILITY** — In addition to the retention of strength and ductility, a structural material must also retain surface and internal stability. Surface stability refers to the resistance of the material to oxidizing or corrosive environments. Lack of internal stability is generally manifested (in some ferrous and several other alloys) by carbide precipitation, spheroidization, sigma-phase formation, temper embrittlement, and internal or structural transformation, depending upon the specific conditions of exposure.

Environmental conditions, which influence metallurgical stability include heat, level of stress, oxidizing or corrosive media and nuclear radiation. The effect of environment on the material can be observed as either improvement or deterioration of properties, depending upon the specific imposed conditions. For example, prolonged heating may progressively raise the strength of a metallic alloy as measured on smooth tensile or fatigue specimens. However, at the same time, ductility may be reduced to such an extent that notched tensile or fatigue behavior becomes erratic or unpredictable. The metallurgy of each alloy should be considered in making material selections.

Under normal temperatures, i.e., between -65°F and 160°F, the stability of most structural metallic alloys is relatively independent of exposure time. However, as temperature is increased, the metallurgical instability becomes increasingly time dependent. The factor of exposure time should be considered in design when applicable.

**1.4.11 BIAXIAL PROPERTIES** — Discussions up to this point pertained to uniaxial conditions of static, fatigue and creep loading. Many structural applications involve both biaxial and triaxial loadings. Because of the difficulties of testing under triaxial loading conditions, few data exist. However, considerable biaxial testing has been conducted and the following paragraphs describe how these results are presented in this Handbook. This does not conflict with data analysis methods presented in Chapter 9. Therein, statistical analysis methodology is presented solely for use in analyzing test data to establish allowables.

If stress axes are defined as being mutually perpendicular along x-, y-, and z-directions in a rectangular coordinate system, a biaxial stress is then defined as a condition in which loads are applied in both of the x- and y-directions. In some special cases, loading may be applied in the z-direction instead of the y-direction. Most of the following discussion will be limited to tensile loadings in the x- and y-directions. Stresses and strains in these directions are referred to as principal stresses and principal strains. See Reference 1.4.11.

When a specimen is tested under biaxial loading conditions, it is customary to plot the results as a biaxial stress-strain diagram. These diagrams are similar to uniaxial stress-strain diagrams shown in Figure 1.4.4. Usually, only the maximum (algebraically larger) principal stress and strain are shown for each test result. When tests of the same material are conducted at different biaxial stress ratios, the resulting curves may be plotted simultaneously, producing a family of biaxial stress-strain curves as shown in Figure 1.4.11 for an isotropic material. For anisotropic materials, biaxial stress-strain curves also require distinction by grain direction.

The reference direction for a biaxial stress ratio, i.e., the direction corresponding to  $B=0$ , should be clearly indicated with each result. The reference direction is always considered as the longitudinal (rolling) direction for flat products and the hoop (circumferential) direction for shells of revolution, e.g., tubes, cones, etc. The letter  $B$  denotes the ratio of applied stresses in the two loading directions. For example,  $B$ -values of 2, 0.5 shown in Figure 1.4.11 indicate results representing both biaxial stress ratios of 2 or 0.5, since this is a hypothetical example for an isotropic material, e.g., cross-rolled sheet. In a similar manner, the curve labeled  $B=1$  indicates a biaxial stress-strain result for equally applied stresses in both directions. The curve labeled  $B=\infty, 0$  indicates the biaxial stress-strain behavior when loading is applied in only one direction, e.g., uniaxial behavior. Biaxial property data presented in the Handbook are to be considered as basic material properties obtained from carefully prepared specimens.

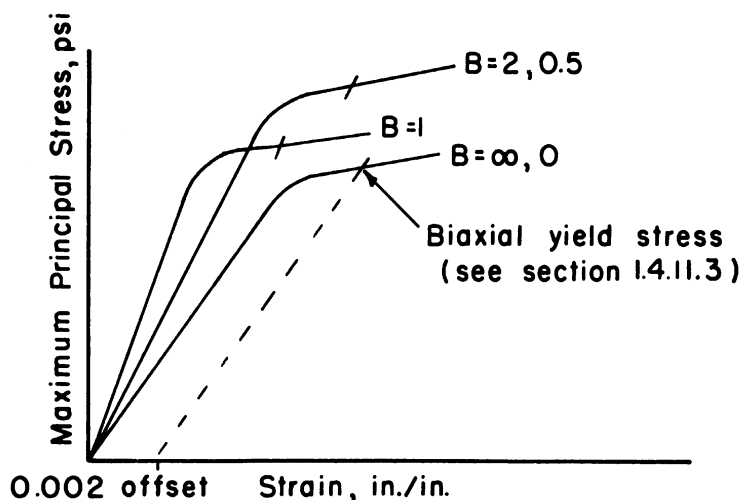


**Figure 1.4.11. Typical biaxial stress-strain diagrams for isotropic materials.**

**1.4.11.1 Biaxial Modulus of Elasticity**—Referring to Figure 1.4.11, it is noted that the original portion of each stress-strain curve is essentially a straight line. In uniaxial tension or compression, the slope of this line is defined as the modulus of elasticity. Under biaxial loading conditions, the initial slope of such curves is defined as the biaxial modulus. It is a function of biaxial stress ratio and Poisson's ratio. See Equation 1.3.7.4.

**1.4.11.2 Biaxial Yield Stress**—Biaxial yield stress is defined as the maximum principal stress corresponding to 0.002 in./in. plastic strain in the same direction, as determined from a test curve.

In the design of aerospace structures, biaxial stress ratios other than those normally used in biaxial testing are frequently encountered. Information can be combined into a single diagram to enable interpolations at intermediate biaxial stress ratios, as shown in Figure 1.4.11.2. An envelope is constructed through test results for each tested condition of biaxial stress ratios. In this case, a typical biaxial yield stress envelope is identified. In the preparation of such envelopes, data are first reduced to nondimensional form (percent of uniaxial tensile yield stress in the specified reference direction), then a best-fit curve is fitted through the nondimensionalized data. Biaxial yield strength allowables are then obtained by multiplying the uniaxial  $F_{ty}$  (or  $F_{cy}$ ) allowable by the applicable coordinate of the biaxial stress ratio curve. To avoid possible confusion, the reference direction used for the uniaxial yield strength is indicated on each figure.

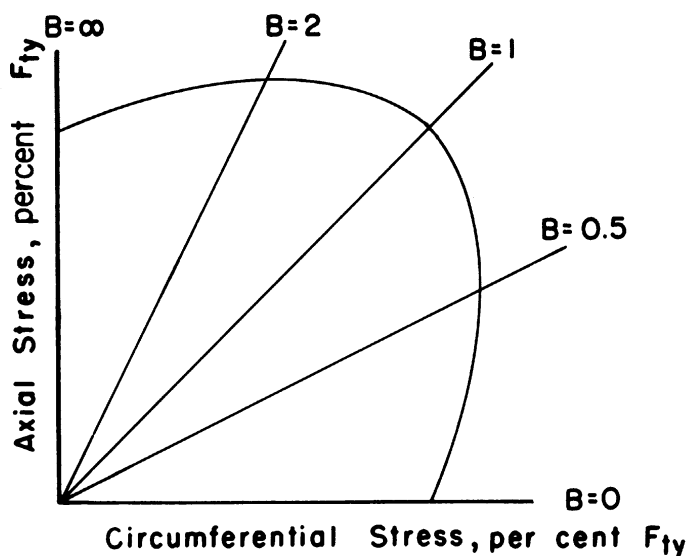


**Figure 1.4.11.2. Typical biaxial yield stress envelope.**

**1.4.11.3 Biaxial Ultimate Stress** — Biaxial ultimate stress is defined as the highest nominal principal stress attained in specimens of a given configuration, tested at a given biaxial stress ratio. This property is highly dependent upon geometric configuration of the test parts. Therefore, such data should be limited in use to the same design configurations.

The method of presenting biaxial ultimate strength data is similar to that described in the preceding section for biaxial yield strength. Both biaxial ultimate strength and corresponding uniform elongation data are reported, when available, as a function of biaxial stress ratio test conditions.

**1.4.12 FRACTURE TOUGHNESS** — The occurrence of flaws in a structural component is an unavoidable circumstance of material processing, fabrication, or service. Flaws may appear as cracks, voids, metallurgical inclusions, weld defects, design discontinuities, or some combination thereof. The fracture toughness of a part containing a flaw is dependent upon flaw size, component geometry, and a material property defined as fracture toughness. The fracture toughness of a material is literally a measure of its resistance to fracture. As with other mechanical properties, fracture toughness is dependent upon alloy type, processing variables, product form, geometry, temperature, loading rate, and other environmental factors.

This discussion is limited to brittle fracture, which is characteristic of high strength materials under conditions of loading resulting in plane-strain through the cross section. Very thin materials are described as being under the condition of plane-stress. The following descriptions of fracture toughness properties applies to the currently recognized practice of testing specimens under slowly increasing loads. Attendant and interacting conditions of cyclic loading, prolonged static loadings, environmental influences other than temperature, and high strain rate loading are not considered.

**1.4.12.1 Brittle Fracture** — For materials that have little capacity for plastic flow, or for flaw and structural configurations, which induce triaxial tension stress states adjacent to the flaw, component behavior is essentially elastic until the fracture stress is reached. Then, a crack propagates from the flaw suddenly and completely through the component. A convenient illustration of brittle fracture is a typical load-compliance record of a brittle structural component containing a flaw, as illustrated in Figure 1.4.12.1. Since little or no plastic effects are noted, this mode is termed brittle fracture.

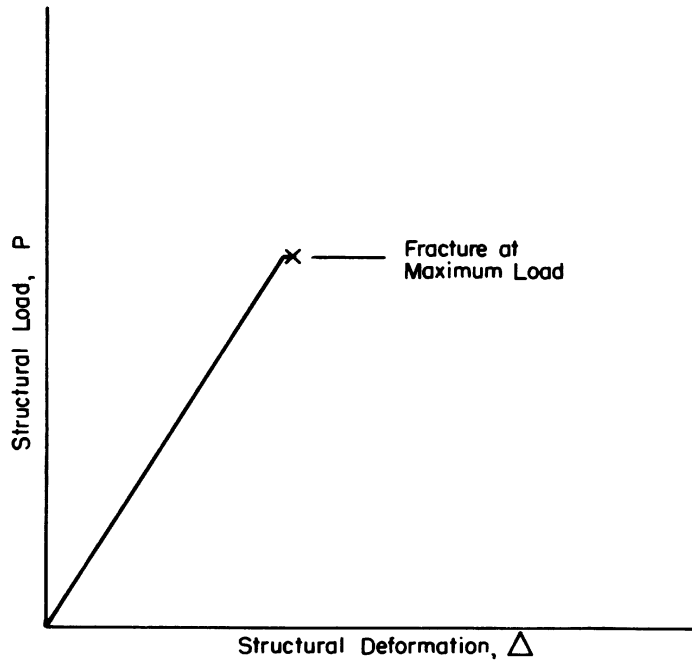


**Figure 1.4.12.1. Typical load-deformation record of a structural component containing a flaw subject to brittle fracture.**

This mode of fracture is characteristic of the very high-strength metallic materials under plane-strain conditions.

**1.4.12.2 Brittle Fracture Analysis** — The application of linear elastic fracture mechanics has led to the stress intensity concept to relate flaw size, component geometry, and fracture toughness. In its very general form, the stress intensity factor,  $K$ , can be expressed as

$$K = f \sqrt{a} Y, \text{ ksi} \cdot \text{in.}^{1/2} \quad [1.4.12.2]$$

where

- $f$  = stress applied to the gross, flaws section, ksi
- $a$  = measure of flaw size, inches
- $Y$  = factor relating component geometry and flaw size, nondimensional. See Reference 1.4.12.2(a) for values.

For every structural material, which exhibits brittle fracture (by nature of low ductility or plane-strain stress conditions), there is a lower limiting value of  $K$  termed the plane-strain fracture toughness,  $K_{IC}$ .

The specific application of this relationship is dependent on flaw type, structural configuration and type of loading, and a variety of these parameters can interact in a real structure. Flaws may occur through the thickness, may be imbedded as voids or metallurgical inclusions, or may be partial-through (surface) cracks. Loadings of concern may be tension and/or flexure. Structural components may vary in section size and may be reinforced in some manner. The ASTM Committee E 8 on Fatigue and Fracture has developed testing and analytical techniques for many practical situations of flaw occurrence subject to brittle fracture. They are summarized in Reference 1.4.12.2(a).



**1.4.12.3 Critical Plane-Strain Fracture Toughness** — A tabulation of fracture toughness data is printed in the general discussion prefacing most alloy chapters in this Handbook. These critical plane-strain fracture toughness values have been determined in accordance with recommended ASTM testing practices. This information is provided for information purposes only due to limitations in available data quantities and product form coverages. The statistical reliability of these properties is not known. Listed properties generally represent the average value of a series of test results.

Fracture toughness of a material commonly varies with grain direction. When identifying either test results or a general critical plane strain fracture toughness average value, it is customary to specify specimen and crack orientations by an ordered pair of grain direction symbols. The first digit denotes the grain direction normal to the crack plane. The second digit denotes the grain direction parallel to the fracture plane. For flat sections of various products, e.g., plate, extrusions, forgings, etc., in which the three grain directions are designated (L) longitudinal, (T) transverse, and (S) short transverse, the six principal fracture path directions are: L-T, L-S, T-L, T-S, S-L and S-T. Figure 1.4.12.3 identifies these orientations.

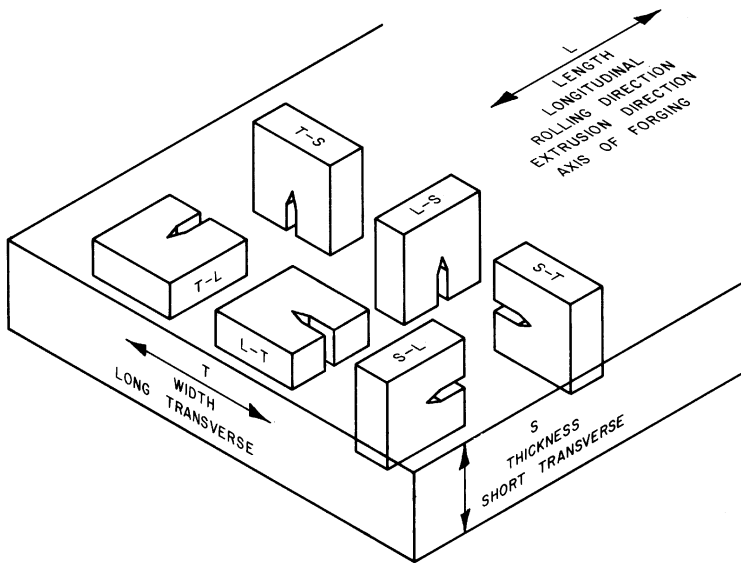


**Figure 1.4.12.3. Typical principal fracture path directions.**

**1.4.12.3.1 Environmental Effects** — Cyclic loading, even well below the fracture threshold stress, may result in the propagation of flaws, leading to fracture. Strain rates in excess of standard static rates may cause variations in fracture toughness properties. There are significant influences of temperature on fracture toughness properties. Temperature effects data are limited. These information are included in each alloy section, when available.

Under the condition of sustained loading, it has been observed that certain materials exhibit increased flaw propagation tendencies when situated in either aqueous or corrosive environments. When such is known to be the case, appropriate precautionary notes have been included with the standard fracture toughness information.

**1.4.12.4 Fracture in Plane-Stress and Transitional-Stress States** — Plane-strain conditions do not describe the condition of certain structural configurations which are either relatively thin or exhibit appreciable ductility. In these cases, the actual stress state may approach the opposite extreme, plane-

stress, or, more generally, some intermediate- or transitional-stress state. The behavior of flaws and cracks under these conditions is different from those of plane-strain. Specifically, under these conditions, significant plastic zones can develop ahead of the crack or flaw tip, and stable extension of the discontinuity occurs as a slow tearing process. This behavior is illustrated in a compliance record by a significant nonlinearity prior to fracture as shown in Figure 1.4.12.4. This nonlinearity results from the alleviation of stress at the crack tip by causing plastic deformation.

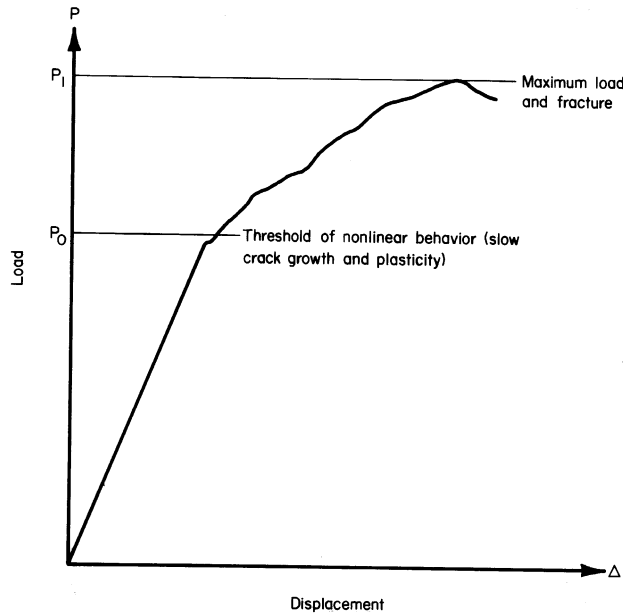


**Figure 1.4.12.4. Typical load-deformation record for non-plane strain fracture.**

**1.4.12.4.1 Analysis of Plane-Stress and Transitional-Stress State Fracture** — The basic concepts of linear elastic fracture mechanics as used in plane-strain fracture analysis also applies to these conditions. The stress intensity factor concept, as expressed in general form by Equation 1.4.12.2, is used to relate load or stress, flaw size, component geometry, and fracture toughness.

However, interpretation of the critical flaw dimension and corresponding stress has two possibilities. This is illustrated in Figure 1.4.12.4.1. One possibility is the onset of nonlinear displacement with increasing load. The other possibility identifies the fracture condition, usually very close to the maximum load. Generally, these two conditions are separated in applied stress and exhibit large differences in flaw dimensions due to stable tearing.

When a compliance record is transformed into a crack growth curve, the difference between the two possible K-factor designations becomes more apparent. In most practical cases, the definition of nonlinear crack length with increasing load is difficult to assess. As a result, an alternate characterization of this behavior is provided by defining an artificial or “apparent” stress intensity factor.

$$K_{app} = f \sqrt{a_o} Y \quad [1.4.12.4.1]$$

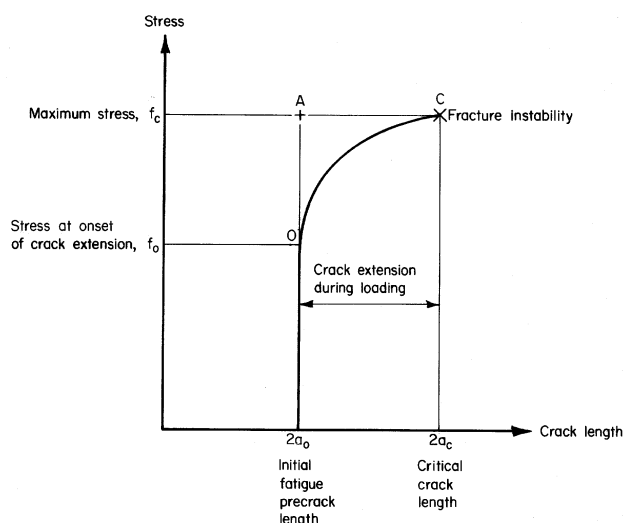


Figure 1.4.12.4.1. Crack growth curve.

The apparent fracture toughness is computed as a function of the maximum stress and initial flaw size. This datum coordinate corresponds to point A in Figure 1.4.12.4.1. This conservative stress intensity factor is a first approximation to the actual property associated with the point of fracture.

**1.4.12.5 Apparent Fracture Toughness Values for Plane-Stress and Transitional-Stress States** — When available, each alloy chapter contains graphical formats of stress versus flaw size. This is provided for each temper, product form, grain direction, thickness, and specimen configuration. Data points shown in these graphs represent the initial flaw size and maximum stress achieved. These data have been screened to assure that an elastic instability existed at fracture, consistent with specimen type. The average  $K_{app}$  curve, as defined in the following subsections, is shown for each set of data.

**1.4.12.5.1 Middle-Tension Panels** — The calculation of apparent fracture toughness for middle-tension panels is given by the following equation.

$$K_{app} = f_c \left( \pi a_o \cdot \sec \pi a_o / W \right)^{1/2} \quad [1.4.12.5.1(a)]$$

Data used to compute  $K_{app}$  values have been screened to ensure that the net section stress at failure did not exceed 80 percent of the tensile yield strength; that is, they satisfied the criterion:

$$f_c \leq 0.8(TYS) / (1 - 2a / W) \quad [1.4.12.5.1(b)]$$

This criterion assures that the fracture was an elastic instability and that plastic effects are negligible.

The average  $K_{app}$  parametric curve is presented on each figure as a solid line with multiple extensions where width effects are displayed in the data. As added information, where data are available, the propensity for slow stable tearing prior to fracture is indicated by a crack extension ratio,  $\Delta 2a / 2a_o$ . The coefficient (2) indicates the total crack length; the half-crack length is designated by the letter “a.” In some cases, where data exist covering a wide range of thicknesses, graphs of  $K_{app}$  versus thickness are presented.

**1.4.13 FATIGUE CRACK GROWTH** — Crack growth deals with material behavior between crack initiation and crack instability. In small size specimens, crack initiation and specimen failure may be nearly

synonymous. However, in larger structural components, the existence of a crack does not necessarily imply imminent failure. Significant structural life exists during cyclic loading and crack growth.

**1.4.13.1 Fatigue Crack Growth** — Fatigue crack growth is manifested as the growth or extension of a crack under cyclic loading. This process is primarily controlled by the maximum load or stress ratio. Additional factors include environment, loading frequency, temperature, and grain direction. Certain factors, such as environment and loading frequency, have interactive effects. Environment is important from a potential corrosion viewpoint. Time at stress is another important factor. Standard testing procedures are documented in Reference 1.4.13.1.

Fatigue crack growth data presented herein are based on constant amplitude tests. Crack growth behaviors based on spectrum loading cycles are beyond the scope of this Handbook. Constant amplitude data consist of crack length measurements at corresponding loading cycles. Such data are presented as crack growth curves as shown in Figure 1.4.13.1(a).

Since the crack growth curve is dependent on initial crack length and the loading conditions, the above format is not the most efficient form to present information. The instantaneous slope,  $\Delta a/\Delta N$ , corresponding to a prescribed number of loading cycles, provides a more fundamental characterization of this behavior. In general, fatigue crack growth rate behavior is evaluated as a function of the applied stress intensity factor range,  $\Delta K$ , as shown in Figure 1.4.13.1(b).

**1.4.13.2 Fatigue Crack Growth Analysis** — It is known that fatigue-crack-growth behavior under constant-amplitude cyclic conditions is influenced by maximum cyclic stress,  $S_{\max}$ , and some measure of cyclic stress range,  $\Delta S$  (such as stress ratio,  $R$ , or minimum cyclic stress,  $S_{\min}$ ), the instantaneous crack size,  $a$ , and other factors such as environment, frequency, and temperature. Thus, fatigue-crack-growth rate behavior can be characterized, in general form, by the relation

$$da/dN \approx \Delta a/\Delta N = g(S_{\max}, \Delta S \text{ or } R \text{ or } S_{\min}, a, \dots). \quad [1.4.13.3(a)]$$

By applying concepts of linear elastic fracture mechanics, the stress and crack size parameters can be combined into the stress-intensity factor parameter,  $K$ , such that Equation 1.4.13.3(a) may be simplified to

$$da/dN \approx \Delta a/\Delta N = g(K_{\max}, \Delta K, \dots) \quad [1.4.13.3(b)]$$

where

|            |   |                                                                                   |
|------------|---|-----------------------------------------------------------------------------------|
| $K_{\max}$ | = | the maximum cyclic stress-intensity factor                                        |
| $\Delta K$ | = | $(1-R)K_{\max}$ , the range of the cyclic stress-intensity factor, for $R \geq 0$ |
| $\Delta K$ | = | $K_{\max}$ , for $R \leq 0$ .                                                     |

At present, in the Handbook, the independent variable is considered to be simply  $\Delta K$  and the data are considered to be parametric on the stress ratio,  $R$ , such that Equation 1.4.13.3(b) becomes

$$da/dN \approx \Delta a/\Delta N = g(\Delta K, R). \quad [1.4.13.3(c)]$$

**1.4.13.3 Fatigue Crack Growth Data Presentation** — Fatigue crack growth rate data for constant amplitude cyclic loading conditions are presented as logarithmic plots of  $da/dN$  versus  $\Delta K$ . Such information, such as that illustrated in Figure 1.4.13.3, are arranged by material alloy and heat treatment condition. Each curve represents a specific stress ratio,  $R$ , environment, and cyclic loading frequency. Specific details regarding test procedures and data interpolations are presented in Chapter 9.

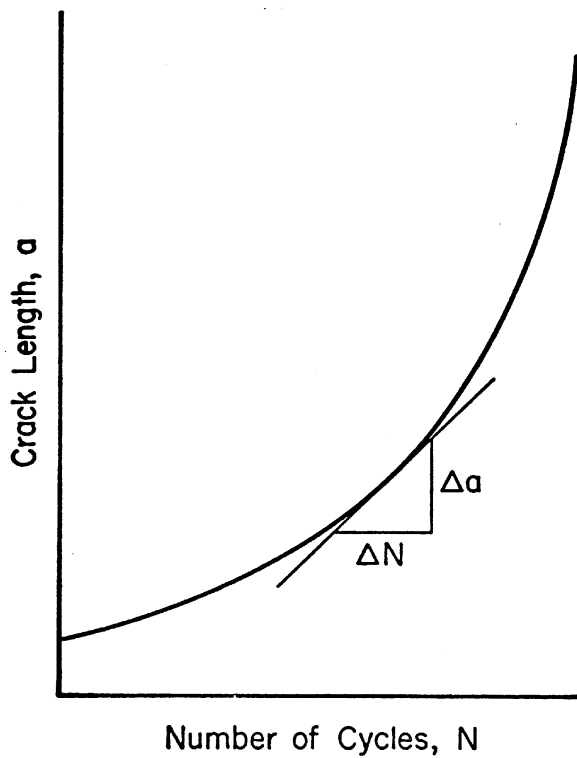


Figure 1.4.13.1(a). Fatigue crack-growth curve.

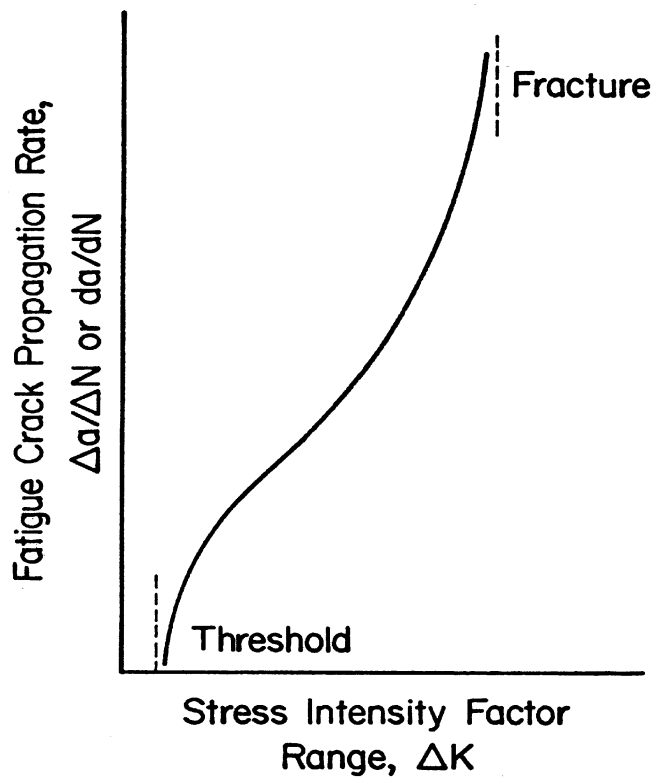


Figure 1.4.13.1(b). Fatigue crack-growth-rate curve.

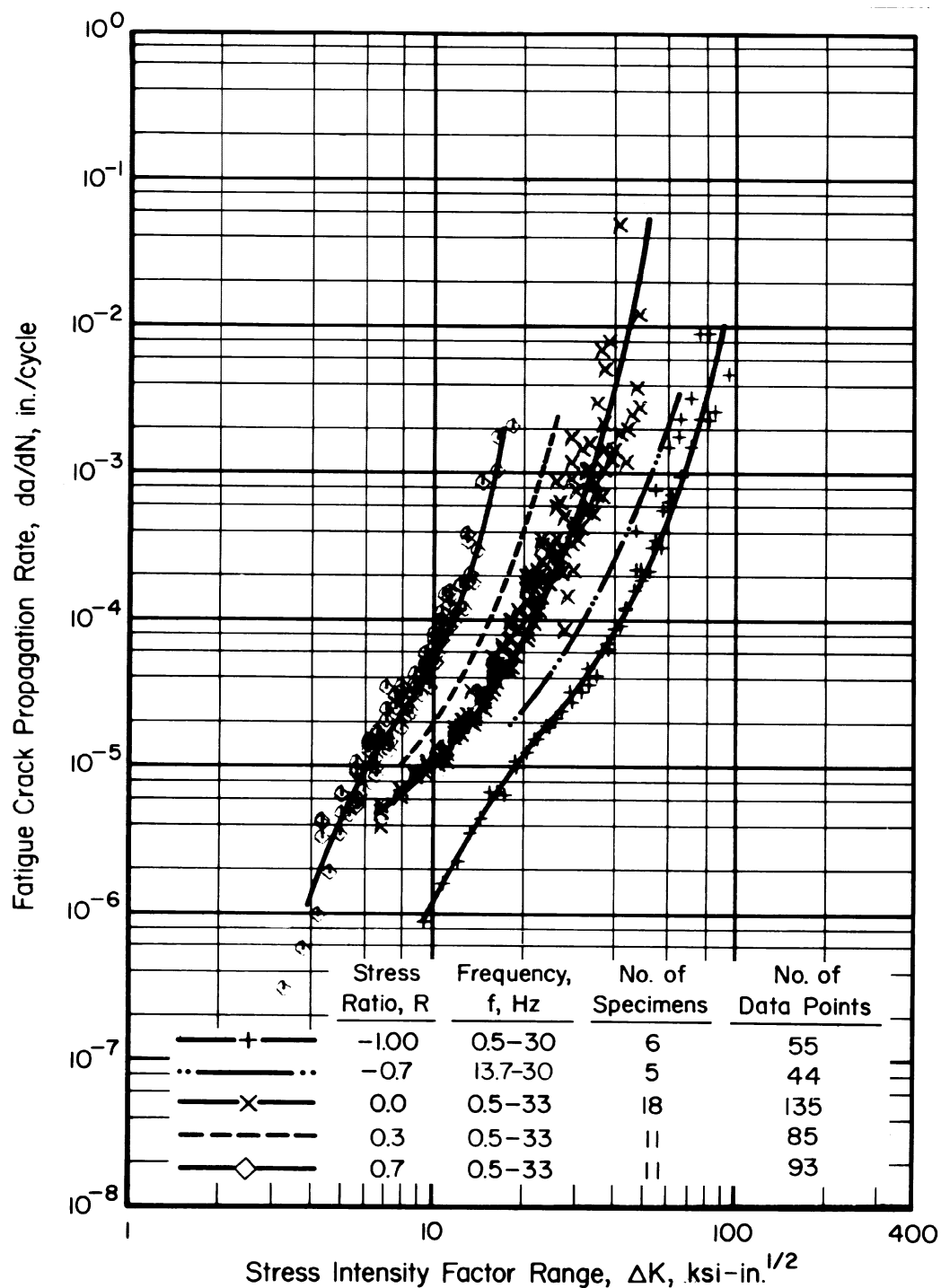


Figure 1.4.13.3. Sample display of fatigue crack growth rate data.

## 1.5 TYPES OF FAILURES

**1.5.1 GENERAL** — In the following discussion, failure will usually indicate fracture of a member or the condition of a member when it has attained maximum load.

**1.5.2 MATERIAL FAILURES** — Fracture can occur in either ductile or brittle fashions in the same material depending on the state of stress, rate of loading, and environment. The ductility of a material has a significant effect on the ability of a part to withstand loading and delay fracture. Although not a specific design property for ductile materials, some ductility data are provided in the Handbook to assist in material selections. The following paragraphs discuss the relationship between failure and the applied or induced stresses.

**1.5.2.1 Direct Tension or Compression** — This type of failure is associated with ultimate tensile or compressive stress of the material. For compression, it can only apply to members having large cross sectional dimensions relative to their lengths. See Section 1.4.5.1.

**1.5.2.2 Shear** — Pure shear failures are usually obtained when the shear load is transmitted over a very short length of a member. This condition is approached in the case of rivets and bolts. In cases where ultimate shear stress is relatively low, a pure shear failure can result. But, generally members subjected to shear loads fail under the action of the resulting normal stress, usually the compressive stress. See Equation 1.3.3.3. Failure of tubes in torsion are not caused by exceeding the shear ultimate stress, but by exceeding a normal compressive stress which causes the tube to buckle. It is customary to determine stresses for members subjected to shear in the form of shear stresses although they are actually indirect measures of the stresses actually causing failure.

**1.5.2.3 Bearing** — Failure of a material in bearing can consist of crushing, splitting, tearing, or progressive rapid yielding in the direction of load application. Failure of this type depends on the relative size and shape of the two connecting parts. The maximum bearing stress may not be applicable to cases in which one of the connecting members is relatively thin.

**1.5.2.4 Bending** — For sections not subject to geometric instability, a bending failure can be classed as either a tensile or compressive failure. Reference 1.5.2.4 provides methodology by which actual bending stresses above the material proportional limit can be used to establish maximum stress conditions. Actual bending stresses are related to the bending modulus of rupture. The bending modulus of rupture ( $f_b$ ) is determined by Equation 1.3.2.3. When the computed bending modulus of rupture is found to be lower than the proportional limit strength, it represents an actual stress. Otherwise, it represents an apparent stress, and is not considered as an actual material strength. This is important when considering complex stress states, such as combined bending and compression or tension.

**1.5.2.5 Failure Due to Stress Concentrations** — Static stress properties represent pristine materials without notches, holes, or other stress concentrations. Such simplistic structural design is not always possible. Consideration should be given to the effect of stress concentrations. When available, references are cited for specific data in various chapters of the Handbook.

**1.5.2.6 Failure from Combined Stresses** — Under combined stress conditions, where failure is not due to buckling or instability, it is necessary to refer to some theory of failure. The “maximum shear” theory is widely accepted as a working basis in the case of isotropic ductile materials. It should be noted that this theory defines failure as the first yielding of a material. Any extension of this theory to cover conditions of final rupture must be based on evidence supported by the user. The failure of brittle materials under combined stresses is generally treated by the “maximum stress” theory. Section 1.4.11 contains a more complete discussion of biaxial behavior. References 1.5.2.6(a) through (c) offer additional information.

**1.5.3 INSTABILITY FAILURES** — Practically all structural members, such as beams and columns, particularly those made from thin material, are subject to failure due to instability. In general, instability can be classed as (1) primary or (2) local. For example, the failure of a tube loaded in compression can occur either through lateral deflection of the tube acting as a column (primary instability) or by collapse of the tube walls at stresses lower than those required to produce a general column failure. Similarly, an I-beam or other formed shape can fail by a general sidewise deflection of the compression flange, by local wrinkling of thin outstanding flanges, or by torsional instability. It is necessary to consider all types of potential failures unless it is apparent that the critical load for one type is definitely the controlling condition.

Instability failures can occur in either the elastic range below the proportional limit or in the plastic range. These two conditions are distinguished by referring to either “elastic instability” or “plastic instability” failures. Neither type of failure is associated with a material’s ultimate strength, but largely depends upon geometry.

A method for determining the local stability of aluminum alloy column sections is provided in Reference 1.7.1(b). Documents cited therein are the same as those listed in References 3.20.2.2(a) through (e).

**1.5.3.1 Instability Failures Under Compression** — Failures of this type are discussed in Section 1.6 (Columns).

**1.5.3.2 Instability Failures Under Bending** — Round tubes when subjected to bending are subject to plastic instability failures. In such cases, the failure criterion is the modulus of rupture. Equation 1.3.2.3, which was derived from theory and confirmed empirically with test data, is applicable. Elastic instability failures of thin walled tubes having high  $D/t$  ratios are treated in later sections.

**1.5.3.3 Instability Failures Under Torsion** — The remarks given in the preceding section apply in a similar manner to round tubes under torsional loading. In such cases, the modulus of rupture in torsion is derived through the use of Equation 1.3.2.6. See Reference 1.5.3.3.

**1.5.3.4 Failure Under Combined Loadings** — For combined loading conditions in which failure is caused by buckling or instability, no theory exists for general application. Due to the various design philosophies and analytical techniques used throughout the aerospace industry, methods for computing margin of safety are not within the scope of this Handbook.

## **1.6 COLUMNS**

**1.6.1 GENERAL** — A theoretical treatment of columns can be found in standard texts on the strength of materials. Some of the problems which are not well defined by theory are discussed in this section. Actual strengths of columns of various materials are provided in subsequent chapters.

**1.6.2 PRIMARY INSTABILITY FAILURES** — A column can fail through primary instability by bending laterally (stable sections) or by twisting about some axis parallel to its own axis. This latter type of primary failure is particularly common to columns having unsymmetrical open sections. The twisting failure of a closed section column is precluded by its inherently high torsional rigidity. Since the amount of available information is limited, it is advisable to conduct tests on all columns subject to this type of failure.

**1.6.2.1 Columns with Stable Sections** — The Euler formula for columns which fail by lateral bending is given by Equation 1.3.8.2. A conservative approach in using this equation is to replace the elastic modulus ( $E$ ) by the tangent modulus ( $E_t$ ) given by Equation 1.3.8.1. Values for the restraint coefficient ( $c$ ) depend on degrees of ends and lateral fixities. End fixities tend to modify the effective column length as



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indicated in Equation 1.3.8.1. For a pin-ended column having no end restraint,  $c = 1.0$  and  $L' = L$ . A fixity coefficient of  $c = 2$  corresponds to an effective column length of  $L' = 0.707$  times the total length.

The tangent modulus equation takes into account plasticity of a material and is valid when the following conditions are met:

- (a) The column adjusts itself to forcible shortening only by bending and not by twisting.
- (b) No buckling of any portion of the cross section occurs.
- (c) Loading is applied concentrically along the longitudinal axis of the column.
- (d) The cross section of the column is constant along its entire length.

MIL-HDBK-5 provides typical stress versus tangent modulus diagrams for many materials, forms, and grain directions. These information are not intended for design purposes. Methodology is contained in Chapter 9 for the development of allowable tangent modulus curves.

**1.6.2.2 Column Stress ( $f_{co}$ )** — The upper limit of column stress for primary failure is designated as  $f_{co}$ . By definition, this term should not exceed the compression ultimate strength, regardless of how the latter term is defined.

**1.6.2.3 Other Considerations** — Methods of analysis by which column failure stresses can be computed, accounting for fixities, torsional instability, load eccentricity, combined lateral loads, or varying column sections are contained in References 1.6.2.3(a) through (d).

**1.6.3 LOCAL INSTABILITY FAILURES** — Columns are subject to failure by local collapse of walls at stresses below the primary failure strength. The buckling analysis of a column subject to local instability requires consideration of the shape of the column cross section and can be quite complex. Local buckling, which can combine with primary buckling, leads to an instability failure commonly identified as crippling.

**1.6.3.1 Crushing or Crippling Stress ( $f_{cc}$ )** — The upper limit of column stress for local failure is defined by either its crushing or crippling stress. The strengths of round tubes have been thoroughly investigated and considerable amounts of test results are available throughout literature. Fewer data are available for other cross sectional configurations and testing is suggested to establish specific information, e.g., the curve of transition from local to primary failure.

**1.6.4 CORRECTION OF COLUMN TEST RESULTS** — In the case of columns having unconventional cross sections which are subject to local instability, it is necessary to establish curves of transition from local to primary failure. In determining these column curves, sufficient tests should be made to cover the following points.

**1.6.4.1 Nature of "Short Column Curve"** — Test specimens should cover a range of  $L'/\rho$  values. When columns are to be attached eccentrically in structural application, tests should be designed to cover such conditions. This is important particularly in the case of open sections, as maximum load carrying capabilities are affected by locations of load and reaction points.

**1.6.4.2 Local Failure** — When local failure occurs, the crushing or crippling stress can be determined by extending the short column curve to a point corresponding to a zero value for  $L'/\rho$ . When a family of columns of the same general cross section is used, it is often possible to determine a relationship between crushing or crippling stress and some geometric factor. Examples are wall thickness, width, diameter, or some combination of these dimensions. Extrapolation of such data to conditions beyond test geometry extremes should be avoided.

**1.6.4.3 Reduction of Column Test Results on Aluminum and Magnesium Alloys to Standard Material** — The use of correction factors provided in Figures 1.6.4.3(a) through (i) is acceptable to the Air Force, the Navy, the Army, and the Federal Aviation Administration for use in reducing aluminum and magnesium alloys column test data into allowables. (Note that an alternate method is provided in Section 1.6.4.4). In using Figures 1.6.4.3(a) through (i), the correction of column test results to standard material is made by multiplying the stress obtained from testing a column specimen by the factor K. This factor may be considered applicable regardless of the type of failure involved, i.e., column crushing, crippling or twisting. Note that not all the information provided in these figures pertains to allowable stresses, as explained below.

The following terms are used in reducing column test results into allowable column stress:

- $F_{cy}$  is the design compression yield stress of the material in question, applicable to the gage, temper and grain direction along the longitudinal axis of a test column.
- $F_c'$  is the maximum test column stress achieved in test. Note that a letter (F) is used rather the customary lower case (f). This value can be an individual test result.
- $F_{cy}'$  is the compressive yield strength of the column material. Note that a letter (F) is used rather than the customary lower case (f). This value can be an individual test result using a standard compression test specimen.

Using the ratio of  $(F_c' / F_{cy}')$ , enter the appropriate diagram along the abscissa and extend a line upwards to the intersection of a curve with a value of  $(F_{cy}' / F_{cy}')$ . Linear interpolation between curves is permissible. At this location, extend a horizontal line to the ordinate and read the corresponding K-factor. This factor is then used as a multiplier on the measured column strength to obtain the allowable. The basis for this allowable is the same as that noted for the compression yield stress allowable obtained from the room temperature allowables table.

If the above method is not feasible, due to an inability of conducting a standard compression test of the column material, the compression yield stress of the column material may be estimated as follows: Conduct a standard tensile test of the column material and obtain its tensile yield stress. Multiply this value by the ratio of compression-to-tensile yield allowables for the standard material. This provides the estimated compression yield stress of the column material. Continue with the analysis as described above using the compression stress of a test column in the same manner.

If neither of the above methods are feasible, it may be assumed that the compressive yield stress allowable for the column is 15 percent greater than minimum established allowable longitudinal tensile yield stress for the material in question.

**1.6.4.4 Reduction of Column Test Results to Standard Material--Alternate Method** — For materials that are not covered by Figures 1.6.4.4(a) through (i), the following method is acceptable for all materials to the Air Force, the Navy, the Army, and the Federal Aviation Administration.

- (1) Obtain the column material compression properties:  $F_{cy}$ ,  $E_c$ ,  $n_c$ .
- (2) Determine the test material column stress ( $f_c'$ ) from one or more column tests.
- (3) Determine the test material compression yield stress ( $f_{cy}'$ ) from one or more tests.
- (4) Assume  $E_c$  and  $n_c$  from (1) apply directly to the column material. They should be the same material.

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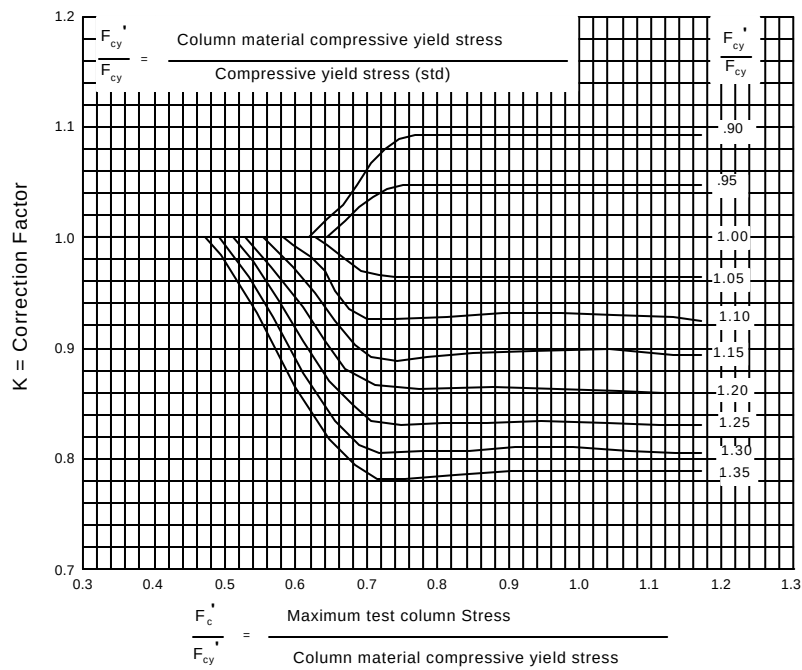


**Figure 1.6.4.4(a). Nondimensional material correction chart for 2024-T3 sheet.**

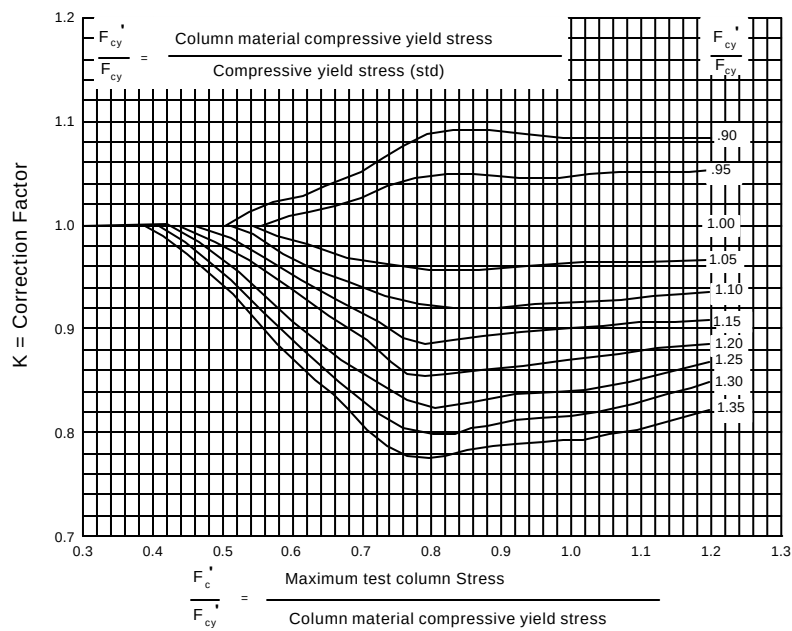


**Figure 1.6.4.4(b). Nondimensional material correction chart for 2024-T3 clad sheet.**

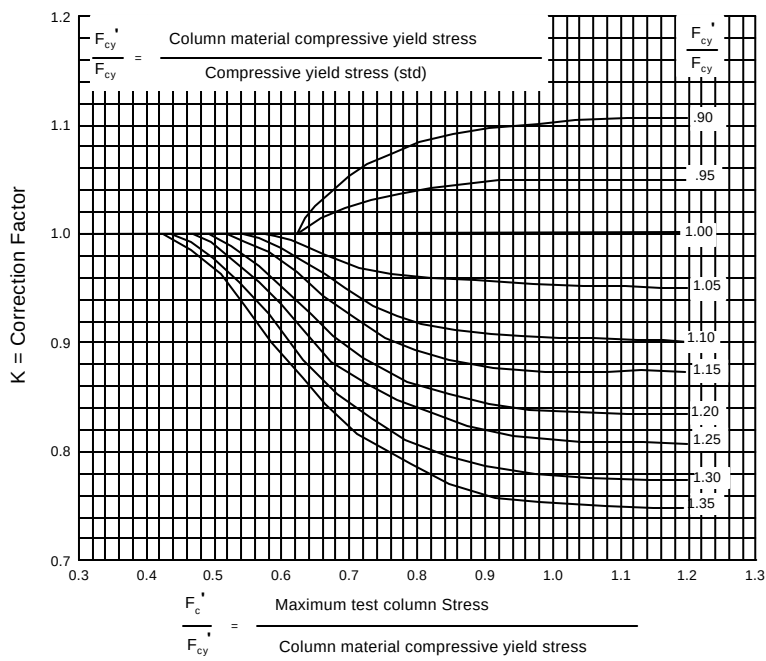


Figure 1.6.4.4(c). Nondimensional material correction chart for 2024-T4 extrusion less than 1/4 inch thick.

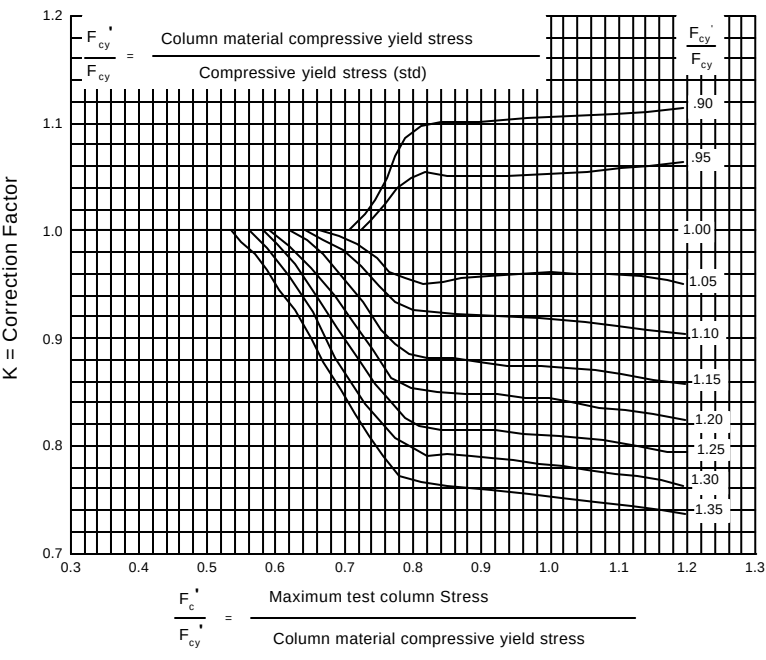


Figure 1.6.4.4(d). Nondimensional material correction chart for 2024-T4 extrusion 1/4 to 1-1/2 inches thick.

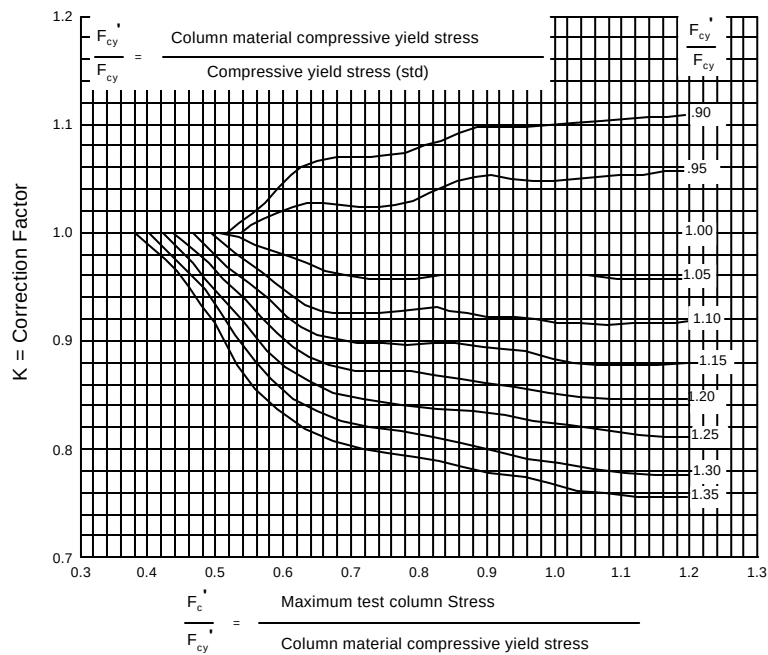


**Figure 1.6.4.4(e). Nondimensional material correction chart for 2024-T3 tubing.**

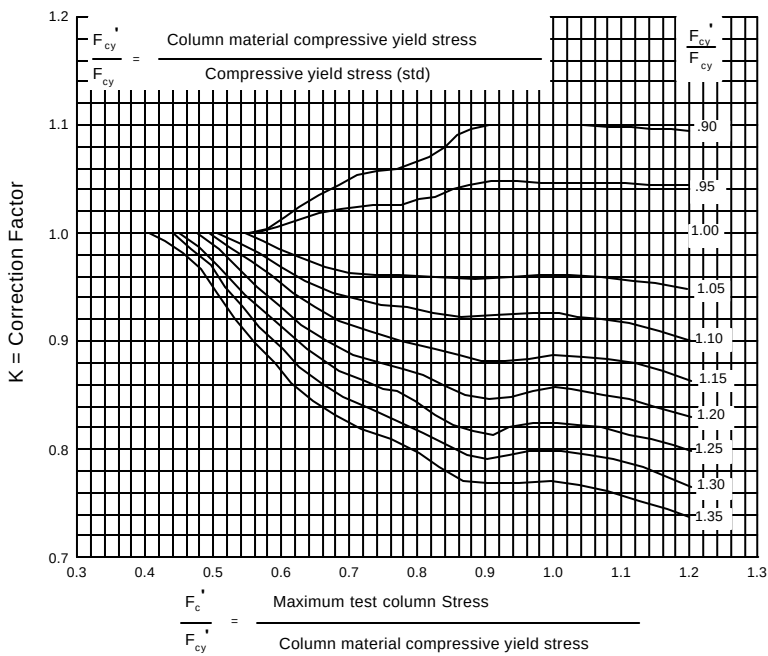


**Figure 1.6.4.4(f). Nondimensional material correction chart for clad 2024-T3 sheet.**

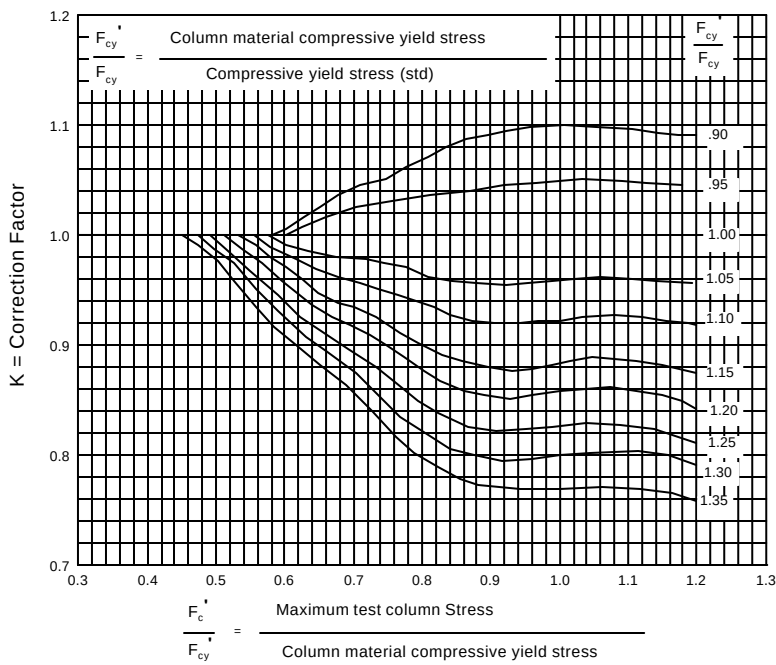


Figure 1.6.4.4(g). Nondimensional material correction chart for 7075-T6 sheet.

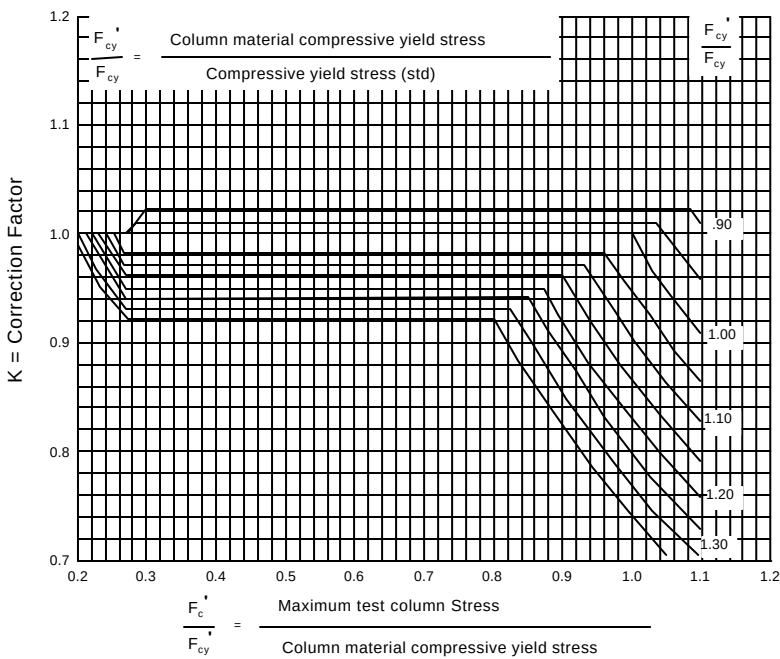


Figure 1.6.4.4(h). Nondimensional material correction chart for AZ31B-F and AZ61A-F extrusion.

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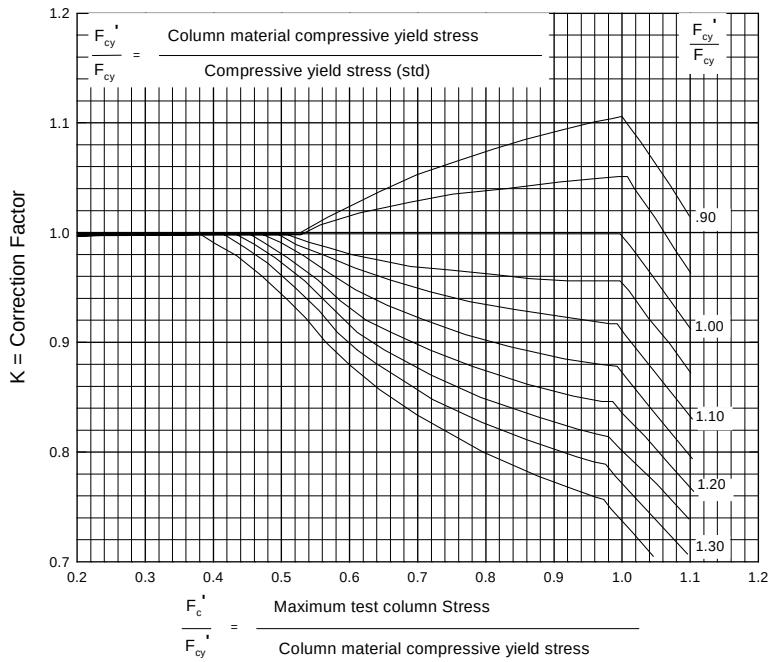


**Figure 1.6.4.4(i). Nondimensional material correction chart for AZ31B-H24 sheet.**

- (5) Assume that geometry of the test column is the same as that intended for design. This means that a critical slenderness ratio value of  $(L'/\rho)$  applies to both cases.
- (6) Using the conservative form of the basic column formula provided in Equation 1.3.8.1, this enables an equality to be written between column test properties and allowables. If

$$(L'/\rho) \text{ for design} = (L'/\rho) \text{ of the column test} \quad [1.6.4.4(a)]$$

Then

$$(F_c/E_t) \text{ for design} = (f'_c/E'_t) \text{ from test} \quad [1.6.4.4(b)]$$

- (7) Tangent modulus is defined as:

$$E_t = df / de \quad [1.6.4.4(c)]$$

- (8) Total strain ( $e$ ) is defined as the sum of elastic and plastic strains, and throughout the Handbook is used as:

$$e = e_E + e_p \quad [1.6.4.4(d)]$$

or,

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$$e = \frac{f}{E} + 0.002 \left( \frac{f}{f_y} \right)^n \quad [1.6.4.4(e)]$$

So, Equation 1.6.4.4(c) can be rewritten as follows:

$$E_t = \frac{f}{\frac{f}{E} + 0.002n \left( \frac{f}{f_y} \right)^n} \quad [1.6.4.4(f)]$$

Tangent modulus, for the material in question, using its compression allowables is:

$$E_t = \frac{F_c}{\frac{F_c}{E_c} + 0.002n_c \left( \frac{F_c}{F_{cy}} \right)^{n_c}} \quad [1.6.4.4(g)]$$

In like manner, tangent modulus for the same material with the desired column configuration is:

$$E_t' = \frac{f_c'}{\frac{f_c'}{E_c} + 0.002n_c \left( \frac{f_c'}{f_{cy}'} \right)^{n_c}} \quad [1.6.4.4(h)]$$

Substitution of Equations 1.6.4.4(g) and 1.6.4.4(h) for their respective terms in Equation 1.6.4.4(b) and simplifying provides the following relationship:

$$\frac{F_c}{E_c} + 0.002n_c \left( \frac{F_c}{F_{cy}} \right)^{n_c} = \frac{f_c'}{E_c} + 0.002n_c \left( \frac{f_c'}{f_{cy}'} \right)^{n_c} \quad [1.6.4.4(i)]$$

The only unknown in the above equation is the term  $F_c$ , the allowable column compression stress. This property can be solved by an iterative process.

This method is also applicable at other than room temperature, having made adjustments for the effect of temperature on each of the properties. It is critical that the test material be the same in all respects as that for which allowables are selected from the Handbook. Otherwise, the assumption made in Equation 1.6.4.4(c) above is not valid. Equation 1.6.4.4(i) must account for such differences in moduli and shape factors when applicable.

## **1.7 THIN-WALLED AND STIFFENED THIN-WALLED SECTIONS**

A bibliography of information on thin-walled and stiffened thin-walled sections is contained in References 1.7(a) and (b).



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| <p>2. YOUR ADDRESS (Print or Type)</p> <p>! ! <b>G</b> IF YOUR ADDRESS HAS CHANGED, X THIS BLOCK</p> <p>! !</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                              |                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| <p>3. ATTENTION:</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                              |                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| <p>4. DOCUMENTS REQUESTED</p> <table border="1"><thead><tr><th>a. STANDARDIZATION DOCUMENT NUMBER</th><th>b. QUANTITY<br/>(Restricted to 5)</th><th>c. TITLE<br/>(From DoD Index of Specifications and Standards)</th></tr></thead><tbody><tr><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td></tr></tbody></table>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                              |                                                            | a. STANDARDIZATION DOCUMENT NUMBER                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | b. QUANTITY<br>(Restricted to 5)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | c. TITLE<br>(From DoD Index of Specifications and Standards) |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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| <p style="text-align: center;"><b>INSTRUCTIONS</b></p> <table border="1"><tr><td><p>1. PRINT OR TYPE ALL INFORMATION.</p><p>2. Enter your customer number, CAGE (formerly FSCM), or UIC number at the top of this form. It will expedite your order.</p><p>3. If you have a customer number, use the Telephone Order Entry System (TOES) for telephone orders: (215) 697-1187 between the hours of 8 a.m. and 8 p.m. Eastern Standard Time, Monday through Friday. See "Guide to Private Industry" for details.</p><p>4. Documents ordered must appear in the DoD Index of Specifications and Standards (DODISS) or DODISS Notice. Requests submitted on this form will speed service. Reorder forms will be enclosed with each shipment.</p><p>5. Requests for Official Use Documents or documents without Distribution Statement "A" must be submitted via cognizant DoD Inspection Officer or Contract Administrator for certification of "need to know."</p></td><td><p>6. Non Government Standardization Documents will not be furnished to commercial concerns. Copies may be purchased from the appropriate Non Government Standards Body.</p><p>7. Questions concerning documents not listed in the Department of Defense Index of Specifications and Standards (DODISS) or DODISS Notice should be directed to: NPFC Attn: Code 105. Telephone: (215) 697-2667 or (215) 697-2179.</p><p>8. Further information may be obtained from NPFC "Guide to Private Industry." Order as GUIDE-1.</p><p>9. FORWARD REQUEST TO:</p><p style="text-align: center;">Standardization Document Order Desk<br/>700 Robbins Avenue<br/>Building #4, Section D<br/>Philadelphia, PA 19111-5094</p></td></tr></table> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                              |                                                            | <p>1. PRINT OR TYPE ALL INFORMATION.</p> <p>2. Enter your customer number, CAGE (formerly FSCM), or UIC number at the top of this form. It will expedite your order.</p> <p>3. If you have a customer number, use the Telephone Order Entry System (TOES) for telephone orders: (215) 697-1187 between the hours of 8 a.m. and 8 p.m. Eastern Standard Time, Monday through Friday. See "Guide to Private Industry" for details.</p> <p>4. Documents ordered must appear in the DoD Index of Specifications and Standards (DODISS) or DODISS Notice. Requests submitted on this form will speed service. Reorder forms will be enclosed with each shipment.</p> <p>5. Requests for Official Use Documents or documents without Distribution Statement "A" must be submitted via cognizant DoD Inspection Officer or Contract Administrator for certification of "need to know."</p> | <p>6. Non Government Standardization Documents will not be furnished to commercial concerns. Copies may be purchased from the appropriate Non Government Standards Body.</p> <p>7. Questions concerning documents not listed in the Department of Defense Index of Specifications and Standards (DODISS) or DODISS Notice should be directed to: NPFC Attn: Code 105. Telephone: (215) 697-2667 or (215) 697-2179.</p> <p>8. Further information may be obtained from NPFC "Guide to Private Industry." Order as GUIDE-1.</p> <p>9. FORWARD REQUEST TO:</p> <p style="text-align: center;">Standardization Document Order Desk<br/>700 Robbins Avenue<br/>Building #4, Section D<br/>Philadelphia, PA 19111-5094</p> |                                                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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| <p>5. SIGNATURE OF REQUESTER</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | <p>6. DATE SIGNED (YYMMDD)</p>                               | <p>7. CLOSING DATE (YYMMDD)<br/>(IFB, RFQ, or RFP)</p>     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

MIL-HDBK-5H, Change Notice 1  
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| STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                   |                              |
| INSTRUCTIONS                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                   |                              |
| 1. The preparing activity must complete blocks 1, 2, 3, and 8. In block 1, both the document number and revision letter should be given.                                                                                                                                                                         |                                                                                                                                                                                                                                   |                              |
| 2. The submitter of this form must complete blocks 4, 5, 6, and 7, and send to preparing activity.                                                                                                                                                                                                               |                                                                                                                                                                                                                                   |                              |
| 3. The preparing activity must provide a reply within 30 days from receipt of the form.                                                                                                                                                                                                                          |                                                                                                                                                                                                                                   |                              |
| NOTE: This form may not be used to request copies of documents, nor to request waivers, or clarification of requirements on current contracts. Comments submitted on this form do not constitute or imply authorization to waive any portion of the referenced document(s) or to amend contractual requirements. |                                                                                                                                                                                                                                   |                              |
| I RECOMMEND A CHANGE:                                                                                                                                                                                                                                                                                            | 1. DOCUMENT NUMBER                                                                                                                                                                                                                | 2. DOCUMENT DATE (YYYYMMDD)  |
| 3. DOCUMENT TITLE                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                   |                              |
| 4. NATURE OF CHANGE (Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)                                                                                                                                                                                        |                                                                                                                                                                                                                                   |                              |
| 5. REASON FOR RECOMMENDATION                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                   |                              |
| 6. SUBMITTER                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                   |                              |
| a. NAME (Last, First, Middle Initial)                                                                                                                                                                                                                                                                            | b. ORGANIZATION                                                                                                                                                                                                                   |                              |
| c. ADDRESS (Include ZIP Code)                                                                                                                                                                                                                                                                                    | d. TELEPHONE (Include Area Code)<br>(1) Commercial<br>(2) DSN<br>(If applicable)                                                                                                                                                  | 7. DATE SUBMITTED (YYYYMMDD) |
| 8. PREPARING ACTIVITY                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                   |                              |
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CHAPTER 2

STEEL

This chapter contains the engineering properties and related characteristics of steels used in aircraft and missile structural applications. General comments on engineering properties and other considerations related to alloy selection are presented in Section 2.1. Mechanical and physical property data and characteristics pertinent to specific steel groups or individual steels are reported in Sections 2.2 through 2.7. Element properties are presented in Section 2.8.

2.1 GENERAL

The selection of the proper grade of steel for a specific application is based on material properties and on manufacturing, environmental, and economic considerations. Some of these considerations are outlined in the sections that follow.

**2.1.1 ALLOY INDEX** — The steel alloys listed in this chapter are arranged in major sections that identify broad classifications of steel partly associated with major alloying elements, partly associated with processing, and consistent generally with steel-making technology. Specific alloys are identified as shown in Table 2.1.1.

Table 2.1.1. Steel Alloy Index

| Section | Alloy Designation                                                   |
|---------|---------------------------------------------------------------------|
| 2.2     | <b>Carbon steels</b>                                                |
| 2.2.1   | AISI 1025                                                           |
| 2.3     | <b>Low-alloy steels (AISI and proprietary grades)</b>               |
| 2.3.1   | Specific alloys                                                     |
| 2.4     | <b>Intermediate alloy steels</b>                                    |
| 2.4.1   | 5Cr-Mo-V                                                            |
| 2.4.2   | 9Ni-4Co-0.20C                                                       |
| 2.4.3   | 9Ni-4Co-0.30C                                                       |
| 2.5     | <b>High alloy steels</b>                                            |
| 2.5.1   | 18 Ni maraging steels                                               |
| 2.5.2   | AF1410                                                              |
| 2.5.3   | AerMet 100                                                          |
| 2.6     | <b>Precipitation and transformation hardening steel (stainless)</b> |
| 2.6.1   | AM-350                                                              |
| 2.6.2   | AM-355                                                              |
| 2.6.3   | Custom 450                                                          |
| 2.6.4   | Custom 455                                                          |
| 2.6.5   | PH13-8Mo                                                            |
| 2.6.6   | 15-5PH                                                              |
| 2.6.7   | PH15-7Mo                                                            |
| 2.6.8   | 17-4PH                                                              |
| 2.6.9   | 17-7PH                                                              |
| 2.7     | <b>Austenitic stainless steels</b>                                  |
| 2.7.1   | AISI Type 301                                                       |

**2.1.2 MATERIAL PROPERTIES** — One of the major factors contributing to the general utility of steels is the wide range of mechanical properties which can be obtained by heat treatment. For example, softness and good ductility may be required during fabrication of a part and very high strength during its service life. Both sets of properties are obtainable in the same material.

All steels can be softened to a greater or lesser degree by annealing, depending on the chemical composition of the specific steel. Annealing is achieved by heating the steel to an appropriate temperature, holding, then cooling it at the proper rate.

Likewise, steels can be hardened or strengthened by means of cold working, heat treating, or a combination of these.

Cold working is the method used to strengthen both the low-carbon unalloyed steels and the highly alloyed austenitic stainless steels. Only moderately high strength levels can be attained in the former, but the latter can be cold rolled to quite high strength levels, or “tempers”. These are commonly supplied to specified minimum strength levels.

Heat treating is the principal method for strengthening the remainder of the steels (the low-carbon steels and the austenitic steels cannot be strengthened by heat treatment). The heat treatment of steel may be of three types: martensitic hardening, age hardening, and austempering. Carbon and alloy steels are martensitic-hardened by heating to a high temperature, or “austenitizing”, and cooling at a recommended rate, often by quenching in oil or water. This is followed by “tempering”, which consists of reheating to an intermediate temperature to relieve internal stresses and to improve toughness.

The maximum hardness of carbon and alloy steels, quenched rapidly to avoid the nose of the isothermal transformation curve, is a function in general of the alloy content, particularly the carbon content. Both the maximum thickness for complete hardening or the depth to which an alloy will harden under specific cooling conditions, and the distribution of hardness can be used as a measure of a material’s hardenability.

A relatively new class of steels is strengthened by age hardening. This heat treatment is designed to dissolve certain constituents in the steel, then precipitate them in some preferred particle size and distribution. Since both the martensitic hardening and the age-hardening treatments are relatively complex, specific details are presented for individual steels elsewhere in this chapter.

Recently, special combinations of working and heat treating have been employed to further enhance the mechanical properties of certain steels. At the present time, the use of these specialized treatments is not widespread.

Another method of heat treatment for steels is austempering. In this process, ferrous steels are austenitized, quenched rapidly to avoid transformation of the austenite to a temperature below the pearlite and above the martensite formation ranges, allowed to transform isothermally at that temperature to a completely bainitic structure, and finally cooled to room temperature. The purpose of austempering is to obtain increased ductility or notch toughness at high hardness levels, or to decrease the likelihood of cracking and distortion that might occur in conventional quenching and tempering.

### **2.1.2.1 Mechanical Properties** —

**2.1.2.1.1 Strength (Tension, Compression, Shear, Bearing)** — The strength properties presented are those used in structural design. The room-temperature properties are shown in tables following the comments for individual steels. The variations in strength properties with temperature are presented

graphically as percentages of the corresponding room-temperature strength property, also described in Section 9.3.1 and associated subsections. These strength properties may be reduced appreciably by prolonged exposure at elevated temperatures.

The strength of steels is temperature-dependent, decreasing with increasing temperature. In addition, steels are strain rate-sensitive above about 600 to 800°F, particularly at temperatures at which creep occurs. At lower strain rates, both yield and ultimate strengths decrease.

The modulus of elasticity is also temperature-dependent and, when measured by the slope of the stress-strain curve, it appears to be strain rate-sensitive at elevated temperatures because of creep during loading. However, on loading or unloading at high rates of strain, the modulus approaches the value measured by dynamic techniques.

Steel bars, billets, forgings, and thick plates, especially when heat treated to high strength levels, exhibit variations in mechanical properties with location and direction. In particular, elongation, reduction of area, toughness, and notched strength are likely to be lower in either of the transverse directions than in the longitudinal direction. This lower ductility and/or toughness results both from the fibering caused by the metal flow and from nonmetallic inclusions which tend to be aligned with the direction of primary flow. Such anisotropy is independent of the depth-of-hardening considerations discussed elsewhere. It can be minimized by careful control of melting practices (including degassing and vacuum-arc remelting) and of hot-working practices. In applications where transverse properties are critical, requirements should be discussed with the steel supplier and properties in critical locations should be substantiated by appropriate testing

**2.1.2.1.2 Elongation** — The elongation values presented in this chapter apply in both the longitudinal and long transverse directions, unless otherwise noted. Elongation in the short transverse (thickness) direction may be lower than the values shown.

**2.1.2.1.3 Fracture Toughness** — Steels (as well as certain other metals), when processed to obtain high strength, or when tempered or aged within certain critical temperature ranges, may become more sensitive to the presence of small flaws. Thus, as discussed in Section 1.4.12, the usefulness of high-strength steels for certain applications is largely dependent on their toughness. It is generally noted that the fracture toughness of a given alloy product decreases relative to increase in the yield strength. The designer is cautioned that the propensity for brittle fracture must be considered in the application of high-strength alloys for the purpose of increased structural efficiency.

Minimum, average, and maximum values, as well as coefficient of variation of plane-strain fracture toughness for several steel alloys, are presented in Table 2.1.2.1.3. These values are presented as indicative information and do not have the statistical reliability of room-temperature mechanical properties. Data showing the effect of temperature are presented in the respective alloy sections where the information is available.

**2.1.2.1.4 Stress-Strain Relationships** — The stress-strain relationships presented in this chapter are prepared as described in Section 9.3.2.

**2.1.2.1.5 Fatigue** — Axial-load fatigue data on unnotched and notched specimens of various steels at room temperature and at other temperatures are shown as S/N curves in the appropriate section. Surface finish, surface finishing procedures, metallurgical effects from heat treatment, environment and other factors influence fatigue behavior. Specific details on these conditions are presented as correlative information for the S/N curve.

**Table 2.1.2.1.3. Values of Room Temperature Plane-Strain Fracture Toughness of Steel Alloys<sup>a</sup>**

| Alloy        | Heat Treat Condition                                     | Product Form | Orientation <sup>b</sup> | Yield Strength Range, ksi | Product Thickness Range, inches | Number of Sources | Sample Size | Specimen Thickness Range, inches | K <sub>IC</sub> , ksi √in. |      |      |                          |
|--------------|----------------------------------------------------------|--------------|--------------------------|---------------------------|---------------------------------|-------------------|-------------|----------------------------------|----------------------------|------|------|--------------------------|
|              |                                                          |              |                          |                           |                                 |                   |             |                                  | Max.                       | Avg. | Min. | Coefficient of Variation |
| D6AC         | 1650 °F, Aus-Bay Quench 975 °F, SQ 375 °F, 1000 °F 2 + 2 | Plate        | L-T                      | 217                       | 1.5                             | 1                 | 19          | 0.6                              | 88                         | 62   | 40   | 22.5                     |
| D6AC         | 1650 °F, Aus-Bay Quench 975 °F, SQ 400 °F, 1000 °F 2 + 2 | Plate        | L-T                      | 217                       | 0.8                             | 1                 | 103         | 0.6-0.8                          | 92                         | 64   | 44   | 18.9                     |
| D6AC         | 1650 °F, Aus-Bay Quench 975 °F, SQ 400 °F, 1000 °F 2 + 2 | Forging      | L-T                      | 214                       | 0.8-1.5                         | 1                 | 53          | 0.6-0.8                          | 96                         | 66   | 39   | 18.6                     |
| D6AC         | 1700 °F, Aus-Bay Quench 975 °F, OQ 140 °F, 1000 °F 2 + 2 | Plate        | L-T                      | 217                       | 0.8-1.5                         | 1                 | 30          | 0.6-0.8                          | 101                        | 92   | 64   | 8.9                      |
| D6AC         | 1700 °F, Aus-Bay Quench 975 °F, OQ 140 °F, 1000 °F 2 + 2 | Forging      | L-T                      | 214                       | 0.8-1.5                         | 1                 | 34          | 0.7                              | 109                        | 95   | 81   | 6.7                      |
| 9Ni-4Co-.20C | Quench and Temper                                        | Hand Forging | L-T                      | 185-192                   | 3.0                             | 2                 | 27          | 1.0-2.0                          | 147                        | 129  | 107  | 8.3                      |
| 9Ni-4Co-.20C | 1650 °F, 1-2 Hr, AC, 1525 °F, 1-2 Hr, OQ, -100 °F, Temp  | Forging      | L-T                      | 186-192                   | 3.0-4.0                         | 3                 | 17          | 1.5-2.0                          | 147                        | 134  | 120  | 8.5                      |
| PH13-8Mo     | H1000                                                    | Forging      | L-T                      | 205-212                   | 4.0-8.0                         | 3                 | 12          | 0.7-2.0                          | 104                        | 90   | 49   | 21.5                     |

a These values are for information only.

b Refer to Figure 1.4.12.3 for definition of symbols.



**2.1.2.2 Physical Properties** — The physical properties ( $\omega$ ,  $C$ ,  $K$ , and  $\alpha$ ) of steels may be considered to apply to all forms and heat treatments unless otherwise indicated.

**2.1.3 ENVIRONMENTAL CONSIDERATIONS**— The effects of exposure to environments such as stress, temperature, atmosphere, and corrosive media are reported for various steels. Fracture toughness of high-strength steels and the growth of cracks by fatigue may be detrimentally influenced by humid air and by the presence of water or saline solutions. Some alleviation may be achieved by heat treatment and all high-strength steels are not similarly affected.

In general, these comments apply to steels in their usual finished surface condition, without surface protection. It should be noted that there are available a number of heat-resistant paints, platings, and other surface coatings that are employed either to improve oxidation resistance at elevated temperature or to afford protection against corrosion by specific media. In employing electrolytic platings, special consideration should be given to the removal of hydrogen by suitable baking. Failure to do so may result in lowered fracture toughness or embrittlement.

## 2.2 CARBON STEELS

### 2.2.0 COMMENTS ON CARBON STEELS

**2.2.0.1 Metallurgical Considerations** — Carbon steels are those steels containing carbon up to about 1 percent and only residual quantities of other elements except those added for deoxidation.

The strength that carbon steels are capable of achieving is determined by carbon content and, to a much lesser extent, by the content of the residual elements. Through cold working or proper choice of heat treatments, these steels can be made to exhibit a wide range of strength properties.

The finish conditions most generally specified for carbon steels include hot-rolled, cold-rolled, cold-drawn, normalized, annealed, spheroidized, stress-relieved, and quenched-and-tempered. In addition, the low-carbon grades (up to 0.25 percent C) may be carburized to obtain high surface hardness and wear resistance with a tough core. Likewise, the higher carbon grades are amenable to selective flame hardening to obtain desired combinations of properties.

#### 2.1.0.2 Manufacturing Considerations —

*Forging* — All of the carbon steels exhibit excellent forgeability in the austenitic state provided the proper forging temperatures are used. As the carbon content is increased, the maximum forging temperature is decreased. At high temperatures, these steels are soft and ductile and exhibit little or no tendency to work harden. The resulfurized grades (free-machining steels) exhibit a tendency to rupture when deformed in certain high-temperature ranges. Close control of forging temperatures is required.

*Cold Forming* — The very low-carbon grades have excellent cold-forming characteristics when in the annealed or normalized conditions. Medium-carbon grades show progressively poorer formability with higher carbon content, and more frequent annealing is required. The high-carbon grades require special softening treatments for cold forming. Many carbon steels are embrittled by warm working or prolonged exposure in the temperature range from 300 to 700°F.

*Machining* — The low-carbon grades (0.30 percent C and less) are soft and gummy in the annealed condition and are preferably machined in the cold-worked or the normalized condition. Medium-carbon (0.30 to 0.50 percent C) grades are best machined in the annealed condition, and high-carbon grades (0.50 to 0.90 percent C) in the spheroidized condition. Finish machining must often be done in the fully heat-treated condition for dimensional accuracy. The resulfurized grades are well known for their good machinability. Nearly all carbon steels are now available with 0.15 to 0.35 percent lead, added to improve machinability. However, resulfurized and leaded steels are not generally recommended for highly stressed aircraft and missile parts because of a drastic reduction in transverse properties.

*Welding* — The low-carbon grades are readily welded or brazed by all techniques. The medium-carbon grades are also readily weldable but may require preheating and postwelding heat treatment. The high-carbon grades are difficult to weld. Preheating and postwelding heat treatment are usually mandatory for the latter, and special care must be taken to avoid overheating. Furnace brazing has been used successfully with all grades.

*Heat Treatment* — Due to the poor oxidation resistance of carbon steels, protective atmospheres must be employed during heat treatment if scaling of the surface cannot be tolerated. Also, these steels are subject to decarburization at elevated temperatures and, where surface carbon content is critical, should be heated in reducing atmospheres.

**2.2.0.3 Environmental Considerations** — Carbon steels have poor oxidation resistance above about 900 to 1000°F. Strength and oxidation-resistance criteria generally preclude the use of carbon steels above 900°F.

Carbon steels may undergo an abrupt transition from ductile to brittle behavior. This transition temperature varies widely for different carbon steels depending on many factors. Cautions should be exercised in the application of carbon steels to assure that the transition temperature of the selected alloy is below the service temperature. Additional information is contained in References 2.2.0.3(a) and (b).

The corrosion resistance of carbon steels is relatively poor; clean surfaces rust rapidly in moist atmospheres. Simple oil film protection is adequate for normal handling. For aerospace applications, the carbon steels are usually plated to provide adequate corrosion protection.

**2.2.1 AISI 1025**

**2.2.1.0 Comments and Properties** — AISI 1025 is an excellent general purpose steel for the majority of shop requirements, including jigs, fixtures, prototype mockups, low torque shafting, and other applications. It is not generally classed as an airframe structural steel. However, it is available in aircraft quality as well as commercial quality.

*Manufacturing Considerations* — Cold-finished flat-rolled products are supplied principally where maximum strength, good surface finish, or close tolerance is desirable. Reasonably good forming properties are found in AISI 1025. The machinability of bar stock is rated next to these sulfurized types of free-machining steels, but the resulting surface finish is poorer.

*Specifications and Properties* — Material specifications for AISI 1025 steel are presented in Table 2.2.1.0(a). The room-temperature mechanical and physical properties are shown in Table 2.2.1.0(b). The effect of temperature on thermal expansion is shown in Figure 2.2.1.0.

**Table 2.2.1.0(a). Material Specifications for AISI 1025 Carbon Steel**

| Specification           | Form                    |
|-------------------------|-------------------------|
| ASTM A 108              | Bar                     |
| AMS 5075                | Seamless tubing         |
| AMS-T-5066 <sup>a</sup> | Tubing                  |
| AMS 5077                | Tubing                  |
| AMS 5046                | Sheet, strip, and plate |
| AMS-S-7952              | Sheet and strip         |

<sup>a</sup> Noncurrent specification

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 2.2.1.0(b). Design Mechanical and Physical Properties of AISI 1025 Carbon Steel**

| Specification . . . . .                           | AMS 5046 and<br>MIL-S-7952 | AMS 5075, AMS 5077<br>and AMS-T-5066 <sup>a</sup> | ASTM A 108     |
|---------------------------------------------------|----------------------------|---------------------------------------------------|----------------|
| Form . . . . .                                    | Sheet, strip, and plate    | Tubing                                            | Bar            |
| Condition . . . . .                               | Annealed                   | Normalized                                        | All            |
| Thickness, in. . . . .                            | ...                        | ...                                               | ...            |
| Basis . . . . .                                   | S                          | S                                                 | S <sup>b</sup> |
| Mechanical Properties:                            |                            |                                                   |                |
| $F_{tu}$ , ksi:                                   |                            |                                                   |                |
| L . . . . .                                       | 55                         | 55                                                | 55             |
| LT . . . . .                                      | 55                         | 55                                                | 55             |
| ST . . . . .                                      | ...                        | ...                                               | 55             |
| $F_{ty}$ , ksi:                                   |                            |                                                   |                |
| L . . . . .                                       | 36                         | 36                                                | 36             |
| LT . . . . .                                      | 36                         | 36                                                | 36             |
| ST . . . . .                                      | ...                        | ...                                               | 36             |
| $F_{cy}$ , ksi:                                   |                            |                                                   |                |
| L . . . . .                                       | 36                         | 36                                                | 36             |
| LT . . . . .                                      | 36                         | 36                                                | 36             |
| ST . . . . .                                      | ...                        | ...                                               | 36             |
| $F_{su}$ , ksi . . . . .                          | 35                         | 35                                                | 35             |
| $F_{bru}$ , ksi:                                  |                            |                                                   |                |
| (e/D = 1.5) . . . . .                             | ...                        | ...                                               | ...            |
| (e/D = 2.0) . . . . .                             | 90                         | 90                                                | 90             |
| $F_{bry}$ , ksi:                                  |                            |                                                   |                |
| (e/D = 1.5) . . . . .                             | ...                        | ...                                               | ...            |
| (e/D = 2.0) . . . . .                             | ...                        | ...                                               | ...            |
| e, percent:                                       |                            |                                                   |                |
| L . . . . .                                       | ...                        | c                                                 | c              |
| LT . . . . .                                      | c                          | ...                                               | ...            |
| $E$ , 10 <sup>3</sup> ksi . . . . .               | 29.0                       |                                                   |                |
| $E_c$ , 10 <sup>3</sup> ksi . . . . .             | 29.0                       |                                                   |                |
| $G$ , 10 <sup>3</sup> ksi . . . . .               | 11.0                       |                                                   |                |
| $\mu$ . . . . .                                   | 0.32                       |                                                   |                |
| Physical Properties:                              |                            |                                                   |                |
| $\dot{u}$ , lb/in. <sup>3</sup> . . . . .         | 0.284                      |                                                   |                |
| $C$ , Btu/(lb)(°F) . . . . .                      | 0.116 (122 to 212°F)       |                                                   |                |
| $K$ , Btu/[(hr)(ft <sup>2</sup> )(°F)/ft] . .     | 30.0 (at 32°F)             |                                                   |                |
| $\dot{a}$ , 10 <sup>-6</sup> in./in./°F . . . . . | See Figure 2.2.1.0         |                                                   |                |

a Noncurrent specification.

[VIEW INTERACTIVE GRAPH](#)

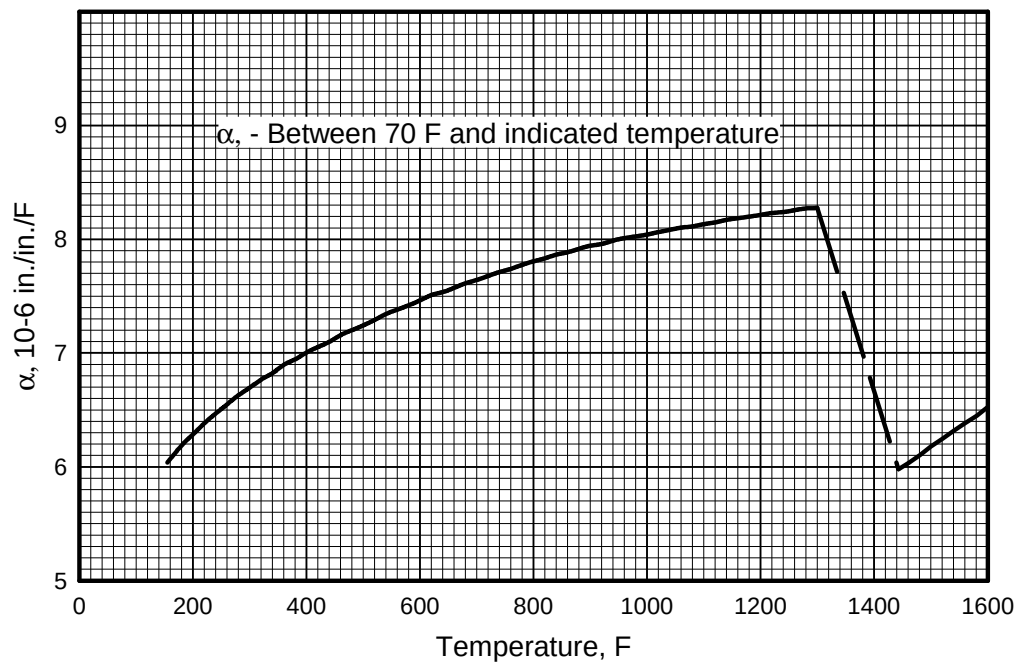


Figure 2.2.1.0 Effect of temperature on the thermal expansion of 1025 steel.

## 2.3 LOW-ALLOY STEELS (AISI GRADES AND PROPRIETARY GRADES)

### 2.3.0 COMMENTS ON LOW-ALLOY STEELS (AISI AND PROPRIETARY GRADES)

**2.2.0.1 Metallurgical Considerations** — The AISI or SAE alloy steels contain, in addition to carbon, up to about 1 percent (up to 0.5 percent for most airframe applications) additions of various alloying elements to improve their strength, depth of hardening, toughness, or other properties of interest. Generally, alloy steels have better strength-to-weight ratios than carbon steels and are somewhat higher in cost on a weight, but not necessarily strength, basis. Their applications in airframes include landing-gear components, shafts, gears, and other parts requiring high strength, through hardening, or toughness.

Some alloy steels are identified by the AISI four-digit system of numbers. The first two digits indicate the alloy group and the last two the approximate carbon content in hundredths of a percent. The alloying elements used in these steels include manganese, silicon, nickel, chromium, molybdenum, vanadium, and boron. Other steels in this section are proprietary steels which may be modifications of the AISI grades. The alloying additions in these steels may provide deeper hardening, higher strength and toughness.

These steels are available in a variety of finish conditions, ranging from hot- or cold-rolled to quenched-and-tempered. They are generally heat treated before use to develop the desired properties. Some steels in this group are carburized, then heat treated to produce a combination of high surface hardness and good core toughness.

#### 2.3.0.2 Manufacturing Conditions —

*Forging* — The alloy steels are only slightly more difficult to forge than carbon steels. However, maximum recommended forging temperatures are generally about 50°F lower than for carbon steels of the same carbon content. Slower heating rates, shorter soaking period, and slower cooling rates are also required for alloy steels.

*Cold Forming* — The alloy steels are usually formed in the annealed condition. Their formability depends mainly on the carbon content and is generally slightly poorer than for unalloyed steels of the same carbon content. Little cold forming is done on these steels in the heat-treated condition because of their high strength and limited ductility.

*Machining* — The alloy steels are generally harder than unalloyed steels of the same carbon content. As a consequence, the low-carbon alloy steels are somewhat easier to finish machine than their counterparts in the carbon steels. It is usually desirable to finish machine the carburizing and through-hardening grades in the final heat-treated condition for better dimensional accuracy. This often leads to two steps in machining: rough machining in the annealed or hot-finished condition, then finish machining after heat treating. The latter operation, because of the relatively high hardness of the material, necessitates the use of sharp, well-designed, high-speed steel cutting tools, proper feeds, speeds, and a generous supply of coolant. Medium- and high-carbon grades are usually spheroidized for optimum machinability and, after heat treatment, may be finished by grinding. Many of the alloy steels are available with added sulfur or lead for improved machinability. However, resulfurized and leaded steels are not recommended for highly stressed aircraft and missile parts, because of drastic reductions in transverse properties.

*Welding* — The low-carbon grades are readily welded or brazed by all techniques. Alloy welding rods comparable in strength to the base metal are used, and moderate preheating (200 to 600°F) is usually necessary. At higher carbon levels, higher preheating temperatures, and often postwelding stress relieving, are required. Certain alloy steels can be welded without loss of strength in the heat-affected zone provided that the welding heat input is carefully controlled. If the composition and strength level are such that the

strength of the welded joint is reduced, the strength of the joint may be restored by heat treatment after welding.

*Heat Treatment* — For the low alloy steels, there are various heat treatment procedures that can be applied to a particular alloy to achieve any one of a number of specific mechanical (for example tensile) properties. Within this chapter, there are mechanical properties for three thermal processing conditions: annealed, normalized, and quenched and tempered. The specific details of these three thermal processing conditions are reviewed in Reference 2.3.0.2.5. In general, the annealed condition is achieved by heating to a suitable temperature and holding for a specified period of time. Annealing generally softens the material, producing the lowest mechanical properties. The normalized condition is achieved by holding to a slightly higher temperature than annealing, but for a shorter period of time. The purpose of normalizing varies depending on the desired properties; it can be used to increase or decrease mechanical properties. The quenched and tempered condition, discussed in more detail below, is used to produce the highest mechanical properties while providing relatively high toughness. The mechanical properties for these three processing conditions for specific steels are as shown in Tables 2.3.1.0(c), (f), and (h).

Maximum hardness in these steels is obtained in the as-quenched condition, but toughness and ductility in this condition are comparatively low. By means of tempering, their toughness is improved, usually accompanied by a decrease in strength and hardness. In general, tempering temperatures to achieve very high strength should be avoided when toughness is an important consideration.

In addition, these steels may be embrittled by tempering or by prolonged exposure under stress within the “blue brittle” range (approximately 500 to 700°F). Strength levels that necessitate tempering within this range should be avoided.

The mechanical properties presented in this chapter represent steels heat treated to produce a quenched structure containing 90 percent martensite at the center and tempered to the desired  $F_{tu}$  level. This degree of through hardening is necessary (regardless of strength level) to insure the attainment of reasonably uniform mechanical properties throughout the cross section of the heat-treated part. The maximum diameter of round bars of various alloy steels capable of being through hardened consistently are given in Table 2.3.0.2. Limiting dimensions for common shapes other than round are determined by means of the “equivalent round” concept in Figure 2.3.0.2. This concept is essentially a correlation between the significant dimensions of a particular shape and the diameter of a round bar, assuming in each instance that the material, heat treatment, and the mechanical properties at the centers of both the respective shape and the equivalent round are substantially the same.

For the quenched and tempered condition, a large range of mechanical property values can be achieved as indicated in Table 2.3.0.2. Various quench media (rates), tempering temperatures, and times can be employed allowing any number of processing routes to achieve these values. As a result of these processing routes, there are a large range of mechanical properties that can be obtained for a specific alloy. Therefore, the properties of a steel can be tailored to meet the needs for a specific component/application.

Because of the potential for several different processing methods for these three conditions, the MIL, Federal, and AMS specifications do not always contain minimum mechanical property values (S-basis). They may contain minimum mechanical property values for one specific quenched and tempered condition. Those specifications cited in this Handbook that do not contain mechanical properties are identified with a footnote in Tables 2.3.1.0(a) and (b). The possible mechanical properties for these alloys covered in the specifications for the normalized, and quenched and tempered conditions in Table 2.3.0.2 are presented in Tables 2.3.1.0 ( $h_1$ ) and ( $h_2$ ). Users must rely on their own in-house specifications or appropriate industry specifications to validate that the required strength was achieved. Therefore, no statistical basis (A, B, S) for these values are indicated in Tables 2.3.1.0 ( $h_1$ ) and ( $h_2$ ).

**Table 2.3.0.2. Maximum Round Diameters for Low-Alloy Steel Bars (Through Hardening to at Least 90 Percent Martensite at Center)**

|                            | Diameter of Round or Equivalent Round, in. <sup>a</sup> |                            |           |                                                    |                                                    |                                             |                   |
|----------------------------|---------------------------------------------------------|----------------------------|-----------|----------------------------------------------------|----------------------------------------------------|---------------------------------------------|-------------------|
| <i>F<sub>u</sub></i> , ksi | 0.5                                                     | 0.8                        | 1.0       | 1.7                                                | 2.5                                                | 3.5                                         | 5.0               |
| 270 & 280                  | ...                                                     | ...                        | ...       | ...                                                | ...                                                | ...                                         | 300M <sup>c</sup> |
| 260                        | ...                                                     | ...                        | ...       | AISI 4340 <sup>b</sup>                             | AISI 4340 <sup>c</sup>                             | AISI 4340 <sup>d</sup>                      | ...               |
| 220                        | ...                                                     | ...                        | ...       | AMS Grades <sup>be</sup>                           | AMS Grades <sup>ce</sup>                           | D6AC <sup>b</sup>                           | D6AC <sup>c</sup> |
| 200                        | ...                                                     | AISI 8740                  | AISI 4140 | AISI 4340 <sup>b</sup><br>AMS Grades <sup>be</sup> | AISI 4340 <sup>c</sup><br>AMS Grades <sup>ce</sup> | AISI 4340 <sup>d</sup>                      | D6AC <sup>c</sup> |
| ≤180                       | AISI 4130<br>and 8630                                   | AISI 8735<br>4135 and 8740 | AISI 4140 | AISI 4340 <sup>b</sup><br>AMS Grades <sup>be</sup> | AISI 4340 <sup>c</sup><br>AMS Grades <sup>ce</sup> | AISI 4340 <sup>d</sup><br>D6AC <sup>b</sup> | D6AC <sup>c</sup> |

a This table indicates the maximum diameters to which these steels may be through hardened consistently by quenching as indicated. Any steels in this table may be used at diameters less than those indicated. The use of steels at diameters greater than those indicated should be based on hardenability data for specific heats of steel.

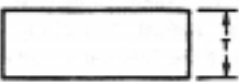
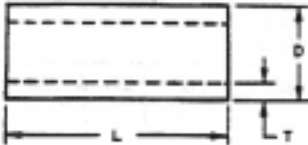
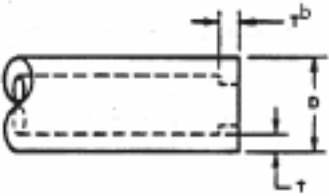
b Quenched in molten salt at desired tempering temperature (“martempering”).

c Quenched in oil at a flow rate of 200 feet per minute.

d Quenched in water at a flow rate of 200 feet per minute.

e 4330V, 4335V, and Hy-Tuf.



| SOLIDS, LENGTH L                                                                                                                    |                                                                                                   |                                                                                   |                                                                                    |
|-------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------|
| ROUND                                                                                                                               | HEXAGON                                                                                           | SQUARE                                                                            | RECTANGULAR OR PLATE                                                               |
|                                                    |                  |  |  |
| ER <sup>a</sup> = T                                                                                                                 | ER = 1.1 T                                                                                        | ER = 1.25 T                                                                       | ER = 1.5 T                                                                         |
| WHEN L IS LESS THAN T, CONSIDER SECTION AS A PLATE OF L THICKNESS                                                                   |                                                                                                   |                                                                                   |                                                                                    |
| TUBE (ANY SECTION)                                                                                                                  |                                                                                                   |                                                                                   |                                                                                    |
| OPEN BOTH ENDS                                                                                                                      | RESTRICTED OR CLOSED AT ONE OR BOTH ENDS                                                          |                                                                                   |                                                                                    |
|                                                    |                 |                                                                                   |                                                                                    |
| ER = 2 T                                                                                                                            | ER = 2.5 T    WHEN D IS LESS THAN 2.5 INCHES.<br>ER = 3.5 T    WHEN D IS GREATER THAN 2.5 INCHES. |                                                                                   |                                                                                    |
| NOTE: WHEN L IS LESS THAN D, CONSIDER AS A PLATE OF T THICKNESS. WHEN L IS LESS THAN T, CONSIDER SECTION AS A PLATE OF L THICKNESS. |                                                                                                   |                                                                                   |                                                                                    |

<sup>a</sup>ER = equivalent round. (Illustration after MIL-H-6875.)  
<sup>b</sup>Use maximum thickness for calculation.

Figure 2.3.0.2. Correlation between significant dimensions of common shapes other than round, and the diameters of round bars.

**2.3.0.3 Environmental Considerations** — Alloy steels containing chromium or high percentages of silicon have somewhat better oxidation resistance than the carbon or other alloy steels. Elevated-temperature strength for the alloy steels is also higher than that of corresponding carbon steels. The mechanical properties of all alloy steels in the heat-treated condition are affected by extended exposure to temperatures near or above the temperature at which they were tempered. The limiting temperatures to which each alloy may be exposed for no longer than approximately 1 hour per inch of thickness or approximately one-half hour for thicknesses under one-half inch without a reduction in strength occurring are listed in Table 2.3.0.3. These values are approximately 100°F below typical tempering temperatures used to achieve the designated strength levels.

**Table 2.3.0.3. Temperature Exposure Limits for Low-Alloy Steels**

| $F_w$ , ksi        | Exposure Limit, °F |      |      |     |     |     |           |
|--------------------|--------------------|------|------|-----|-----|-----|-----------|
|                    | 125                | 150  | 180  | 200 | 220 | 260 | 270 & 280 |
| Alloy:             |                    |      |      |     |     |     |           |
| AISI 4130 and 8630 | 925                | 775  | 575  | ... | ... | ... | ...       |
| AISI 4140 and 8740 | 1025               | 875  | 725  | 625 | ... | ... | ...       |
| AISI 4340          | 1100               | 950  | 800  | 700 | ... | 350 | ...       |
| AISI 4135 and 8735 | 975                | 825  | 675  | ... | ... | ... | ...       |
| D6AC               | 1150               | 1075 | 1000 | 950 | 900 | 500 | ...       |
| Hy-Tuf             | 875                | 750  | 650  | 550 | 450 | ... | ...       |
| 4330V              | 925                | 850  | 775  | 700 | 500 | ... | ...       |
| 4335V              | 975                | 875  | 775  | 700 | 500 | ... | ...       |
| 300M               | ...                | ...  | ...  | ... | ... | ... | 475       |

a Quenched and tempered to  $F_w$  indicated. If the material is exposed to temperatures exceeding those listed, a reduction in strength is likely to occur.

Low-alloy steels may undergo a transition from ductile to brittle behavior at low temperatures. This transition temperature varies widely for different alloys. Caution should be exercised in the application of low-alloy steels at temperatures below -100°F. For use at a temperature below -100°F, an alloy with a transition temperature below the service temperature should be selected. For low temperatures, the steel should be heat treated to a tempered martensitic condition for maximum toughness.

Heat-treated alloy steels have better notch toughness than carbon steels at equivalent strength levels. The decrease in notch toughness is less pronounced and occurs at lower temperatures. Heat-treated alloy steels may be useful for subzero applications, depending on their alloy content and heat treatment. Heat treating to strength levels higher than 150 ksi  $F_{ty}$  may decrease notch toughness.

The corrosion properties of the AISI alloy steels are comparable to the plain carbon steels.

### 2.3.1 SPECIFIC ALLOYS

**2.3.1.0 Comments and Properties** — AISI 4130 is a chromium-molybdenum steel that is in general use due to its well-established heat-treating practices and processing techniques. It is available in all sizes of sheet, plate, and tubing. Bar stock of this material is also used for small forgings under one-half inch in thickness. AISI 4135, a slightly higher carbon version of AISI 4130, is available in sheet, plate, and tubing.

AISI 4140 is a chromium-molybdenum steel that can be heat treated in thicker sections and to higher strength levels than AISI 4130. This steel is generally used for structural machined and forged parts one-half inch and over in thickness. It can be welded but it is more difficult to weld than the lower carbon grade AISI 4130.

AISI 4340 is a nickel-chromium-molybdenum steel that can be heat treated in thicker sections and to higher strength levels than AISI 4140.

AISI 8630, 8735, and 8740 are nickel-chromium-molybdenum steels that are considered alternates to AISI 4130, 4135, and 4140, respectively.

There are a number of steels available with compositions that represent modifications to the AISI grades described above. Four of the steels that have been used rather extensively at  $F_{tu} = 220$  ksi are D6AC, Hy-Tuf, 4330V, and 4335V. It should be noted that this strength level is not used for AISI 4340 due to embrittlement encountered during tempering in the range of 500 to 700°F. In addition, AISI 4340 and 300M are utilized at strength levels of  $F_{tu} = 260$  ksi or higher. The alloys, AISI 4340, D6AC, 4330V, 4335V, and 300M, are available in the consumable electrode melted grade. Material specifications for these steels are presented in Tables 2.3.1.0(a) and (b).

The room-temperature mechanical and physical properties for these steels are presented in Tables 2.3.1.0(c) through 2.3.1.0(g). Mechanical properties for heat-treated materials are valid only for steel heat treated to produce a quenched structure containing 90 percent or more martensite at the center. Figure 2.3.1.0 contains elevated temperature curves for the physical properties of AISI 4130 and AISI 4340 steels.

**2.3.1.1 AISI Low-Alloy Steels** — Elevated temperature curves for heat-treated AISI low-alloy steels are presented in Figures 2.3.1.1.1 through 2.3.1.1.4. These curves are considered valid for each of these steels in each heat-treated condition but only up to the maximum temperatures listed in Table 2.3.0.1(b).

**2.3.1.2 AISI 4130 and 8630 Steels** — Typical stress-strain and tangent-modulus curves for AISI 8630 are shown in Figures 2.3.1.2.6(a) through (c). Best-fit S/N curves for AISI 4130 steel are presented in Figures 2.3.1.2.8(a) through (h).

**2.3.1.3 AISI 4340 Steel** — Typical stress-strain and tangent-modulus curves for AISI 4340 are shown in Figures 2.3.1.3.6(a) through (c). Typical biaxial stress-strain curves and yield-stress envelopes for AISI 4340 alloy steel are presented in Figures 2.3.1.3.6(d) through (g). Best-fit S/N curves for AISI 4340 are presented in Figures 2.3.1.3.8(a) through (o).

**2.3.1.4 300M Steel** — Best-fit S/N curves for 300M steel are presented in Figures 2.3.1.4.8(a) through (d). Fatigue-crack-propagation data for 300M are shown in Figure 2.3.1.4.9.

**2.3.1.5 D6AC Steel** — Fatigue-crack-propagation data for D6AC steel are presented in Figure 2.3.1.5.9.

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Table 2.3.1.0(a). Material Specifications for Air Melted Low-Alloy Steels

| Alloy | Form                                                       |                                                                                                 |                                                                                      |
|-------|------------------------------------------------------------|-------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
|       | Sheet, strip, and plate                                    | Bars and forgings                                                                               | Tubing                                                                               |
| 4130  | AMS-S-18729, AMS 6350 <sup>a</sup> , AMS 6351 <sup>a</sup> | AMS-S-6758 <sup>a</sup> , AMS 6348 <sup>a</sup> , AMS 6370 <sup>a</sup> , AMS 6528 <sup>a</sup> | AMS-T-6736, AMS 6371 <sup>a</sup> , AMS 6360, AMS 6361, AMS 6362, AMS 6373, AMS 6374 |
| 8630  | AMS-S-18728, AMS 6355 <sup>a</sup>                         | AMS-S-6050, AMS 6280 <sup>a</sup>                                                               | AMS 6281 <sup>a</sup>                                                                |
| 4135  | AMS 6352 <sup>a</sup>                                      | ...                                                                                             | AMS 6372 <sup>a</sup> , AMS 6365, AMS-T-6735 <sup>b</sup>                            |
| 8735  | AMS 6357 <sup>a</sup>                                      | AMS 6320 <sup>a</sup>                                                                           | AMS 6282 <sup>a</sup>                                                                |
| 4140  | AMS 6395 <sup>a</sup>                                      | AMS-S-5626 <sup>a</sup> , AMS 6382 <sup>a</sup> , AMS 6349 <sup>a</sup> , AMS 6529 <sup>a</sup> | AMS 6381 <sup>a</sup>                                                                |
| 4340  | AMS 6359 <sup>a</sup>                                      | AMS-S-5000 <sup>a</sup> , AMS 6415 <sup>a</sup>                                                 | AMS 6415 <sup>a</sup>                                                                |
| 8740  | AMS 6358 <sup>a</sup>                                      | AMS-S-6049 <sup>b</sup> , AMS 6327, AMS 6322 <sup>a</sup>                                       | AMS 6323 <sup>a</sup>                                                                |
| 4330V | ...                                                        | AMS 6427 <sup>a</sup>                                                                           | AMS 6427 <sup>a</sup>                                                                |
| 4335V | AMS 6433                                                   | AMS 6430                                                                                        | AMS 6430                                                                             |

a Specification does not contain minimum mechanical properties.

b Noncurrent specification.

Table 2.3.1.0(b). Material Specifications for Consumable Electrode Melted Low-Alloy Steels

| Alloy           | Form                    |                    |                    |
|-----------------|-------------------------|--------------------|--------------------|
|                 | Sheet, strip, and plate | Bar and forgings   | Tubing             |
| 4340            | AMS 6454 <sup>a</sup>   | AMS 6414           | AMS 6414           |
| D6AC            | AMS 6439                | AMS 6431, AMS 6439 | AMS 6431           |
| 4330V           | ...                     | AMS 6411           | AMS 6411           |
| Hy-Tuf          | ...                     | AMS 6425           | AMS 6425           |
| 4335V           | AMS 6435                | AMS 6429           | AMS 6429           |
| 300M<br>(0.40C) | ...                     | AMS 6417           | AMS 6417           |
| 300M<br>(0.42C) | ...                     | AMS 6419, AMS 6257 | AMS 6419, AMS 6257 |

a Specification does not contain minimum mechanical properties.

**Table 2.3.1.0(c<sub>1</sub>). Design Mechanical and Physical Properties of Air Melted Low-Alloy Steels**

|                                                         |                                                               |        |                                     |        |                         |        |
|---------------------------------------------------------|---------------------------------------------------------------|--------|-------------------------------------|--------|-------------------------|--------|
| Alloy . . . . .                                         | AISI 4130                                                     |        | AISI 4135                           |        | AISI 8630               |        |
| Specification [see Tables 2.3.1.0(a) and (b)] . . . . . | AMS 6360<br>AMS 6373<br>AMS 6374<br>AMS-T-6736<br>AMS-S-18729 |        | AMS 6365<br>AMS-T-6735 <sup>a</sup> |        | AMS-S-18728             |        |
| Form . . . . .                                          | Sheet, strip, plate,<br>and tubing                            |        | Tubing                              |        | Sheet, strip, and plate |        |
| Condition . . . . .                                     | Normalized and tempered, stress relieved <sup>b</sup>         |        |                                     |        |                         |        |
| Thickness or diameter, in. . . . .                      | *0.188                                                        | >0.188 | *0.188                              | *0.188 | *0.188                  | *0.188 |
| Basis . . . . .                                         | S                                                             | S      | S                                   | S      | S                       | S      |
| Mechanical Properties:                                  |                                                               |        |                                     |        |                         |        |
| $F_{tu}$ , ksi . . . . .                                | 95                                                            | 90     | 100                                 | 95     | 95                      | 90     |
| $F_{ty}$ , ksi . . . . .                                | 75                                                            | 70     | 85                                  | 80     | 75                      | 70     |
| $F_{cy}$ , ksi . . . . .                                | 75                                                            | 70     | 89                                  | 84     | 75                      | 70     |
| $F_{su}$ , ksi . . . . .                                | 57                                                            | 54     | 60                                  | 57     | 57                      | 54     |
| $F_{bru}$ , ksi:                                        |                                                               |        |                                     |        |                         |        |
| (e/D = 1.5) . . . . .                                   | ...                                                           | ...    | ...                                 | ...    | ...                     | ...    |
| (e/D = 2.0) . . . . .                                   | 200                                                           | 190    | 190                                 | 180    | 200                     | 190    |
| $F_{bry}$ , ksi:                                        |                                                               |        |                                     |        |                         |        |
| (e/D = 1.5) . . . . .                                   | ...                                                           | ...    | ...                                 | ...    | ...                     | ...    |
| (e/D = 2.0) . . . . .                                   | 129                                                           | 120    | 146                                 | 137    | 129                     | 120    |
| $e$ , percent . . . . .                                 | See Table 2.3.1.0(d)                                          |        |                                     |        |                         |        |
| $E$ , 10 <sup>3</sup> ksi . . . . .                     | 29.0                                                          |        |                                     |        |                         |        |
| $E_c$ , 10 <sup>3</sup> ksi . . . . .                   | 29.0                                                          |        |                                     |        |                         |        |
| $G$ , 10 <sup>3</sup> ksi . . . . .                     | 11.0                                                          |        |                                     |        |                         |        |
| $\mu$ . . . . .                                         | 0.32                                                          |        |                                     |        |                         |        |
| Physical Properties:                                    |                                                               |        |                                     |        |                         |        |
| $\dot{u}$ , lb/in. <sup>3</sup> . . . . .               | 0.283                                                         |        |                                     |        |                         |        |
| $C$ , $K$ , and $\acute{a}$ . . . . .                   | See Figure 2.3.1.0                                            |        |                                     |        |                         |        |

a Noncurrent specification.  
b Design values are applicable only to parts for which the indicated  $F_{tu}$  has been substantiated by adequate quality control testing.

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 2.3.1.0(c<sub>2</sub>). Design Mechanical and Physical Properties of Air Melted Low-Alloy Steels**

|                                                         |                                    |                        |            |
|---------------------------------------------------------|------------------------------------|------------------------|------------|
| Alloy . . . . .                                         | AISI 4130                          |                        |            |
| Specification [see Tables 2.3.1.0(a) and (b)] . . . . . | AMS 6361<br>AMS-T-6736             | AMS 6362<br>AMS-T-6736 | AMS-T-6736 |
| Form . . . . .                                          | Tubing                             |                        |            |
| Condition . . . . .                                     | Quenched and tempered <sup>a</sup> |                        |            |
| Thickness or diameter, in. . . . .                      | *0.188                             | *0.188                 | All Walls  |
| Basis . . . . .                                         | S                                  | S                      | S          |
| Mechanical Properties:                                  |                                    |                        |            |
| $F_{tu}$ , ksi . . . . .                                | 125                                | 150                    | 180        |
| $F_{ty}$ , ksi . . . . .                                | 100                                | 135                    | 165        |
| $F_{cy}$ , ksi . . . . .                                | 109                                | 141                    | 173        |
| $F_{su}$ , ksi . . . . .                                | 75                                 | 90                     | 108        |
| $F_{bru}$ , ksi:                                        |                                    |                        |            |
| (e/D = 1.5) . . . . .                                   | 194                                | 231                    | 277        |
| (e/D = 2.0) . . . . .                                   | 251                                | 285                    | 342        |
| $F_{bry}$ , ksi:                                        |                                    |                        |            |
| (e/D = 1.5) . . . . .                                   | 146                                | 210                    | 257        |
| (e/D = 2.0) . . . . .                                   | 175                                | 232                    | 284        |
| $e$ , percent . . . . .                                 | See Table 2.3.1.0(e)               |                        |            |
| $E$ , 10 <sup>3</sup> ksi . . . . .                     | 29.0                               |                        |            |
| $E_c$ , 10 <sup>3</sup> ksi . . . . .                   | 29.0                               |                        |            |
| $G$ , 10 <sup>3</sup> ksi . . . . .                     | 11.0                               |                        |            |
| $\mu$ . . . . .                                         | 0.32                               |                        |            |
| Physical Properties:                                    |                                    |                        |            |
| $\dot{u}$ , lb/in. <sup>3</sup> . . . . .               | 0.283                              |                        |            |
| $C$ , $K$ , and $\acute{a}$ . . . . .                   | See Figure 2.3.1.0                 |                        |            |

a Design values are applicable only to parts for which the indicated  $F_{tu}$  has been substantiated by adequate quality control testing.

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

Table 2.3.1.0(c<sub>3</sub>). Design Mechanical and Physical Properties of Air Melted Low-Alloy Steels

|                                                         |                                    |                         |          |
|---------------------------------------------------------|------------------------------------|-------------------------|----------|
| Alloy . . . . .                                         | AISI 8630                          | AISI 8740               |          |
| Specification [see Tables 2.3.1.0(a) and (b)] . . . . . | AMS-S-6050                         | AMS-S-6049 <sup>a</sup> | AMS 6327 |
| Form . . . . .                                          | Bars and forgings                  |                         |          |
| Condition . . . . .                                     | Quenched and tempered <sup>b</sup> |                         |          |
| Thickness or diameter, in. . . . .                      | *1.500                             | *1.750                  |          |
| Basis . . . . .                                         | S                                  | S                       |          |
| Mechanical Properties:                                  |                                    |                         |          |
| $F_{tu}$ , ksi . . . . .                                | 125                                | 125                     | 125      |
| $F_{ty}$ , ksi . . . . .                                | 100                                | 103                     | 100      |
| $F_{cy}$ , ksi . . . . .                                | 109                                | 108                     | 109      |
| $F_{su}$ , ksi . . . . .                                | 75                                 | 75                      | 75       |
| $F_{bru}$ , ksi:                                        |                                    |                         |          |
| (e/D = 1.5) . . . . .                                   | 194                                | 192                     | 194      |
| (e/D = 2.0) . . . . .                                   | 251                                | 237                     | 251      |
| $F_{bry}$ , ksi:                                        |                                    |                         |          |
| (e/D = 1.5) . . . . .                                   | 146                                | 160                     | 146      |
| (e/D = 2.0) . . . . .                                   | 175                                | 177                     | 175      |
| $e$ , percent . . . . .                                 | See Table 2.3.1.0(e)               |                         |          |
| $E$ , 10 <sup>3</sup> ksi . . . . .                     | 29.0                               |                         |          |
| $E_c$ , 10 <sup>3</sup> ksi . . . . .                   | 29.0                               |                         |          |
| $G$ , 10 <sup>3</sup> ksi . . . . .                     | 11.0                               |                         |          |
| $\mu$ . . . . .                                         | 0.32                               |                         |          |
| Physical Properties:                                    |                                    |                         |          |
| $\dot{u}$ , lb/in. <sup>3</sup> . . . . .               | 0.283                              |                         |          |
| $C$ , $K$ , and $\acute{a}$ . . . . .                   | See Figure 2.3.1.0                 |                         |          |

a Noncurrent specification  
b Design values are applicable only to parts for which the indicated  $F_{tu}$  has been substantiated by adequate quality control testing.

**Table 2.3.1.0 (c<sub>4</sub>). Design Mechanical and Physical properties of Air Melted Low-Alloy Steels**

|                                                         |                                     |     |     |                   |
|---------------------------------------------------------|-------------------------------------|-----|-----|-------------------|
| Alloy                                                   | AISI 4135                           |     |     |                   |
| Specification [see Tables 2.3.1.0(a) and (b)] . . . . . | MIL-T-6753                          |     |     |                   |
| Form . . . . .                                          | Tubing                              |     |     |                   |
| Condition . . . . .                                     | Quenched and tempered <sup>1a</sup> |     |     |                   |
| Wall thickness, in . . . . .                            | ≤0.8                                |     |     | <0.5 <sup>b</sup> |
| Basis . . . . .                                         | S                                   | S   | S   | S                 |
| Mechanical Properties:                                  |                                     |     |     |                   |
| $F_{tu}$ , ksi                                          | 125                                 | 150 | 180 | 200               |
| $F_{ty}$ , ksi                                          | 100                                 | 135 | 165 | 165               |
| $F_{cy}$ , ksi .                                        | 109                                 | 141 | 173 | 181               |
| $F_{su}$ , ksi .                                        | 75                                  | 90  | 108 | 120               |
| $F_{bru}$ , ksi:                                        |                                     |     |     |                   |
| (e/D = 1.5)                                             | 194                                 | 231 | 277 | 308               |
| (e/D = 2.0)                                             | 251                                 | 285 | 342 | 380               |
| $F_{brv}$ , ksi:                                        |                                     |     |     |                   |
| (e/D = 1.5)                                             | 146                                 | 210 | 257 | 274               |
| (e/D = 2.0)                                             | 175                                 | 232 | 284 | 302               |
| $e$ , percent                                           | See Table 2.3.1.0(e)                |     |     |                   |
| $E$ , 10 <sup>3</sup> ksi                               | 29.0                                |     |     |                   |
| $E_c$ , 10 <sup>3</sup> ksi                             | 29.0                                |     |     |                   |
| $G$ , 10 <sup>3</sup> ksi                               | 11.0                                |     |     |                   |
| $\mu$                                                   | 0.32                                |     |     |                   |
| Physical Properties:                                    |                                     |     |     |                   |
| $\omega$ , lb/in. <sup>3</sup>                          | 0.283                               |     |     |                   |
| $C$ , $K$ , and $\alpha$                                | See Figure 2.3.1.0                  |     |     |                   |

a Design values are applicable only to parts for which the indicated  $F_{tu}$  and through hardening has been substantiated by adequate quality control testing.

b Wall thickness at which through hardening is achieved and verified through quality control testing.



Table 2.3.1.0(d). Minimum Elongation Values for Low-Alloy Steels in Condition N

| Form                                  | Thickness, in.                     | Elongation, percent |       |
|---------------------------------------|------------------------------------|---------------------|-------|
|                                       |                                    | Full tube           | Strip |
| Sheet, strip, and plate (T) . . . . . | Less than 0.062 . . . . .          | --                  | 8     |
|                                       | Over 0.062 to 0.125 incl. . . . .  | --                  | 10    |
|                                       | Over 0.125 to 0.187 incl. . . . .  | --                  | 12    |
|                                       | Over 0.187 to 0.249 incl. . . . .  | --                  | 15    |
|                                       | Over 0.249 to 0.749 incl. . . . .  | --                  | 16    |
|                                       | Over 0.749 to 1.500 incl. . . . .  | --                  | 18    |
| Tubing (L) . . . . .                  | Up to 0.035 incl. (wall) . . . . . | 10                  | 5     |
|                                       | Over 0.035 to 0.188 incl. . . . .  | 12                  | 7     |
|                                       | Over 0.188 . . . . .               | 15                  | 10    |

Table 2.3.1.0(e). Minimum Elongation Values for Heat-Treated Low-Alloy Steels

| F <sub>w</sub> , ksi | Round specimens (L)       |                            | Elongation in 2 in., percent |                          |                      |            |       |
|----------------------|---------------------------|----------------------------|------------------------------|--------------------------|----------------------|------------|-------|
|                      |                           |                            | Sheet specimens              |                          |                      | Tubing (L) |       |
|                      | Elongation in 4D, percent | Reduction of area, percent | Less than 0.032 in. thick    | 0.032 to 0.060 in. thick | Over 0.060 in. thick | Full tube  | Strip |
| 125                  | 17                        | 55                         | 5                            | 7                        | 10                   | 12         | 7     |
| 140                  | 15                        | 53                         | 4                            | 6                        | 9                    | 10         | 6     |
| 150                  | 14                        | 52                         | 4                            | 6                        | 9                    | 10         | 6     |
| 160                  | 13                        | 50                         | 3                            | 5                        | 8                    | 9          | 6     |
| 180                  | 12                        | 47                         | 3                            | 5                        | 7                    | 8          | 5     |
| 200                  | 10                        | 43                         | 3                            | 4                        | 6                    | 6          | 5     |

Table 2.3.1.0(f<sub>1</sub>). Design Mechanical and Physical Properties of Low-Alloy Steels

| Alloy .....                           | Hy-Tuf                             | 4330V          | 4335V    | 4335V    | D6AC     | AISI 4340 <sup>a</sup> | 0.40C<br>300M    | 0.42C<br>300M        |
|---------------------------------------|------------------------------------|----------------|----------|----------|----------|------------------------|------------------|----------------------|
| Specification .....                   | AMS 6425                           | AMS 6411       | AMS 6430 | AMS 6429 | AMS 6431 | AMS 6414               | AMS 6417         | AMS 6257<br>AMS 6419 |
| Form .....                            | Bar, forging, tubing               |                |          |          |          |                        |                  |                      |
| Condition .....                       | Quenched and tempered <sup>b</sup> |                |          |          |          |                        |                  |                      |
| Thickness or diameter, in.            | c                                  |                |          |          | d        | e                      | f                |                      |
| Basis .....                           | S                                  | S              | S        | S        | S        | S                      | S                | S                    |
| Mechanical Properties:                |                                    |                |          |          |          |                        |                  |                      |
| $F_{tu}$ , ksi .....                  | 220                                | 220            | 205      | 240      | 220      | 260                    | 270              | 280                  |
| $F_y$ , ksi .....                     | 185                                | 185            | 190      | 210      | 190      | 217                    | 220              | 230                  |
| $F_{cy}$ , ksi .....                  | 193                                | 193            | 199      | 220      | 198      | 235                    | 236              | 247                  |
| $F_{su}$ , ksi .....                  | 132                                | 132            | 123      | 144      | 132      | 156                    | 162              | 168                  |
| $F_{bru}$ , ksi:                      |                                    |                |          |          |          |                        |                  |                      |
| ( $e/D = 1.5$ ) .....                 | 297                                | 297            | 315      | 369      | 297      | 347                    | 414 <sup>g</sup> | 430 <sup>g</sup>     |
| ( $e/D = 2.0$ ) .....                 | 385                                | 385            | 389      | 465      | 385      | 440                    | 506 <sup>g</sup> | 525 <sup>g</sup>     |
| $F_{bry}$ , ksi:                      |                                    |                |          |          |          |                        |                  |                      |
| ( $e/D = 1.5$ ) .....                 | 267                                | 267            | 296      | 327      | 274      | 312                    | 344 <sup>c</sup> | 360 <sup>c</sup>     |
| ( $e/D = 2.0$ ) .....                 | 294                                | 294            | 327      | 361      | 302      | 346                    | 379 <sup>c</sup> | 396 <sup>c</sup>     |
| $e$ , percent:                        |                                    |                |          |          |          |                        |                  |                      |
| L .....                               | 10                                 | 10             | 10       | 10       | 12       | 10                     | 8                | 7                    |
| LT .....                              | 5 <sup>a</sup>                     | 5 <sup>a</sup> | 7        | 7        | 9        | ...                    | ...              | ...                  |
| $E$ , 10 <sup>3</sup> ksi .....       | 29.0                               |                |          |          |          |                        |                  |                      |
| $E_c$ , 10 <sup>3</sup> ksi .....     | 29.0                               |                |          |          |          |                        |                  |                      |
| $G$ , 10 <sup>3</sup> ksi .....       | 11.0                               |                |          |          |          |                        |                  |                      |
| $\mu$ .....                           | 0.32                               |                |          |          |          |                        |                  |                      |
| Physical Properties:                  |                                    |                |          |          |          |                        |                  |                      |
| $\dot{u}$ , lb/in. <sup>3</sup> ..... | 0.283                              |                |          |          |          |                        |                  |                      |
| $C$ , $K$ , and $\dot{a}$ .....       | See Figure 2.3.1.0                 |                |          |          |          |                        |                  |                      |

a Applicable to consumable-electrode vacuum-melted material only.

b Design values are applicable only to parts for which the indicated  $F_{tu}$  has been substantiated by adequate quality control testing.

c Thickness \* 1.70 in. for quenching in molten salt at desired tempering temperature (martempering); \*2.50 in. for quenching in oil at flow rate of 200 feet/min.

d Thickness \* 3.50 in. for quenching in molten salt at desired tempering temperature (martempering); \*5.00 in. for quenching in oil at flow rate of 200 feet/min.

e Thickness \* 1.70 in. for quenching in molten salt at desired tempering temperature (martempering); \*2.50 in. for quenching in oil at flow rate of 200 feet/min.; \*3.50 in. for quenching in water at a flow rate of 200 feet/min.

f Thickness \*5.00 in. for quenching in oil at a flow rate of 200 feet/min.

g Bearing values are “dry pin” values per Section 1.4.7.1.

**Table 2.3.1.0(f<sub>2</sub>). Design Mechanical and Physical Properties of Low-Alloy Steels**

|                                           |                                    |          |        |
|-------------------------------------------|------------------------------------|----------|--------|
| Alloy . . . . .                           | 4335V                              | D6AC     |        |
| Specification . . . . .                   | AMS 6435                           | AMS 6439 |        |
| Form . . . . .                            | Sheet, strip, and plate            |          |        |
| Condition . . . . .                       | Quenched and tempered <sup>a</sup> |          |        |
| Thickness or diameter, in. . . . .        | b                                  | ·0.250   | ·0.251 |
| Basis . . . . .                           | S                                  | S        | S      |
| Mechanical Properties:                    |                                    |          |        |
| $F_{tu}$ , ksi . . . . .                  | 220                                | 215      | 224    |
| $F_y$ , ksi . . . . .                     | 190                                | 190      | 195    |
| $F_{cy}$ , ksi . . . . .                  | 198                                | 198      | 203    |
| $F_{su}$ , ksi . . . . .                  | 132                                | 129      | 134    |
| $F_{bru}$ , ksi: <sup>c</sup>             |                                    |          |        |
| (e/D = 1.5) . . . . .                     | 297                                | 290      | 302    |
| (e/D = 2.0) . . . . .                     | 385                                | 376      | 392    |
| $F_{bry}$ , ksi: <sup>c</sup>             |                                    |          |        |
| (e/D = 1.5) . . . . .                     | 274                                | 274      | 281    |
| (e/D = 2.0) . . . . .                     | 302                                | 302      | 310    |
| e, percent:                               |                                    |          |        |
| L . . . . .                               | 10                                 | ...      | ...    |
| LT . . . . .                              | 7                                  | 7        | 7      |
| $E$ , 10 <sup>3</sup> ksi . . . . .       | 29.0                               |          |        |
| $E_c$ , 10 <sup>3</sup> ksi . . . . .     | 29.0                               |          |        |
| $G$ , 10 <sup>3</sup> ksi . . . . .       | 11.0                               |          |        |
| $\mu$ . . . . .                           | 0.32                               |          |        |
| Physical Properties:                      |                                    |          |        |
| $\dot{u}$ , lb/in. <sup>3</sup> . . . . . | 0.283                              |          |        |
| C, K, and $\acute{a}$ . . . . .           | See Figure 2.3.1.0                 |          |        |

a Design values are applicable only to parts for which the indicated  $F_{tu}$  has been substantiated by adequate quality control testing.

b Thickness •1.70 in. for quenching in molten salt at desired tempering temperature (martempering); •2.50 in. for quenching in oil at a flow rate of 200 feet/min.

c Bearing values are “dry pin” values per Section 1.4.7.1.

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**1 October 2001**

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[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

Table 2.3.1.0(h<sub>1</sub>). Design Mechanical and Physical Properties of Low-Alloy Steels

|                                           |                                                       |        |                                    |        |           |        |                            |        |
|-------------------------------------------|-------------------------------------------------------|--------|------------------------------------|--------|-----------|--------|----------------------------|--------|
| Alloy . . . . .                           | AISI 4130                                             |        | AISI 4135                          |        | AISI 8630 |        | AISI 8735                  |        |
|                                           | AMS 6350<br>AMS 6528<br>AMS-S-6758                    |        | AMS 6352<br>AMS 6372               |        | AMS 6281  |        | AMS 6357                   |        |
|                                           | Sheet, strip, plate,<br>bars, and forgings            |        | Sheet, strip, plate, and<br>tubing |        | Tubing    |        | Sheet, strip, and<br>plate |        |
|                                           | Normalized and tempered, stress relieved <sup>a</sup> |        |                                    |        |           |        |                            |        |
|                                           | •0.188                                                | >0.188 | •0.188                             | >0.188 | •0.188    | >0.188 | •0.188                     | >0.188 |
| Thickness or diameter, in. . . . .        | b                                                     |        |                                    |        |           |        |                            |        |
| Basis . . . . .                           |                                                       |        |                                    |        |           |        |                            |        |
| Mechanical Properties:                    |                                                       |        |                                    |        |           |        |                            |        |
| $F_{tu}$ , ksi . . . . .                  | 95                                                    | 90     | 95                                 | 90     | 95        | 90     | 95                         | 90     |
| $F_{ty}$ , ksi . . . . .                  | 75                                                    | 70     | 75                                 | 70     | 75        | 70     | 75                         | 70     |
| $F_{cy}$ , ksi . . . . .                  | 75                                                    | 70     | 75                                 | 70     | 75        | 70     | 75                         | 70     |
| $F_{su}$ , ksi . . . . .                  | 57                                                    | 54     | 57                                 | 54     | 57        | 54     | 57                         | 54     |
| $F_{bru}$ , ksi:                          |                                                       |        |                                    |        |           |        |                            |        |
| (e/D = 1.5) . . . . .                     | ...                                                   | ...    | ...                                | ...    | ...       | ...    | ...                        | ...    |
| (e/D = 2.0) . . . . .                     | 200                                                   | 190    | 200                                | 190    | 200       | 190    | 200                        | 190    |
| $F_{bry}$ , ksi:                          |                                                       |        |                                    |        |           |        |                            |        |
| (e/D = 1.5) . . . . .                     | ...                                                   | ...    | ...                                | ...    | ...       | ...    | ...                        | ...    |
| (e/D = 2.0) . . . . .                     | 129                                                   | 120    | 129                                | 120    | 129       | 120    | 129                        | 120    |
| $e$ , percent . . . . .                   | See Table 2.3.1.0(d)                                  |        |                                    |        |           |        |                            |        |
| $E$ , 10 <sup>3</sup> ksi . . . . .       | 29.0                                                  |        |                                    |        |           |        |                            |        |
| $E_c$ , 10 <sup>3</sup> ksi . . . . .     | 29.0                                                  |        |                                    |        |           |        |                            |        |
| $G$ , 10 <sup>3</sup> ksi . . . . .       | 11.0                                                  |        |                                    |        |           |        |                            |        |
| $\mu$ . . . . .                           | 0.32                                                  |        |                                    |        |           |        |                            |        |
| Physical Properties:                      |                                                       |        |                                    |        |           |        |                            |        |
| $\dot{u}$ , lb/in. <sup>3</sup> . . . . . | 0.283                                                 |        |                                    |        |           |        |                            |        |
| $C$ , $K$ , and $\acute{a}$ . . . . .     | See Figure 2.3.1.0                                    |        |                                    |        |           |        |                            |        |

a Design values are applicable only to parts for which the indicated  $F_{tu}$  has been substantiated by adequate quality control testing.

b There is no statistical basis ( $T_{99}$  or  $T_{90}$ ) or specification basis (S) to support the mechanical property values in this table. See Sections 2.3.0.2.5 and 2.3.0.2.5.1.

[Interactive Table - Design Properties](#)      [Interactive Table - Typical Properties](#)

Table 2.3.1.0(h<sub>2</sub>). Design Mechanical and Physical Properties of Low-Alloy Steels

|                                           |                                    |                                                                       |     |     |     |     |     |
|-------------------------------------------|------------------------------------|-----------------------------------------------------------------------|-----|-----|-----|-----|-----|
| Alloy . . . . .                           | 4330V                              | See steels listed in Table 2.3.0.2 for the applicable strength levels |     |     |     |     |     |
| Specification . . . . .                   | AMS 6427                           | See Tables 2.3.1.0(a) and (b)                                         |     |     |     |     |     |
| Form . . . . .                            | All wrought forms                  |                                                                       |     |     |     |     |     |
| Condition . . . . .                       | Quenched and tempered <sup>a</sup> |                                                                       |     |     |     |     |     |
| Thickness or diameter, in. . . . .        | • 2.5                              | b                                                                     |     |     |     | c   |     |
| Basis . . . . .                           | d                                  |                                                                       |     |     |     |     |     |
| Mechanical Properties:                    |                                    |                                                                       |     |     |     |     |     |
| $F_{tu}$ , ksi . . . . .                  | 220                                | 125                                                                   | 140 | 150 | 160 | 180 | 200 |
| $F_{ty}$ , ksi . . . . .                  | 185                                | 100                                                                   | 120 | 132 | 142 | 163 | 176 |
| $F_{cy}$ , ksi . . . . .                  | 193                                | 109                                                                   | 131 | 145 | 154 | 173 | 181 |
| $F_{su}$ , ksi . . . . .                  | 132                                | 75                                                                    | 84  | 90  | 96  | 108 | 120 |
| $F_{bru}$ , ksi:                          |                                    |                                                                       |     |     |     |     |     |
| (e/D = 1.5) . . . . .                     | 297                                | 209                                                                   | 209 | 219 | 230 | 250 | 272 |
| (e/D = 2.0) . . . . .                     | 385                                | 251                                                                   | 273 | 287 | 300 | 326 | 355 |
| $F_{bry}$ , ksi:                          |                                    |                                                                       |     |     |     |     |     |
| (e/D = 1.5) . . . . .                     | 267                                | 146                                                                   | 173 | 189 | 202 | 230 | 255 |
| (e/D = 2.0) . . . . .                     | 294                                | 175                                                                   | 203 | 218 | 231 | 256 | 280 |
| e, percent:                               | 10                                 | See Table 2.3.1.0(e)                                                  |     |     |     |     |     |
| L . . . . .                               | 5 <sup>a</sup>                     |                                                                       |     |     |     |     |     |
| LT . . . . .                              |                                    |                                                                       |     |     |     |     |     |
| $E$ , 10 <sup>3</sup> ksi . . . . .       | 29.0                               |                                                                       |     |     |     |     |     |
| $E_c$ , 10 <sup>3</sup> ksi . . . . .     |                                    |                                                                       |     |     |     |     |     |
| $G$ , 10 <sup>3</sup> ksi . . . . .       |                                    |                                                                       |     |     |     |     |     |
| $\mu$ . . . . .                           |                                    |                                                                       |     |     |     |     |     |
| Physical Properties:                      |                                    |                                                                       |     |     |     |     |     |
| $\dot{u}$ , lb/in. <sup>3</sup> . . . . . | 0.283                              |                                                                       |     |     |     |     |     |
| C, K, and $\acute{a}$ . . . . .           | See Figure 2.3.1.0                 |                                                                       |     |     |     |     |     |

a Design values are applicable only to parts for which the indicated  $F_{tu}$  has been substantiated by adequate quality control testing.

b For  $F_{tu}$  • 180 ksi, thickness • 0.50 in. for AISI 4130 and 8630; • 0.80 in. for AISI 8735, 4135, and 8740; • 1.00 in. for AISI 4140; • 1.70 in. for AISI 4340, 4330V, 4335V, and Hy-Tuf [Quenched in molten salt at desired tempering temperature (martempering)]; • 2.50 in. for AISI 4340, 4330V, 4335V, and Hy-Tuf (Quenched in oil at a flow rate of 200 feet/min.); • 3.50 in. for AISI 4340 (Quenched in water at a flow rate of 200 feet/min.); • 5.00 in. for D6AC (Quenched in oil at a flow rate of 200 feet/min.)

c For  $F_{tu}$  = 200 ksi AISI 4130, 8630, 4135, 8740 not available; thickness • 0.80 in. for AISI 8740; • 1.00 in. for AISI 4140; • 1.70 in. for AISI 4340, 4330V, 4335V, and Hy-Tuf [Quenched in molten salt at desired tempering temperature (martempering)]; • 2.50 in. for AISI 4340, 4330V, 4335V, and Hy-Tuf (Quenched in oil at a flow rate of 200 feet/min.); • 3.50 in. for AISI 4340 (Quenched in water at a flow rate of 200 feet/min.); • 5.00 in. for D6AC (Quenched in oil at a flow rate of 200 feet/min.)

d There is no statistical basis ( $T_{99}$  or  $T_{90}$ ) or specification basis (S) to support the mechanical property values in this table. See Sections 2.3.0.2.5 and 2.3.0.2.5.1.

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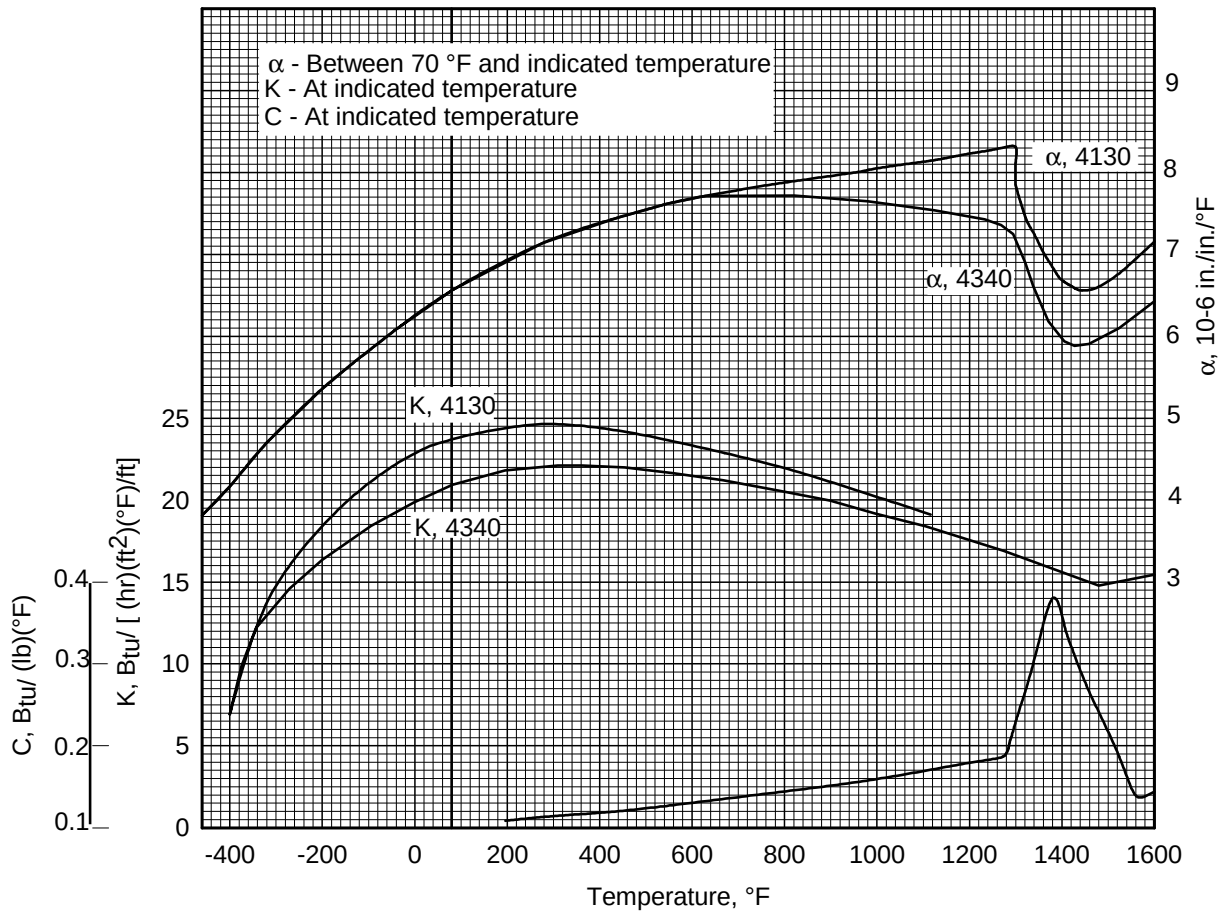


Figure 2.3.1.0. Effect of temperature on the physical properties of 4130 and 4340 alloy steels.

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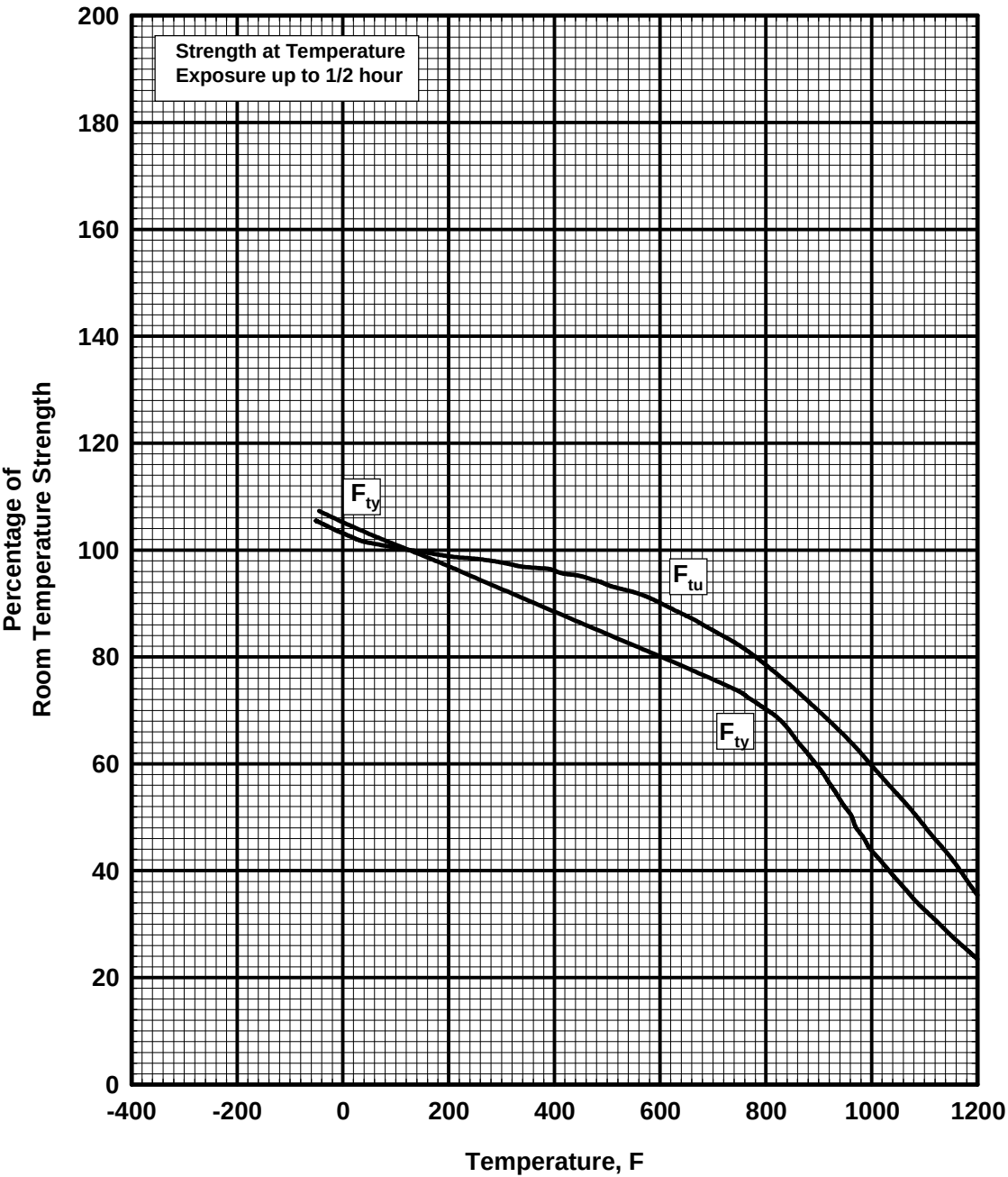


Figure 2.3.1.1.1. Effect of temperature on the tensile ultimate strength ( $F_{tu}$ ) and tensile yield strength ( $F_{ty}$ ) of AISI low-alloy steels (all products).



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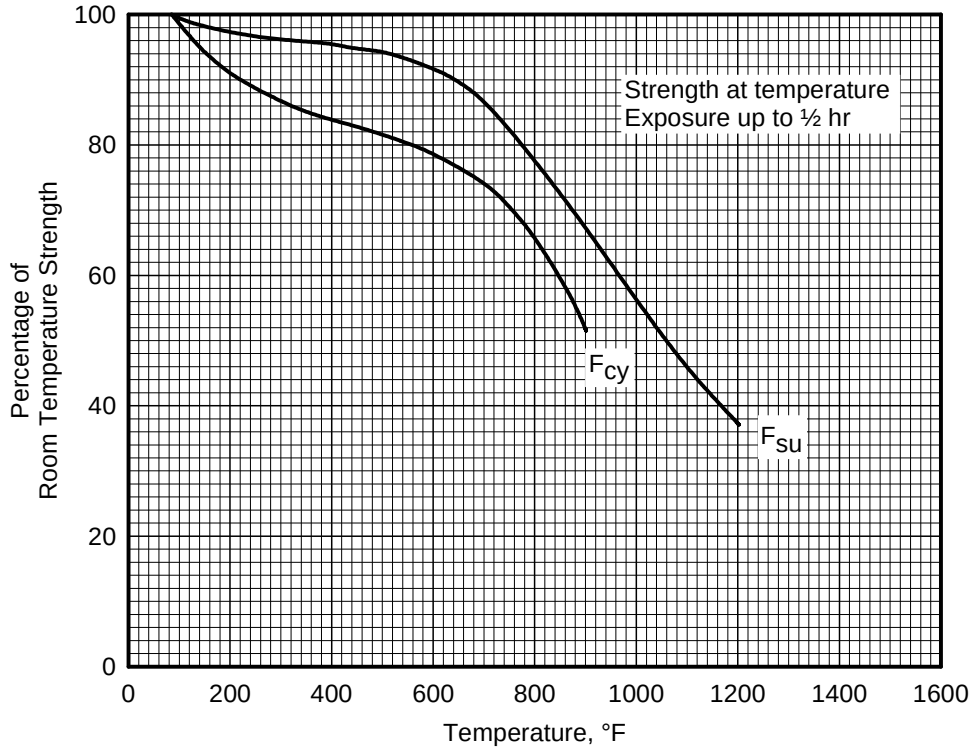


Figure 2.3.1.1.2. Effect of temperature on the compressive yield strength ( $F_{cy}$ ) and the shear ultimate strength ( $F_{su}$ ) of heat-treated AISI low-alloy steels (all products).

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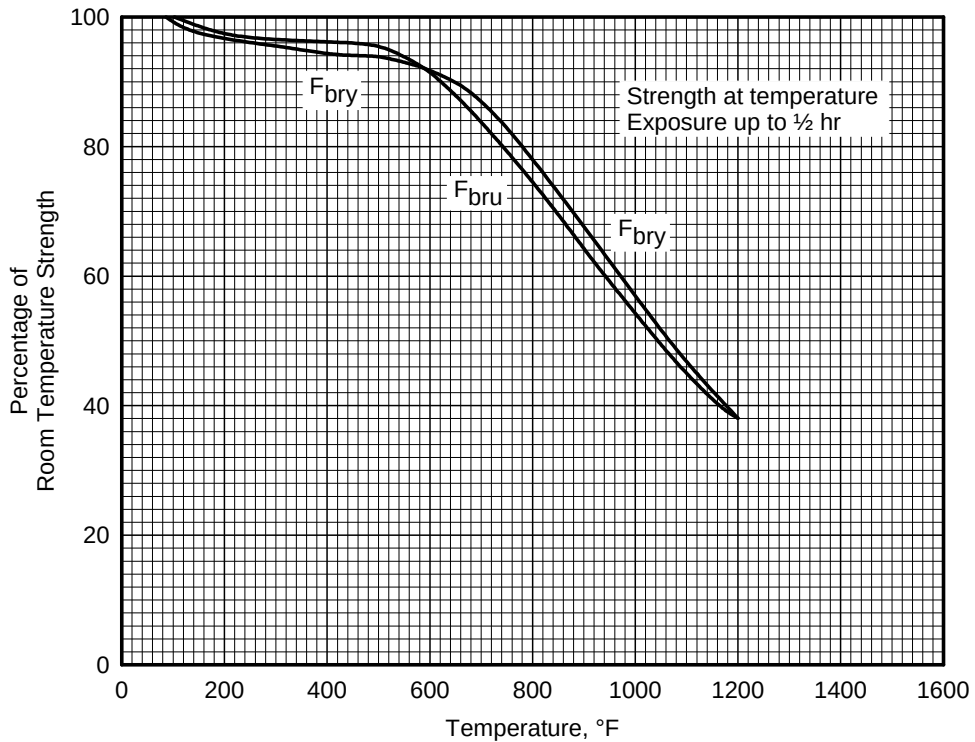


Figure 2.3.1.1.3. Effect of temperature on the bearing ultimate strength ( $F_{bru}$ ) and the bearing yield strength ( $F_{bry}$ ) of heat-treated AISI low-alloy steels (all products).

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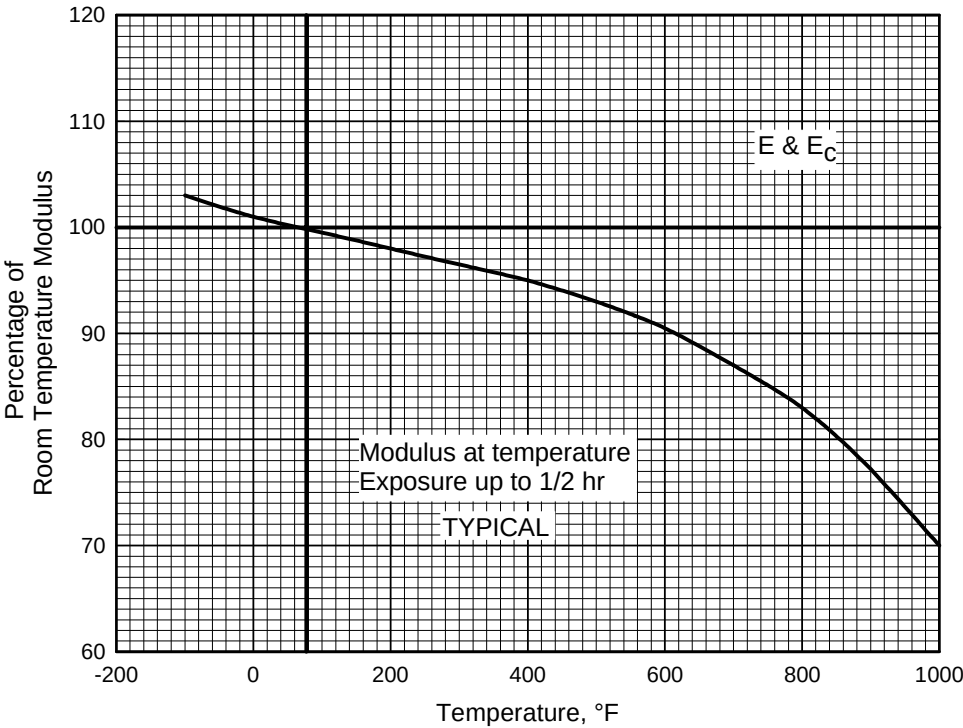


Figure 2.3.1.1.4. Effect of temperature on the tensile and compressive modulus (E and E<sub>c</sub>) of AISI low-alloy steels.

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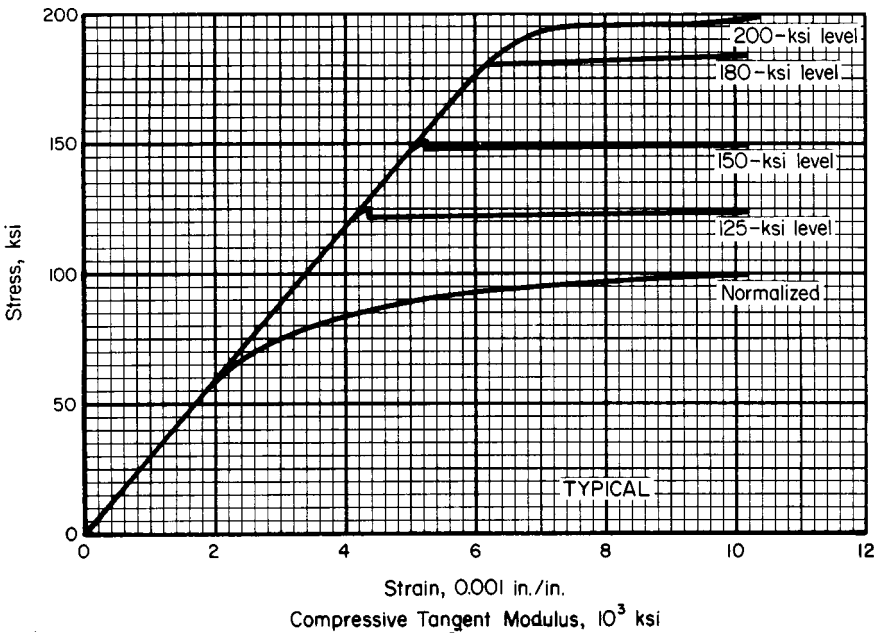


Figure 2.3.1.2.6(a). Typical tensile stress-strain curves at room temperature for heat-treated AISI 8630 alloy steel (all products).

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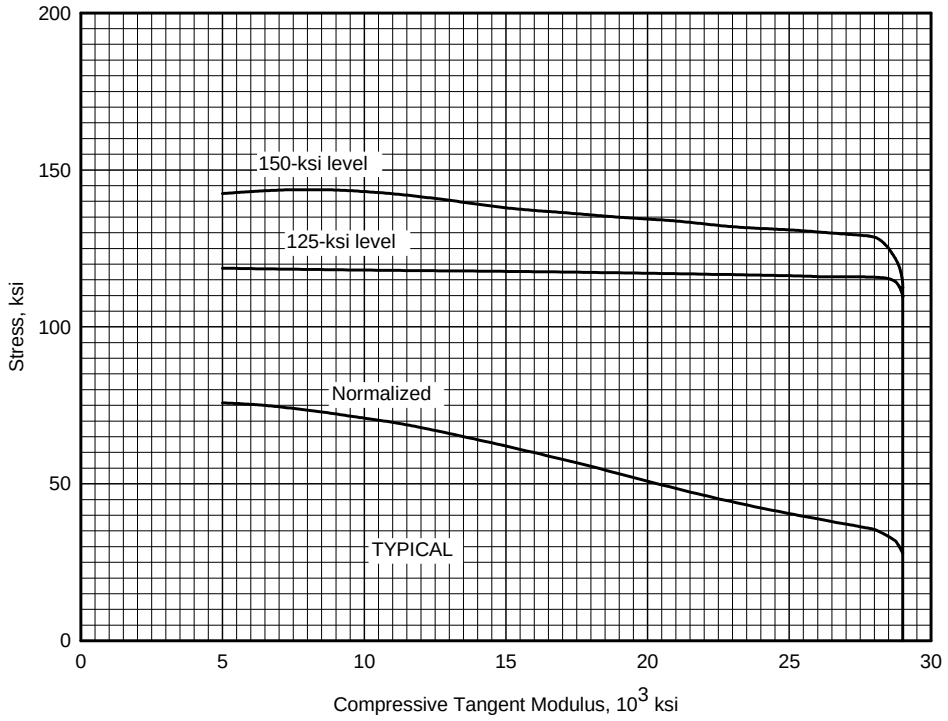


**Figure 2.3.1.2.6(b). Typical compressive tangent-modulus curves at room temperature for heat-treated AISI 8630 alloy steel (all products).**

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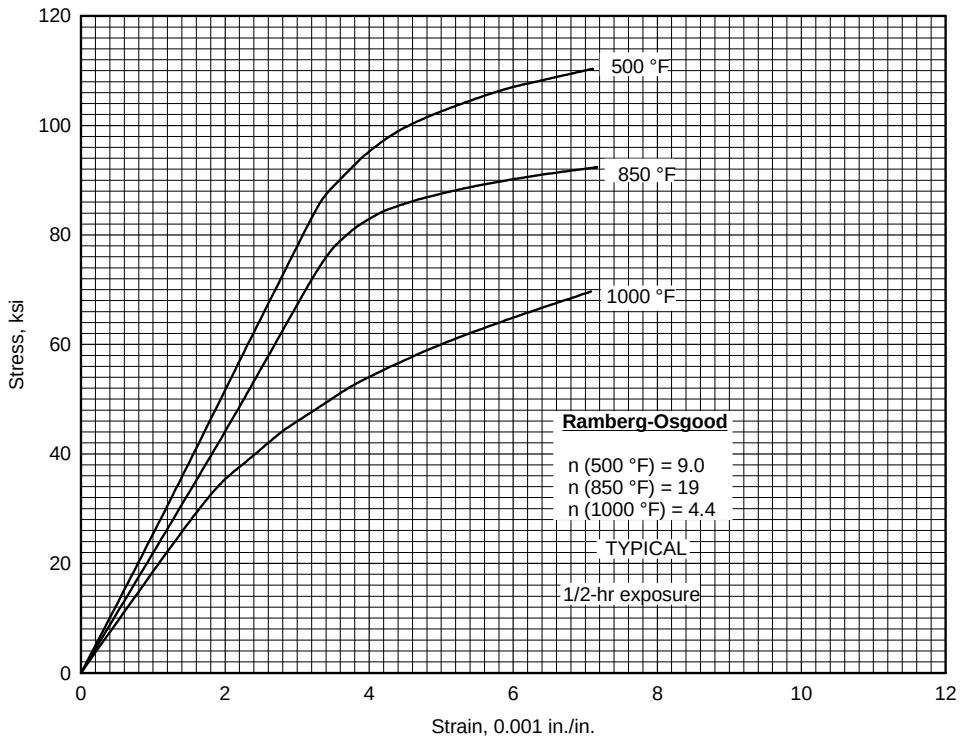


**Figure 2.3.1.2.6(c). Typical tensile stress-strain curves at room temperature for heat-treated AISI 8630 alloy steel,  $F_{tu} = 125$  ksi (all products).**

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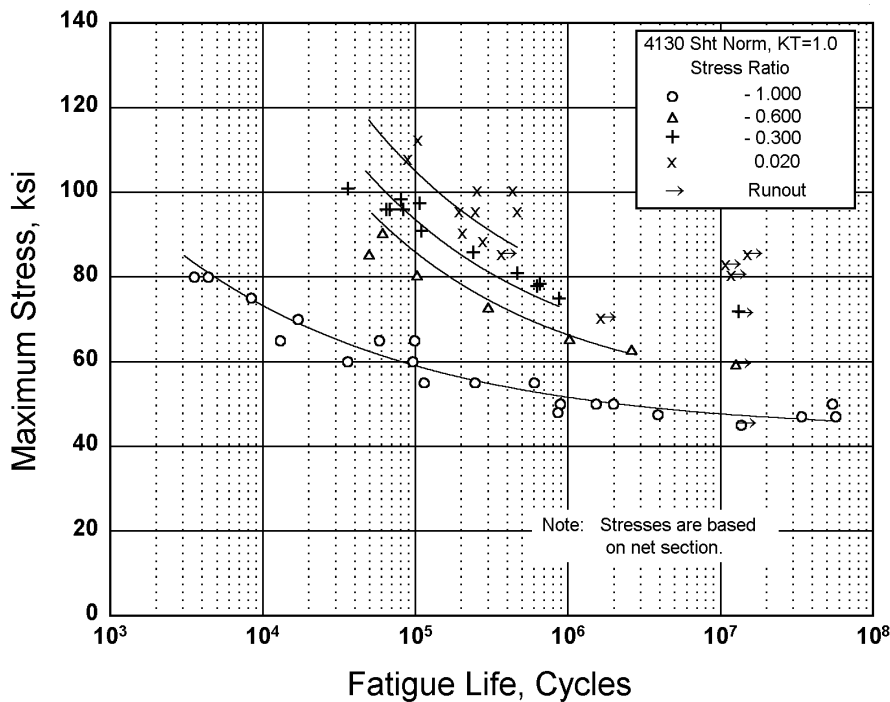


**Figure 2.3.1.2.8(a). Best-fit S/N curves for unnotched 4130 alloy steel sheet, normalized, longitudinal direction.**

Correlative Information for Figure 2.3.1.2.8(a)

Product Form: Sheet, 0.075-inch thick

Properties: TUS, ksi TYS, ksi Temp., °F  
117 99 RT

Specimen Details: Unnotched  
2.88-3.00 inches gross width  
0.80-1.00 inch net width  
12.0 inch net section radius

Surface Condition: Electropolished

References: 3.2.3.1.8(a) and (f)

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

Test Parameters:

Loading - Axial  
Frequency - 1100-1800 cpm  
Temperature - RT  
Environment - Air

No. of Heats/Lots: Not specified

Equivalent Stress Equations:

For stress ratios of -0.60 to +0.02

$\log N_f = 9.65 - 2.85 \log (S_{eq} - 61.3)$

$S_{eq} = S_{max} (1 - R)^{0.41}$

Std. Error of Estimate,  $\log (\text{Life}) = 0.21$

Standard Deviation,  $\log (\text{Life}) = 0.45$

$R^2 = 78\%$

Sample Size = 23

For a stress ratio of -1.0

$\log N_f = 9.27 - 3.57 \log (S_{max} - 43.3)$

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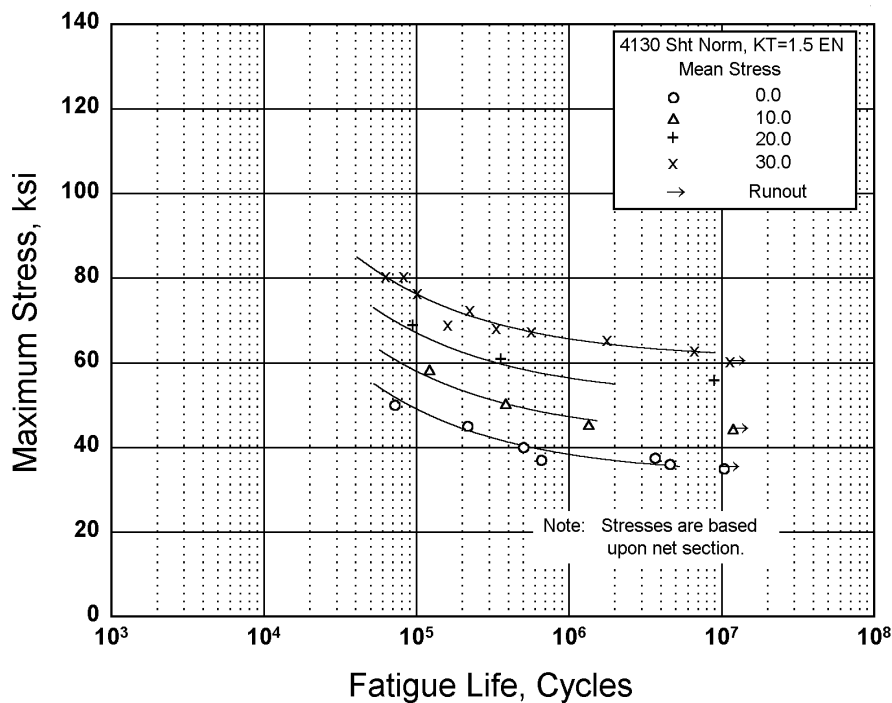


**Figure 2.3.1.2.8(b). Best-fit S/N curves for notched,  $K_t = 1.5$ , 4130 alloy steel sheet, normalized, longitudinal direction.**

Correlative Information for Figure 2.3.1.2.8(b)

|                           |                           |                 |                  |                                                              |
|---------------------------|---------------------------|-----------------|------------------|--------------------------------------------------------------|
| <u>Product Form:</u>      | Sheet, 0.075-inch thick   |                 |                  | <u>Test Parameters:</u>                                      |
| <u>Properties:</u>        | <u>TUS, ksi</u>           | <u>TYS, ksi</u> | <u>Temp., °F</u> | Loading - Axial                                              |
|                           | 117                       | 99              | RT               | Frequency - 1100-1500 cpm                                    |
|                           |                           |                 | (unnotched)      | Temperature - RT                                             |
|                           | 123                       | --              | RT               | Environment - Air                                            |
|                           |                           |                 | (notched)        |                                                              |
|                           |                           |                 | $K_t 1.5$        | <u>No. of Heats/Lots:</u> Not specified                      |
| <u>Specimen Details:</u>  | Edge Notched, $K_t = 1.5$ |                 |                  | <u>Equivalent Stress Equations:</u>                          |
|                           | 3.00 inches gross width   |                 |                  | $\text{Log } N_f = 7.94 - 2.01 \text{ log } (S_{eq} - 61.3)$ |
|                           | 1.50 inches net width     |                 |                  | $S_{eq} = S_{max} (1-R)^{0.88}$                              |
|                           | 0.76-inch notch radius    |                 |                  | Std. Error of Estimate, Log (Life) = 0.27                    |
| <u>Surface Condition:</u> | Electropolished           |                 |                  | Standard Deviation, Log (Life) = 0.67                        |
| <u>Reference:</u>         | 3.2.3.1.8(d)              |                 |                  | $R^2 = 84\%$                                                 |
|                           |                           |                 |                  | <u>Sample Size</u> = 21                                      |

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

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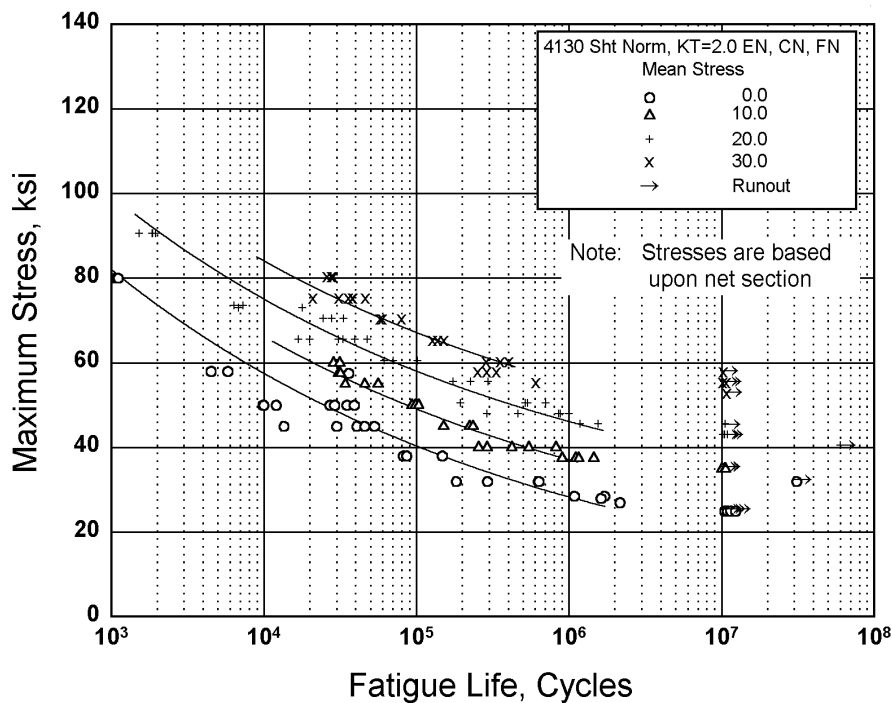


**Figure 2.3.1.2.8(c). Best-fit S/N curves for notched,  $K_t = 2.0$ , 4130 alloy steel sheet, normalized, longitudinal direction.**

Correlative Information for Figure 2.3.1.2.8(c)

|                      |                         |                 |                              |
|----------------------|-------------------------|-----------------|------------------------------|
| <u>Product Form:</u> | Sheet, 0.075-inch thick |                 |                              |
| <u>Properties:</u>   | <u>TUS, ksi</u>         | <u>TYS, ksi</u> | <u>Temp., °F</u>             |
|                      | 117                     | 99              | RT<br>(unnotched)            |
|                      | 120                     | --              | RT<br>(notched)<br>$K_t$ 2.0 |

Test Parameters:  
Loading - Axial  
Frequency - 1100-1800 cpm  
Temperature - RT  
Environment - Air  
  
No. of Heats/Lots: Not specified

Equivalent Stress Equation:

$\text{Log } N_f = 17.1 - 6.49 \log (S_{eq})$   
 $S_{eq} = S_{max} (1-R)^{0.86}$   
Std. Error of Estimate,  $\text{Log (Life)} = 0.19$   
Standard Deviation,  $\text{Log (Life)} = 0.78$   
 $R^2 = 94\%$

Sample Size = 107

Surface Condition: Electropolished

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

References: 3.2.3.1.8(b) and (f)

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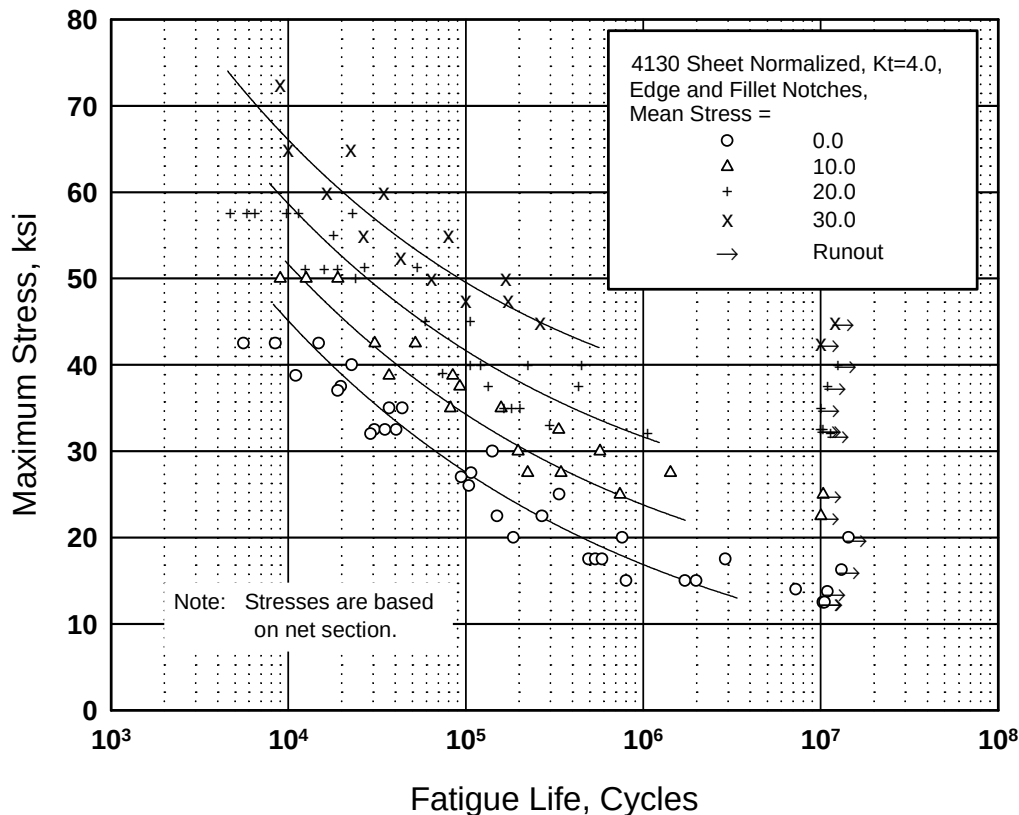


Figure 2.3.1.2.8(d). Best-fit S/N curves diagram for notched,  $K_t = 4.0$ , 4130 alloy steel sheet, normalized, longitudinal direction.

Correlative Information for Figure 2.3.1.2.8(d)

|               |                         |          |                                |
|---------------|-------------------------|----------|--------------------------------|
| Product Form: | Sheet, 0.075-inch thick |          |                                |
| Properties:   | TUS, ksi                | TYS, ksi | Temp., °F                      |
|               | 117                     | 99       | RT<br>(unnotched)              |
|               | 120                     | —        | RT<br>(notched)<br>$K_t = 4.0$ |

|                                        |             |           |              |
|----------------------------------------|-------------|-----------|--------------|
| Specimen Details: Notched, $K_t = 4.0$ |             |           |              |
| Notch Type                             | Gross Width | Net Width | Notch Radius |
| Edge                                   | 2.25        | 1.500     | 0.057        |
| Edge                                   | 4.10        | 1.496     | 0.070        |
| Fillet                                 | 2.25        | 1.500     | 0.0195       |

Surface Condition: Electropolished

References: 3.2.3.1.8(b), (f), and (g)

|                                  |
|----------------------------------|
| Test Parameters:                 |
| Loading - Axial                  |
| Frequency - 1100-1800 cpm        |
| Temperature - RT                 |
| Environment - Air                |
| No. of Heats/Lots: Not specified |
| Equivalent Stress Equation:      |

$\log N_f = 12.6 - 4.69 \log (S_{eq})$   
 $S_{eq} = S_{max} (1-R)^{0.63}$   
Std. Error of Estimate,  $\log (\text{Life}) = 0.24$   
Standard Deviation,  $\log (\text{Life}) = 0.70$   
 $R^2 = 88\%$

Sample Size = 87

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

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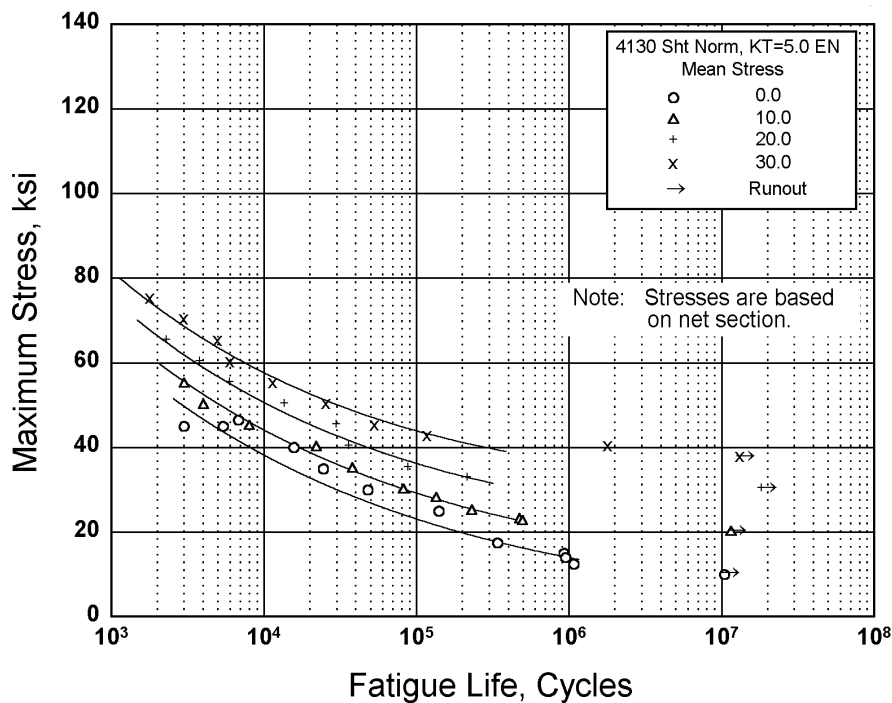


Figure 2.3.1.2.8(e). Best-fit S/N curves diagram for notched,  $K_t = 5.0$ , 4130 alloy steel sheet, normalized, longitudinal direction.

Correlative Information for Figure 2.3.1.2.8(e)

|                      |                         |                 |                                |
|----------------------|-------------------------|-----------------|--------------------------------|
| <u>Product Form:</u> | Sheet, 0.075-inch thick |                 |                                |
| <u>Properties:</u>   | <u>TUS, ksi</u>         | <u>TYS, ksi</u> | <u>Temp., °F</u>               |
|                      | 117                     | 99              | RT<br>(unnotched)              |
|                      | 120                     | —               | RT<br>(notched)<br>$K_t = 5.0$ |

|                                         |
|-----------------------------------------|
| <u>Test Parameters:</u>                 |
| Loading - Axial                         |
| Frequency - 1100-1500 cpm               |
| Temperature - RT                        |
| Environment - Air                       |
| <u>No. of Heats/Lots:</u> Not specified |
| <u>Equivalent Stress Equation:</u>      |

Specimen Details: Edge Notched,  $K_t = 5.0$   
Gross width = 2.25 inches  
Net width = 1.50 inches  
Notch radius = 0.075 inch

$\text{Log } N_f = 12.0 - 4.57 \text{ log } (S_{eq})$   
 $S_{eq} = S_{max} (1-R)^{0.56}$   
Std. Error of Estimate,  $\text{Log (Life)} = 0.18$   
Standard Deviation,  $\text{Log (Life)} = 0.87$   
 $R^2 = 96\%$

Surface Condition: Electropolished

Sample Size = 38

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

Reference: 3.2.3.1.8(c)



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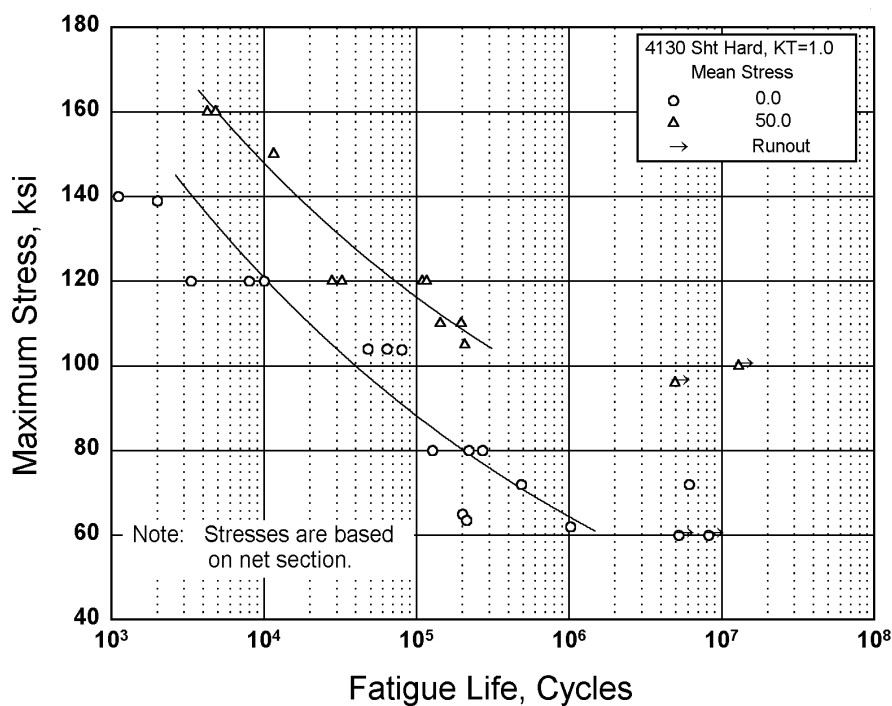


**Figure 2.3.1.2.8(f). Best-fit S/N curves for unnotched 4130 alloy steel sheet,  $F_{tu} = 180$  ksi, longitudinal direction.**

Correlative Information for Figure 2.3.1.2.8(f)

Product Form: Sheet, 0.075-inch thick

Properties:    TUS, ksi    TYS, ksi    Temp., °F

                  180        174        RT

Test Parameters:

Loading - Axial  
Frequency - 20-1800 cpm  
Temperature - RT  
Environment - Air

Specimen Details: Unnotched  
2.88 inches gross width  
1.00 inch net width  
12.0 inch net section radius

No. of Heats/Lots: Not specified

Surface Condition: Electropolished

Equivalent Stress Equation:

$\log N_f = 20.3 - 7.31 \log (S_{eq})$   
 $S_{eq} = S_{max} (1-R)^{0.49}$   
Std. Error of Estimate,  $\log (\text{Life}) = 0.39$   
Standard Deviation,  $\log (\text{Life}) = 0.89$   
 $R^2 = 81\%$

Reference: 3.2.3.1.8(f)

Sample Size = 27

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

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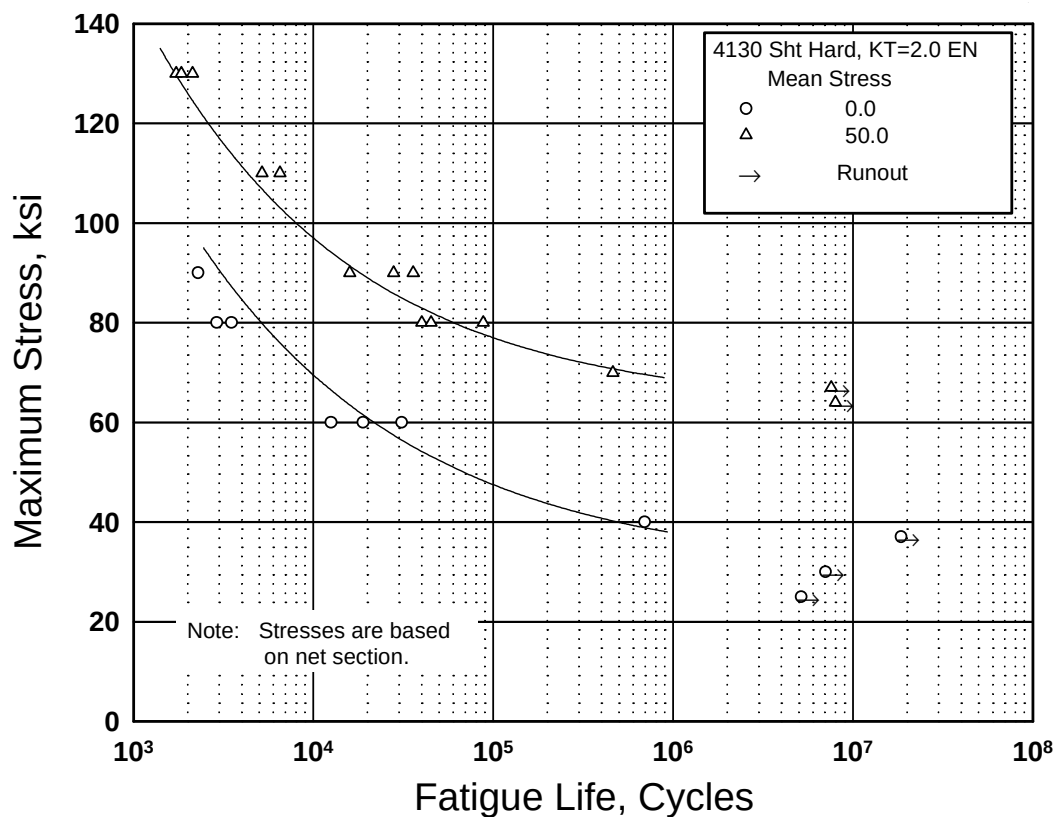


Figure 2.3.1.2.8(g). Best-fit S/N curves for notched,  $K_t = 2.0$ , 4130 alloy steel sheet,  $F_{tu} = 180$  ksi, longitudinal direction.

Correlative Information for Figure 2.3.1.2.8(g)

Product Form: Sheet, 0.075-inch thick

Properties:     TUS, ksi   TYS, ksi   Temp., °F

                    180        174        RT

Specimen Details: Edge Notched  
2.25 inches gross width  
1.50 inches net width  
0.3175-inch notch radius

Surface Condition: Electropolished

Reference:        3.2.3.1.8(f)

Test Parameters:  
Loading - Axial  
Frequency - 21-1800 cpm  
Temperature - RT  
Environment - Air

No. of Heats/Lots: Not specified

Equivalent Stress Equation:

$\log N_f = 8.87 - 2.81 \log (S_{eq} - 41.5)$   
 $S_{eq} = S_{max} (1-R)^{0.46}$   
Std. Error of Estimate,  $\log (\text{Life}) = 0.18$   
Standard Deviation,  $\log (\text{Life}) = 0.77$   
 $R^2 = 94\%$

Sample Size = 19

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

[VIEW INTERACTIVE GRAPH](#)

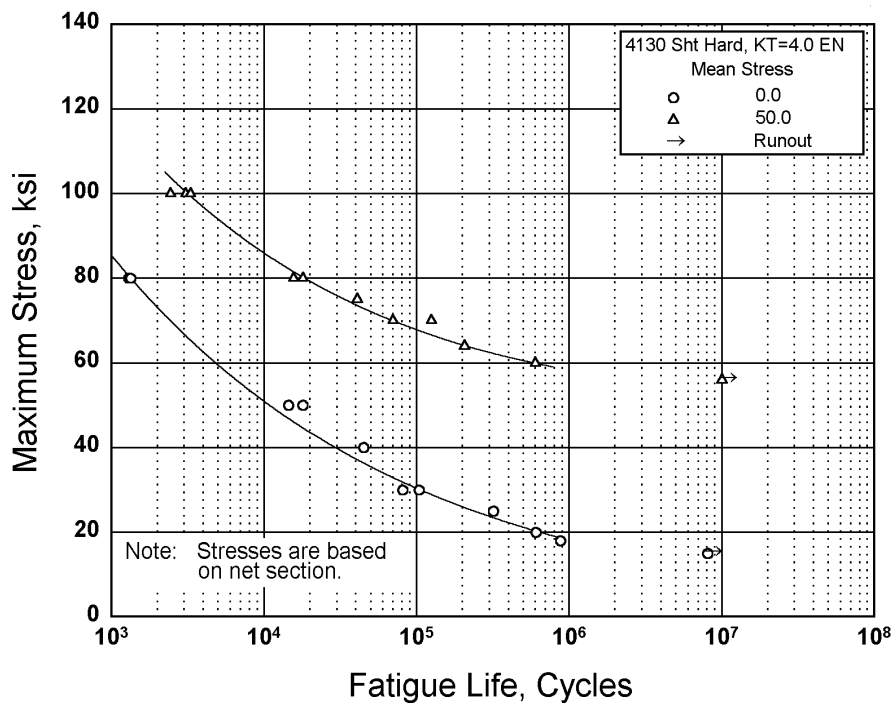


Figure 2.3.1.2.8(h). Best-fit S/N curves for notched,  $K_t = 4.0$ , 4130 alloy steel sheet,  $F_{tu} = 180$  ksi, longitudinal direction.

Correlative Information for Figure 2.3.1.2.8(h)

Product Form: Sheet, 0.075-inch thick

Properties:     TUS, ksi    TYS, ksi    Temp., °F

                    180            174            RT

Test Parameters:

Loading - Axial  
Frequency - 23-1800 cpm  
Temperature - RT  
Environment - Air

Specimen Details: Edge Notched  
2.25 inches gross width  
1.50 inches net width  
0.057-inch notch radius

No. of Heats/Lots: Not specified

Surface Condition: Electropolished

Equivalent Stress Equation:

$\log N_f = 12.4 - 4.45 \log (S_{eq})$   
 $S_{eq} = S_{max} (1-R)^{0.60}$   
Std. Error of Estimate,  $\log (\text{Life}) = 0.11$   
Standard Deviation,  $\log (\text{Life}) = 0.90$   
 $R^2 = 98\%$

Reference: 3.2.3.1.8(f)

Sample Size = 20

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

[VIEW INTERACTIVE GRAPH](#)

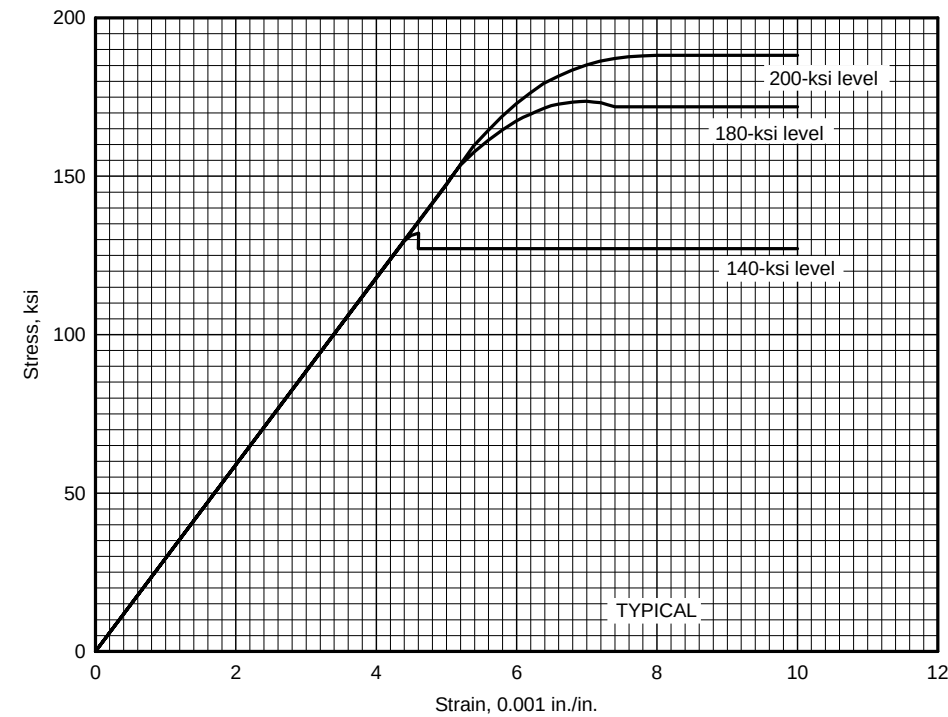


Figure 2.3.1.3.6(a). Typical tensile stress-strain curves at room temperature for heat-treated AISI 4340 alloy steel (all products).

[VIEW INTERACTIVE GRAPH](#)

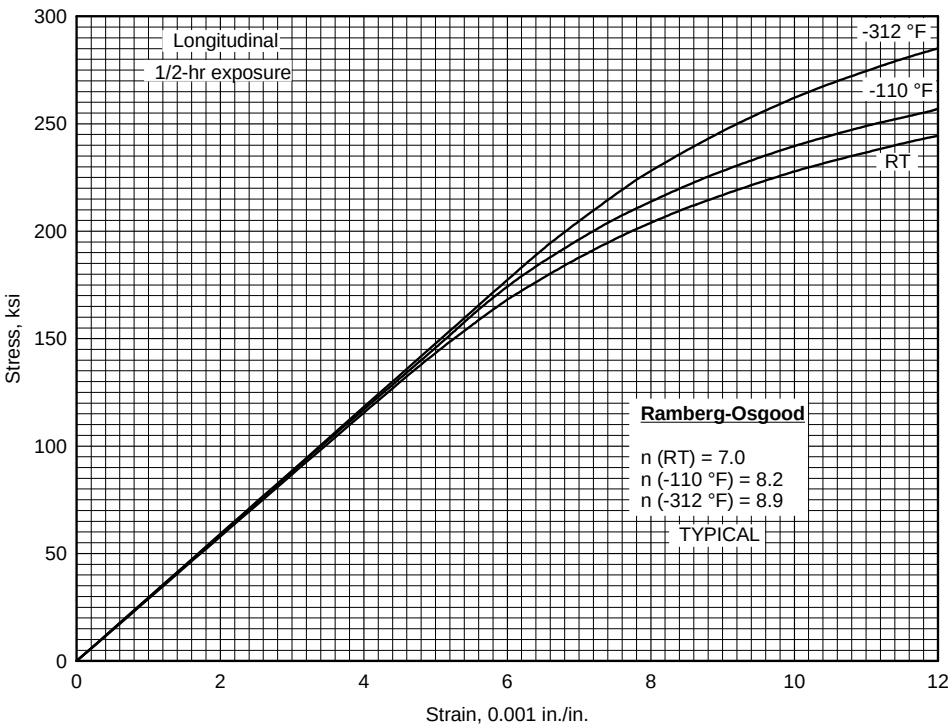


Figure 2.3.1.3.6(b). Typical tensile stress-strain curves at cryogenic and room temperature for AISI 4340 alloy steel bar,  $F_{tu} = 260$  ksi.

[VIEW INTERACTIVE GRAPH](#)

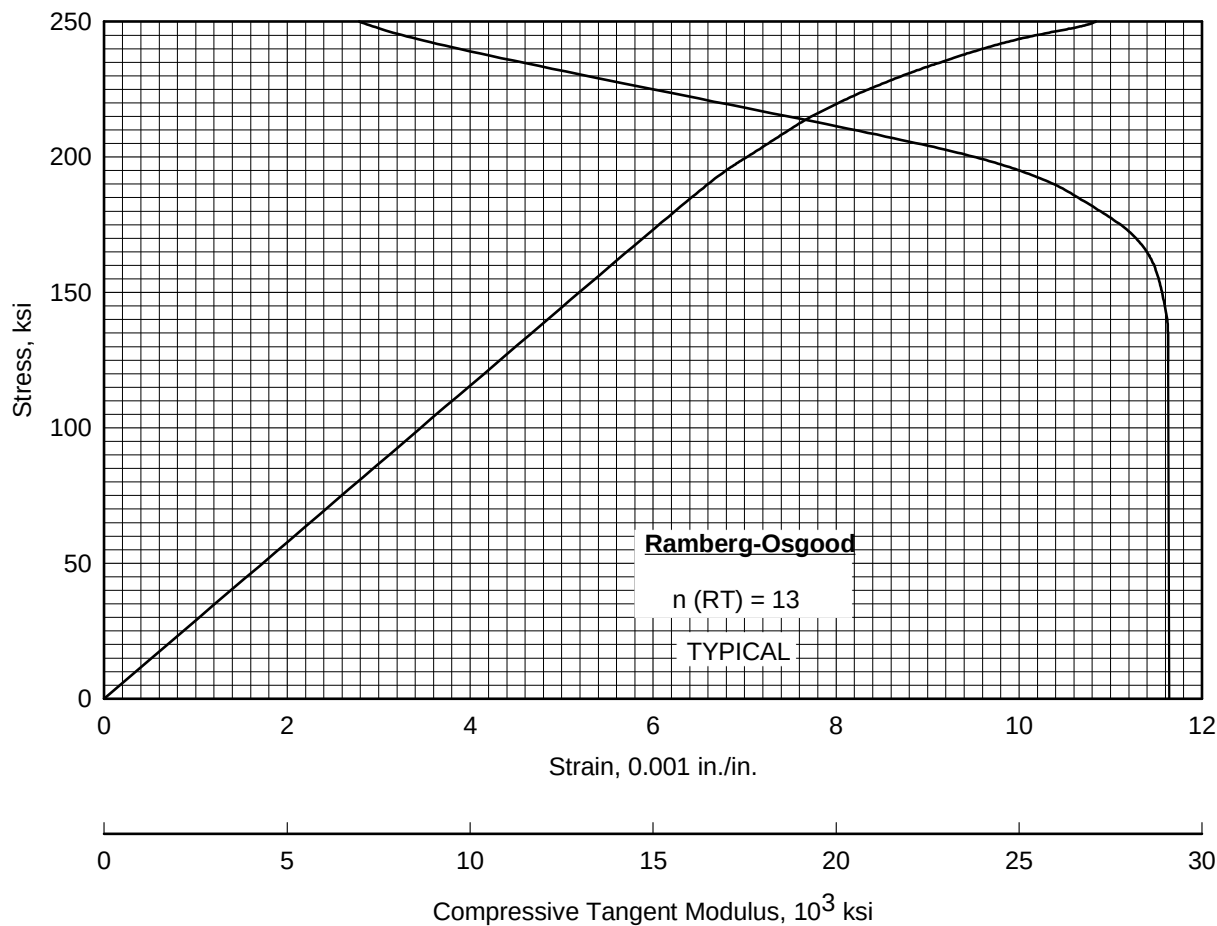


**Figure 2.3.1.3.6(c). Typical compressive stress-strain and compressive tangent-modulus curves at room temperature for AISI 4340 alloy steel bar,  $F_{su} = 260$  ksi.**

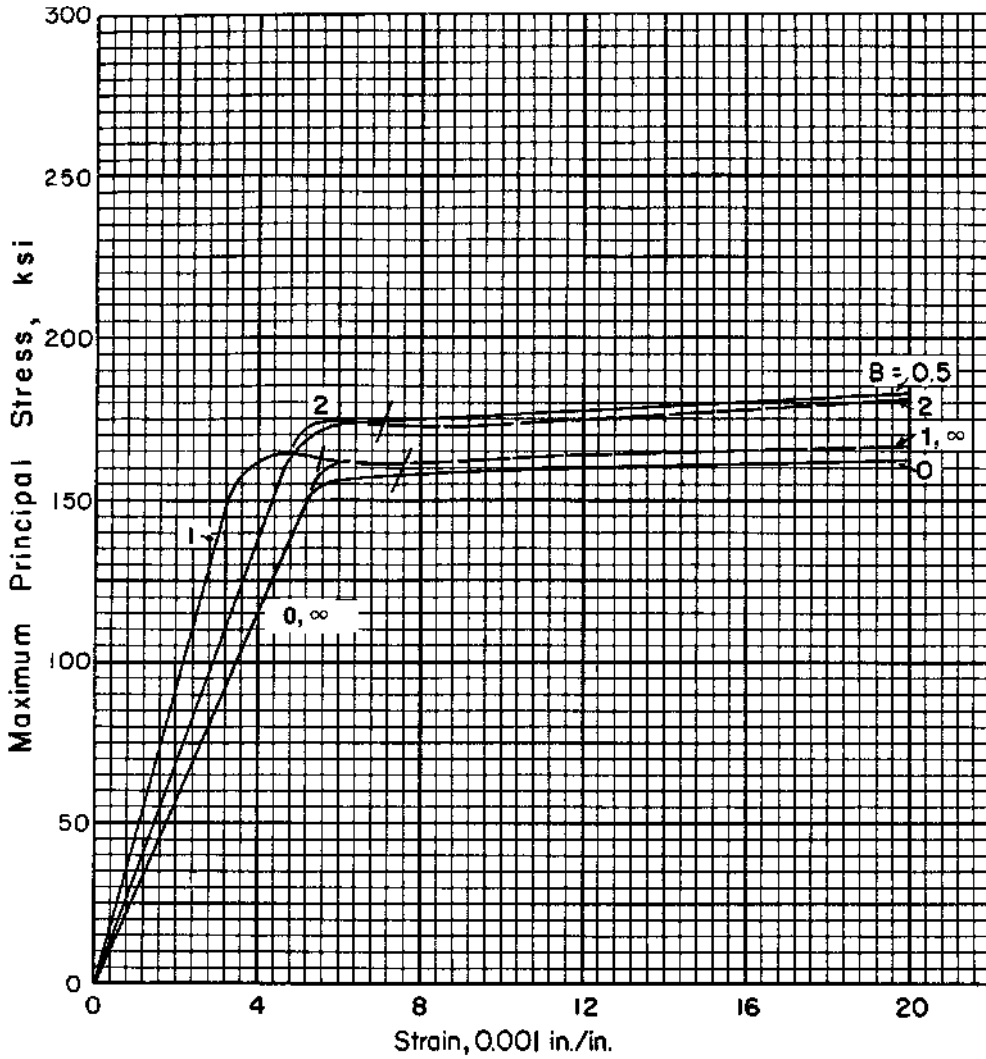
[VIEW INTERACTIVE GRAPH](#)

**Figure 2.3.1.3.6(d). Typical biaxial stress-strain curves at room temperature for AISI 4340 alloy steel (machined thin-wall cylinders, axial direction = longitudinal direction of bar stock),  $F_{tu} = 180$  ksi. A biaxial ratio,  $B$ , denotes the ratio of hoop stresses to axial stresses.**

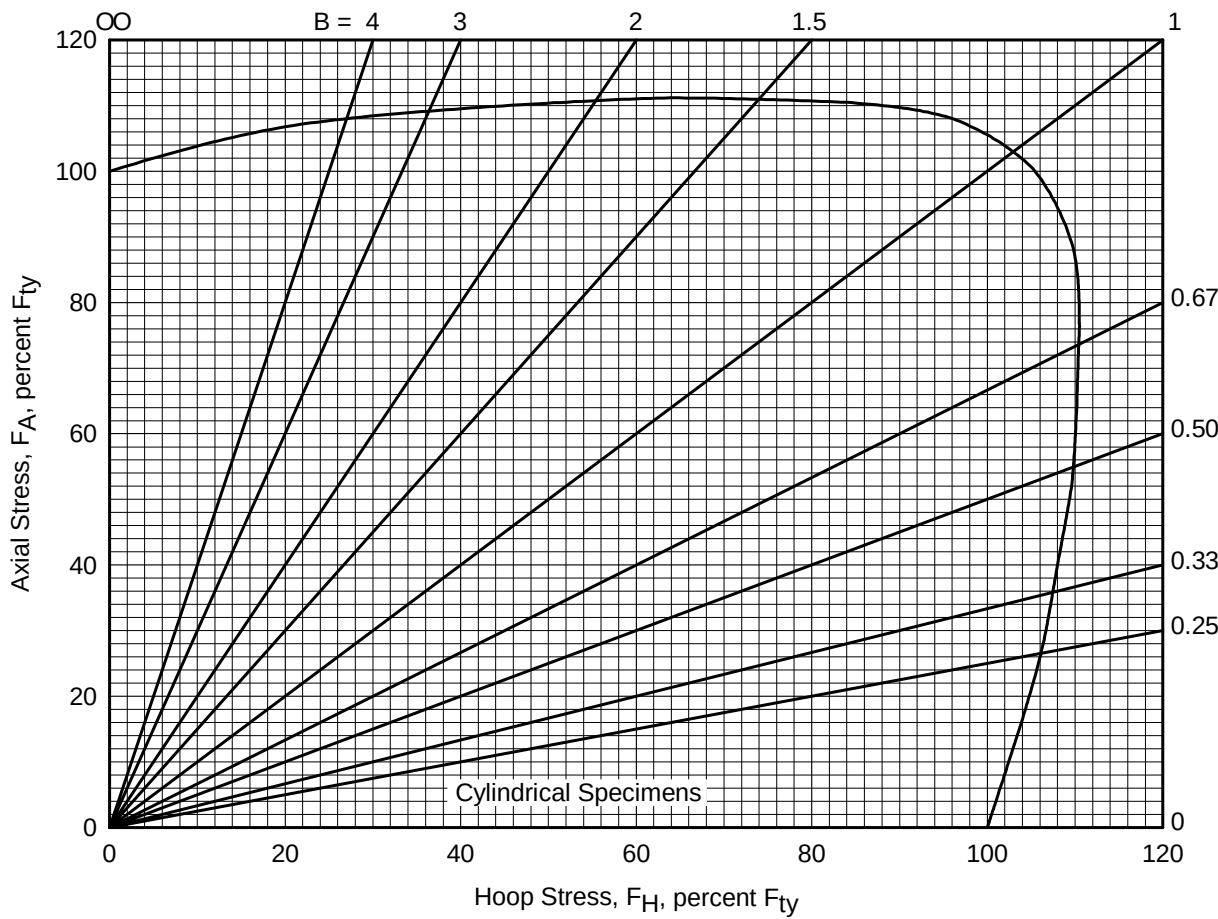


**Figure 2.3.1.3.6(e). Biaxial yield-stress envelope at room temperature for AISI 4340 alloy steel (machined thin-wall cylinders, axial direction = longitudinal direction of bar stock),  $F_{tu} = 180$  ksi,  $F_{ty}$  measures in the hoop direction.**

[VIEW INTERACTIVE GRAPH](#)

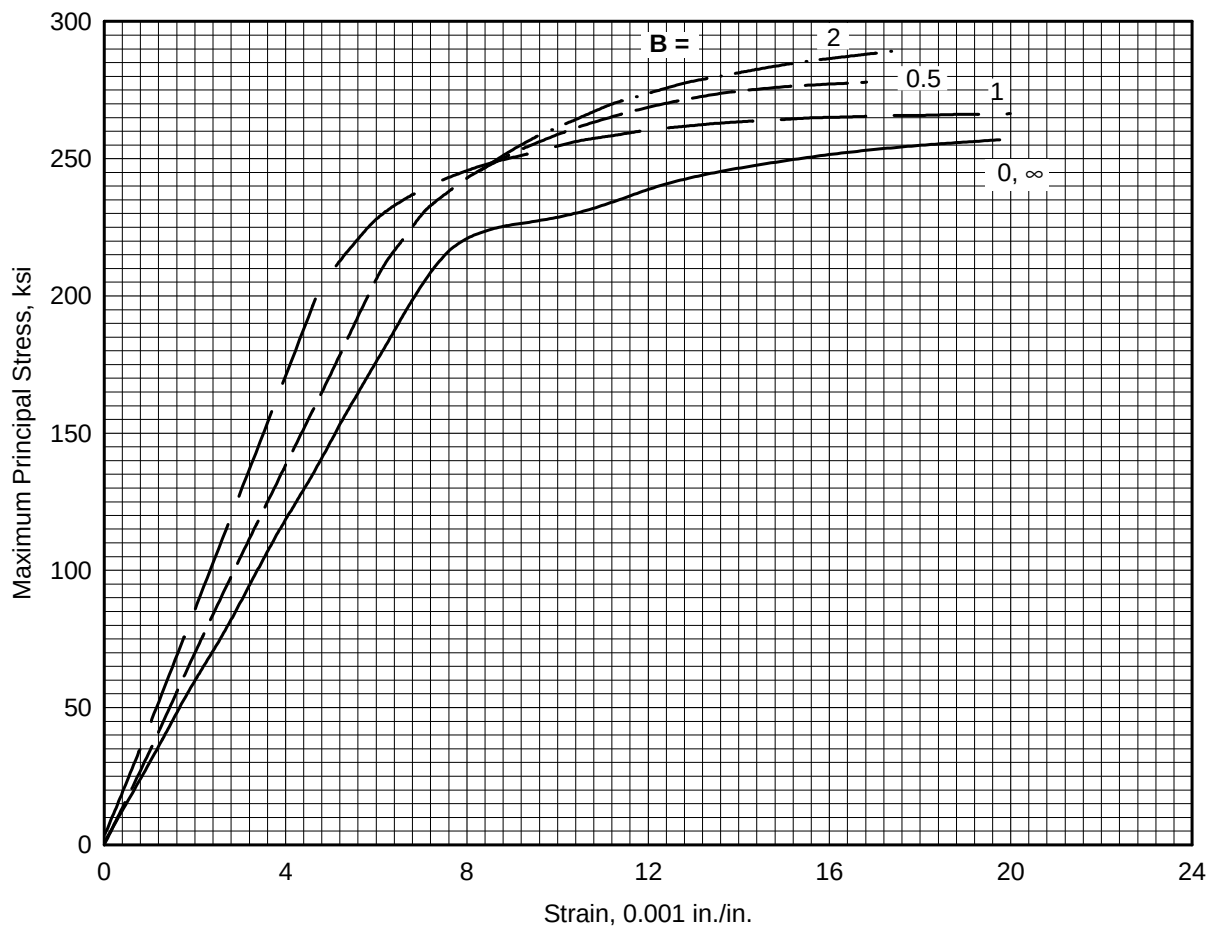


Figure 2.3.1.3.6(f). Typical biaxial stress-strain curves at room temperature for AISI 4340 alloy steel (machined thin-wall cylinders, axial direction = longitudinal direction of bar stock),  $F_{tu} = 260$  ksi. A biaxial ratio  $B$  of zero corresponds to the hoop direction.



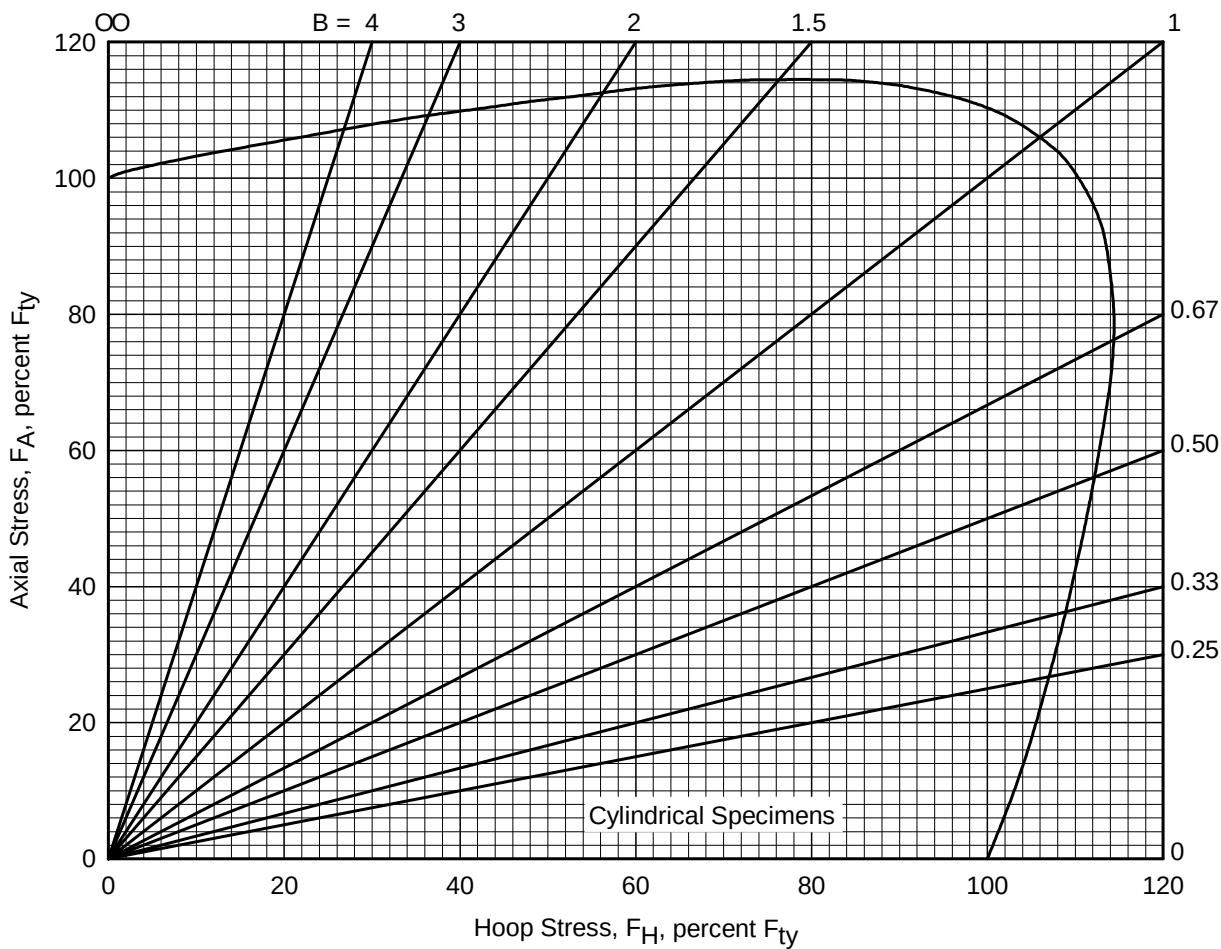


Figure 2.3.1.3.6(g). Biaxial yield-stress envelope at room temperature for AISI 4340 alloy steel (machined thin-wall cylinders, axial direction = longitudinal direction of bar stock),  $F_{tu} = 260$  ksi,  $F_{ty}$  measured in the hoop direction.

VIEW INTERACTIVE GRAPH

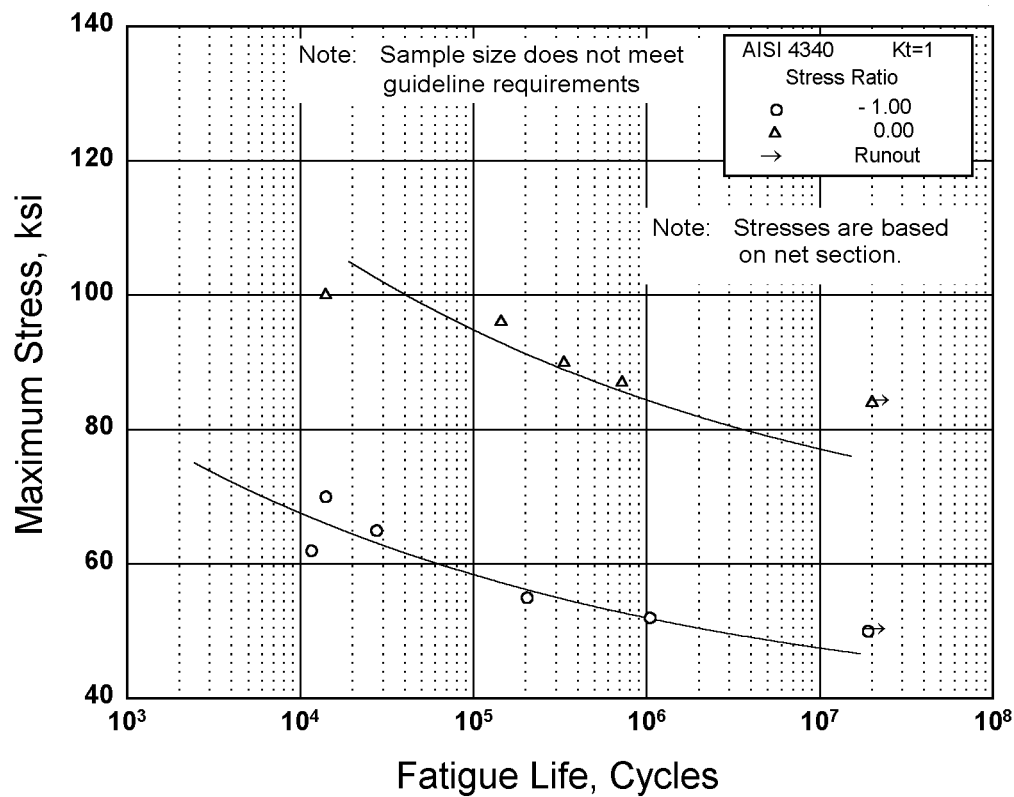


Figure 2.3.1.3.8(a). Best-fit S/N curves for unnotched AISI 4340 alloy steel bar,  $F_{tu} = 125$  ksi, longitudinal direction.

Correlative Information for Figure 2.3.1.3.8(a)

Product Form: Rolled bar, 1-1/8 inches diameter, air melted

Properties:      TUS, ksi    TYS, ksi    Temp., °F  
                         125           —           RT  
                                                           (unnotched)  
                         150           —           RT  
                                                           (notched)

Specimen Details: Unnotched  
                                 0.400-inch diameter

Surface Condition: Hand polished to RMS 10

Reference:        2.3.1.3.8(a)

Test Parameters:  
Loading - Axial  
Frequency - 2000 to 2500 cpm  
Temperature - RT  
Atmosphere - Air

No. of Heat/Lots: 1

Equivalent Stress Equation:  
 $\log N_f = 14.96 - 6.46 \log (S_{eq} - 60)$   
 $S_{eq} = S_{max} (1 - R)^{0.70}$   
Std. Error of Estimate, Log (Life) = 0.35  
Standard Deviation, Log (Life) = 0.77  
 $R^2 = 75\%$

Sample Size = 9

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

VIEW INTERACTIVE GRAPH

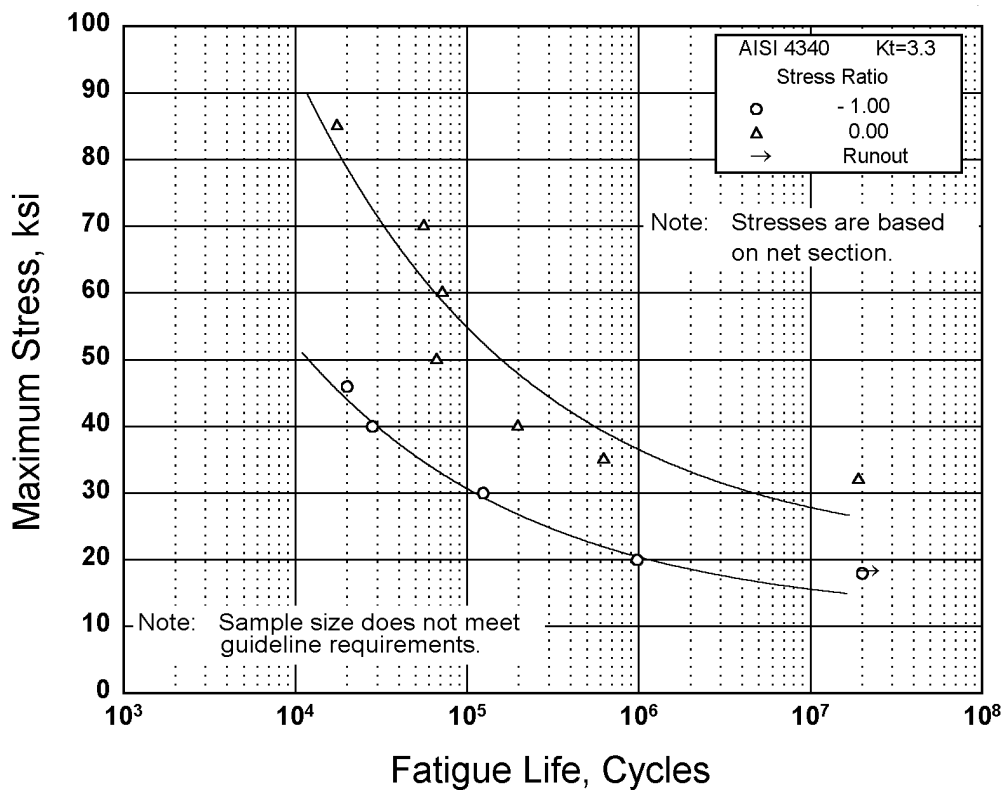


Figure 2.3.1.3.8(b). Best-fit S/N curves for notched,  $K_t = 3.3$ , AISI 4340 alloy steel bar,  $F_{tu} = 125$  ksi, longitudinal direction.

Correlative Information for Figure 2.3.1.3.8(b)

Product Form: Rolled bar, 1-1/8 inches diameter, air melted

Properties: TUS, ksi TYS, ksi Temp., °F

|     |   |                |
|-----|---|----------------|
| 125 | — | RT (unnotched) |
| 150 | — | RT (notched)   |

Specimen Details: Notched, V-Groove,  $K_t = 3.3$   
0.450-inch gross diameter  
0.400-inch net diameter  
0.010-inch root radius, r  
60° flank angle,  $\omega$

Surface Condition: Lathe turned to RMS 10

Reference: 2.3.1.3.8(a)

Test Parameters:  
Loading - Axial  
Frequency - 2000 to 2500 cpm  
Temperature - RT  
Atmosphere - Air

No. of Heat/Lots: 1

Equivalent Stress Equation:  
 $\log N_f = 9.75 - 3.08 \log (S_{eq} - 20.0)$   
 $S_{eq} = S_{max} (1 - R)^{0.84}$   
Std. Error of Estimate,  $\log (\text{Life}) = 0.40$   
Standard Deviation,  $\log (\text{Life}) = 0.90$   
 $R^2 = 80\%$

Sample Size = 11

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

[VIEW INTERACTIVE GRAPH](#)

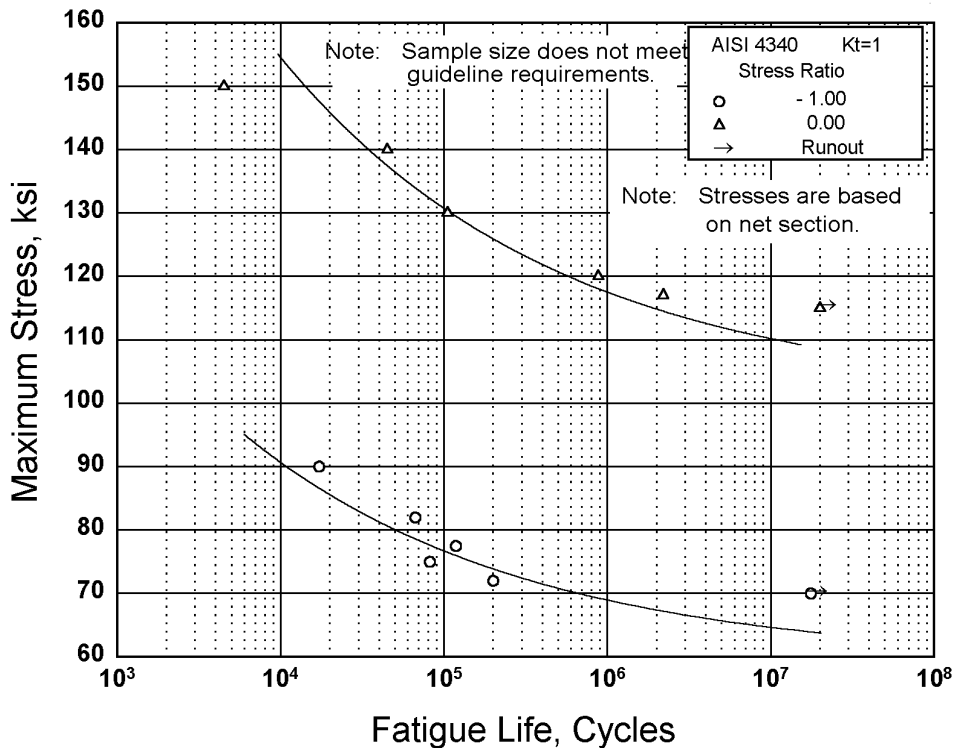


**Figure 2.3.1.3.8(c). Best-fit S/N curves for unnotched AISI 4340 alloy steel bar,  $F_{tu}$  = 150 ksi, longitudinal direction.**

Correlative Information for Figure 2.3.1.3.8(c)

Product Form: Rolled bar, 1.125 inches diameter, air melted

Test Parameters:  
Loading - Axial  
Frequency - 2000 to 2500 cpm  
Temperature - RT  
Atmosphere - Air

Properties:      TUS, ksi    TYS, ksi    Temp., °F  
  
158            147            RT  
                                 (unnotched)  
190            —            RT  
                                 (notched)

No. of Heat/Lots: 1

Specimen Details: Unnotched  
0.400-inch diameter

Equivalent Stress Equation:  
 $\log N_f = 10.76 - 3.91 \log (S_{eq} - 101.0)$   
 $S_{eq} = S_{max} (1-R)^{0.77}$   
Std. Error of Estimate, Log (Life) = 0.17  
Standard Deviation, Log (Life) = 0.33  
Adjusted  $R^2$  Statistic = 73%

Surface Condition: Hand polished to RMS 10

Sample Size = 9

Reference: 2.3.1.3.8(b)

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

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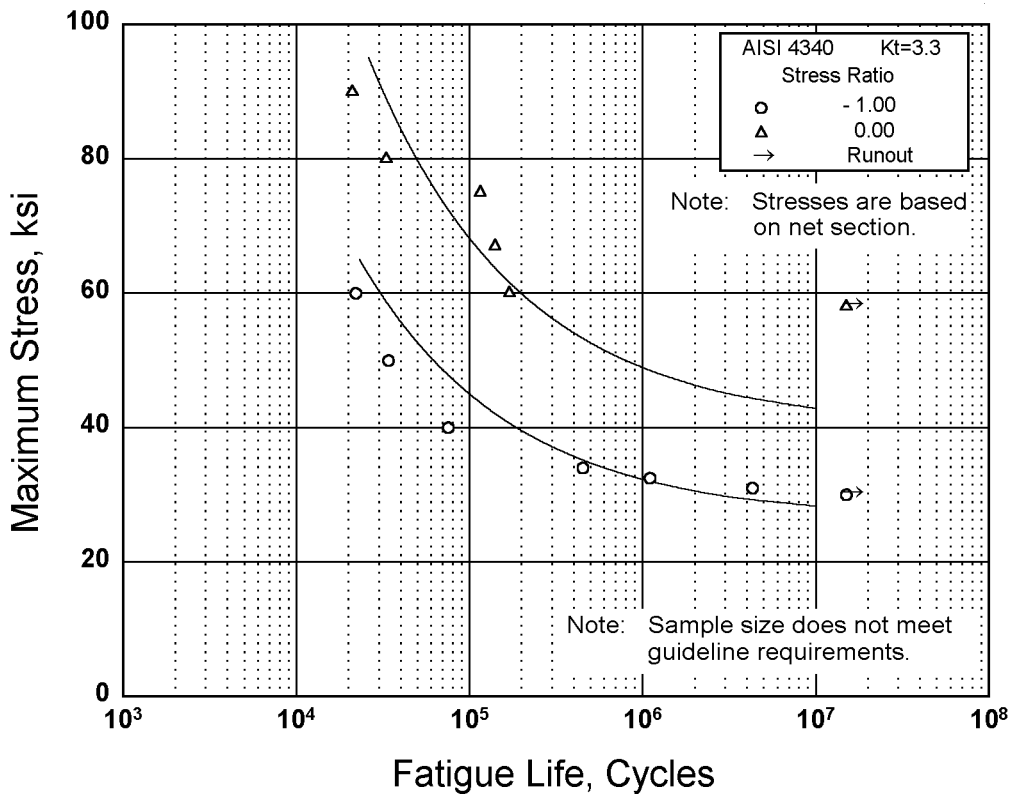


Figure 2.3.1.3.8(d). Best-fit S/N curves for notched AISI 4340 alloy steel bar,  $F_{tu} = 150$  ksi, longitudinal direction.

Correlative Information for Figure 2.3.1.3.8(d)

Product Form: Rolled bar, 1-1/8 inches diameter, air melted

Properties:

| TUS, ksi | TYS, ksi | Temp., °F      |
|----------|----------|----------------|
| 158      | 147      | RT (unnotched) |
| 190      | —        | RT (notched)   |

Specimen Details: Notched, V-Groove,  $K_t = 3.3$   
0.450-inch gross diameter  
0.400-inch net diameter  
0.010-inch root radius, r  
60° flank angle,  $\omega$

Surface Condition: Lathe turned to RMS 10

Reference: 2.3.1.3.8(a)

Test Parameters:  
Loading - Axial  
Frequency - 2000 to 2500 cpm  
Temperature - RT  
Atmosphere - Air

No. of Heat/Lots: 1

Equivalent Stress Equation:  
 $\log N_f = 7.90 - 2.00 \log (S_{eq} - 40.0)$   
 $S_{eq} = S_{max} (1 - R)^{0.60}$   
Std. Error of Estimate,  $\log (\text{Life}) = 0.27$   
Standard Deviation,  $\log (\text{Life}) = 0.74$   
 $R^2 = 86\%$

Sample Size = 11

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

VIEW INTERACTIVE GRAPH

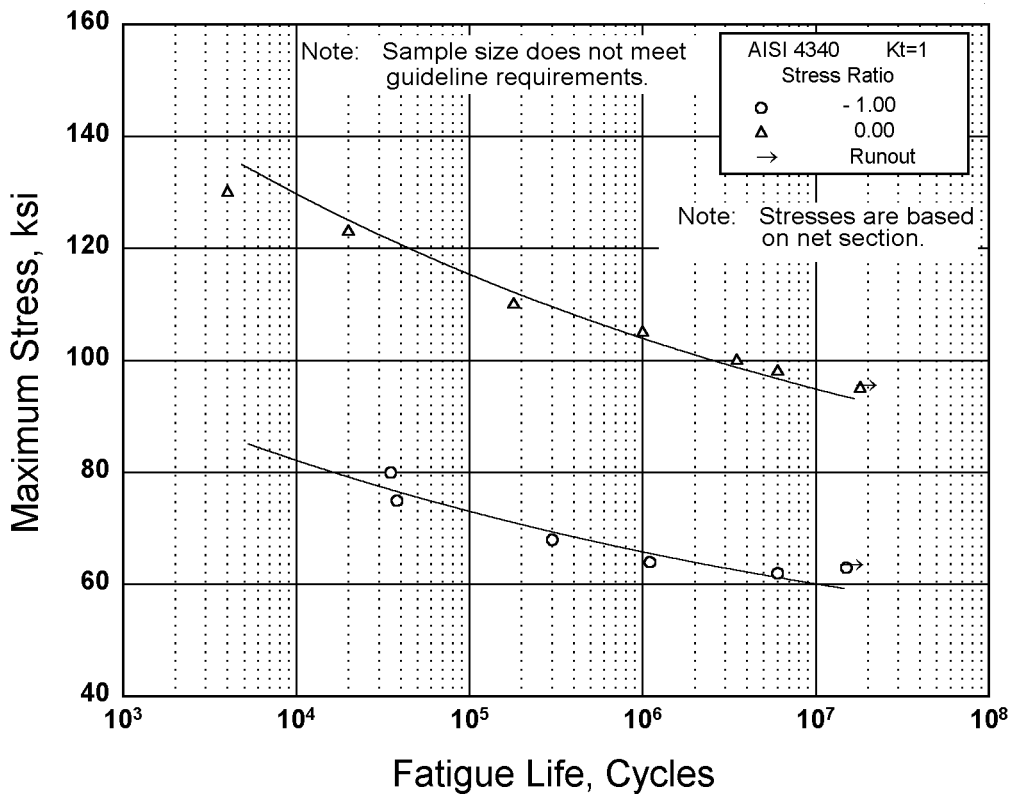


**Figure 2.3.1.3.8(e). Best-fit S/N curves for unnotched AISI 4340 alloy steel bar at 600°F,  $F_{tu} = 150$  ksi, longitudinal direction.**

Correlative Information for Figure 2.3.1.3.8(e)

Product Form: Rolled bar, 1-1/8 inches diameter, air melted

Test Parameters:  
Loading - Axial  
Frequency - 2000 to 2500 cpm  
Temperature - 600°F  
Atmosphere - Air

| <u>Properties:</u> | <u>TUS, ksi</u> | <u>TYS, ksi</u> | <u>Temp., °F</u> |
|--------------------|-----------------|-----------------|------------------|
|                    | 158             | 147             | RT               |
|                    |                 |                 | (unnotched)      |
|                    | 153             | 121             | 600              |
|                    |                 |                 | (unnotched)      |
|                    | 190             | —               | RT               |
|                    |                 |                 | (notched)        |
|                    | 176             | —               | 600              |
|                    |                 |                 | (notched)        |

No. of Heat/Lots: 1

Equivalent Stress Equation:  
 $\text{Log } N_f = 22.36 - 9.98 \log (S_{eq} - 60.0)$   
 $S_{eq} = S_{max} (1 - R)^{0.66}$   
Std. Error of Estimate Log (Life) = 0.24  
Standard Deviation, Log (Life) = 1.08  
 $R^2 = 95\%$

Specimen Details: Unnotched  
0.400-inch diameter

Sample Size = 11

Surface Condition: Hand polished to RMS 10

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

Reference: 2.3.1.3.8(b)

VIEW INTERACTIVE GRAPH

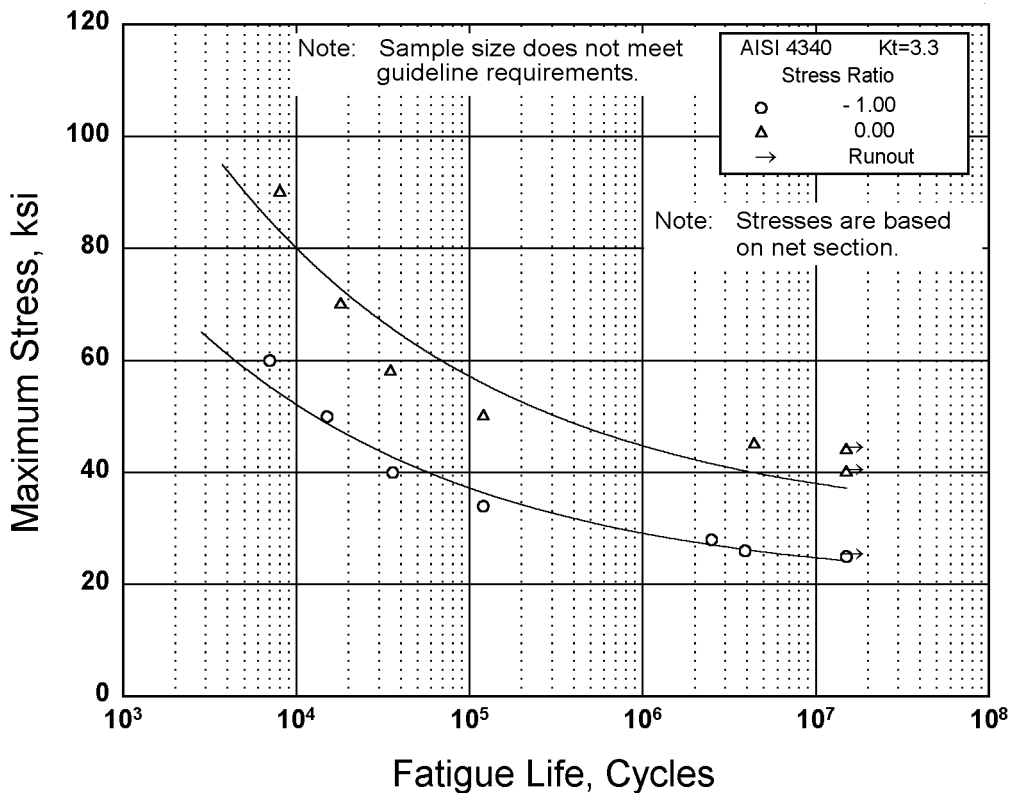


**Figure 2.3.1.3.8(f). Best-fit S/N curves for notched,  $K_t = 3.3$ , AISI 4340 alloy steel bar at 600°F,  $F_{tu} = 150$  ksi, longitudinal direction.**

Correlative Information for Figure 2.3.1.3.8(f)

Product Form: Rolled bar, 1-1/8 inches diameter, air melted

Reference: 2.3.1.3.8(b)

| <u>Properties:</u> | <u>TUS, ksi</u> | <u>TYS, ksi</u> | <u>Temp., °F</u> |
|--------------------|-----------------|-----------------|------------------|
|                    | 158             | 147             | RT               |
|                    |                 |                 | (unnotched)      |
|                    | 153             | 121             | 600              |
|                    |                 |                 | (unnotched)      |
|                    | 190             | —               | RT               |
|                    |                 |                 | (notched)        |
|                    | 176             | —               | 600              |
|                    |                 |                 | (notched)        |

Test Parameters:

Loading - Axial  
Frequency - 2000 to 2500 cpm  
Temperature - RT  
Atmosphere - Air

No. of Heat/Lots: 1

Equivalent Stress Equation:

$\log N_f = 10.39 - 3.76 \log (S_{eq} - 30.0)$   
 $S_{eq} = S_{max} (1 - R)^{0.62}$   
Std. Error of Estimate,  $\log (\text{Life}) = 0.36$   
Standard Deviation,  $\log (\text{Life}) = 1.06$   
 $R^2 = 89\%$

Specimen Details: Notched, V-Groove,  $K_t = 3.3$   
0.450-inch gross diameter  
0.400-inch net diameter  
0.010-inch root radius, r  
60° flank angle,  $\omega$

Sample Size = 11

Surface Condition: Lathe turned to RMS 10

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

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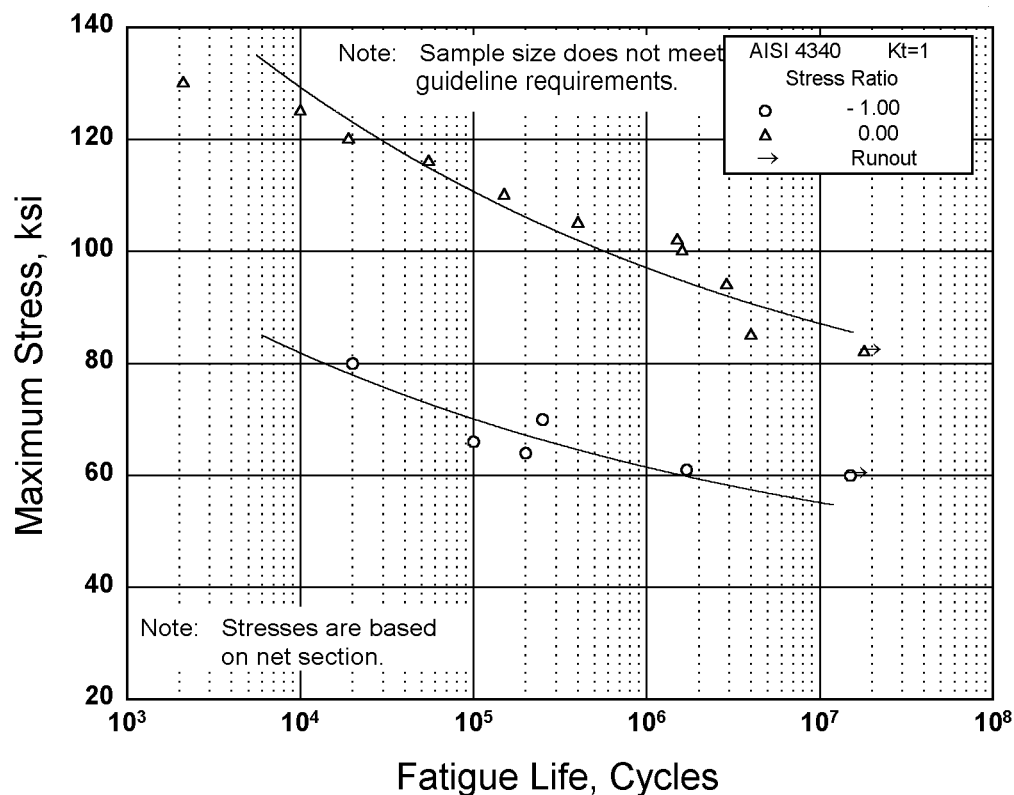


Figure 2.3.1.3.8(g). Best-fit S/N curves for unnotched AISI 4340 alloy steel bar at 800°F,  $F_w = 150$  ksi, longitudinal direction.

Correlative Information for Figure 2.3.1.3.8(g)

Product Form: Rolled bar, 1-1/8 inches diameter, air melted

| <u>Properties:</u> | <u>TUS, ksi</u> | <u>TYS, ksi</u> | <u>Temp., °F</u> |
|--------------------|-----------------|-----------------|------------------|
|                    | 158             | 147             | RT               |
|                    |                 |                 | (unnotched)      |
|                    | 125             | 101             | 800              |
|                    |                 |                 | (unnotched)      |
|                    | 190             | —               | RT               |
|                    |                 |                 | (notched)        |
|                    | 154             | —               | 800              |
|                    |                 |                 | (notched)        |

Specimen Details: Unnotched  
0.400-inch diameter

Surface Condition: Hand polished to RMS 10

Reference: 2.3.1.3.8(b)

Test Parameters:  
Loading - Axial  
Frequency - 2000 to 2500 cpm  
Temperature - 800°F  
Atmosphere - Air

No. of Heat/Lots: 1

Equivalent Stress Equation:  
 $\log N_f = 17.53 - 7.35 \log (S_{eq} - 60.0)$   
 $S_{eq} = S_{max} (1 - R)^{0.66}$   
Std. Error of Estimate, Log (Life) = 0.42  
Standard Deviation, Log (Life) = 0.99  
 $R^2 = 82\%$

Sample Size = 15

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]



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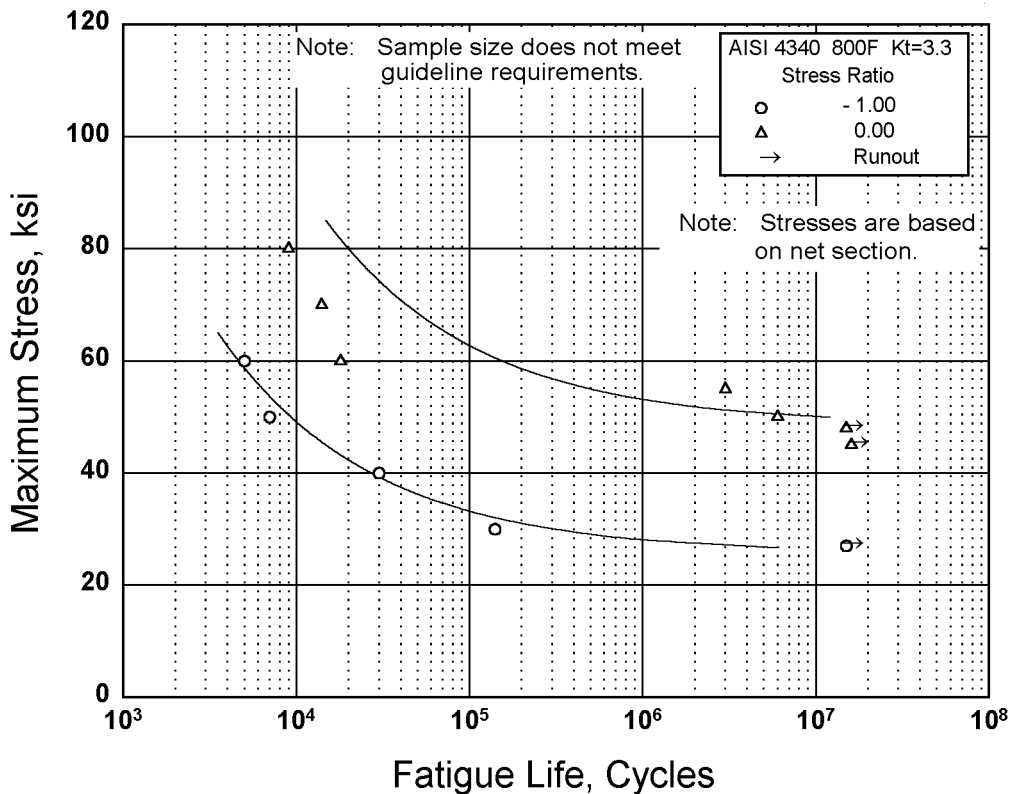


Figure 2.3.1.3.8(h). Best-fit S/N curves for notched,  $K_t = 3.3$ , AISI 4340 alloy steel bar at 800°F,  $F_{tu} = 150$  ksi, longitudinal direction.

Correlative Information for Figure 2.3.1.3.8(h)

Product Form: Rolled bar, 1-1/8 inches diameter, air melted

Properties:

| TUS, ksi | TYS, ksi | Temp., °F   |
|----------|----------|-------------|
| 158      | 147      | RT          |
|          |          | (unnotched) |
| 125      | 101      | 800         |
|          |          | (unnotched) |
| 190      | —        | RT          |
|          |          | (notched)   |
| 154      | —        | 800         |
|          |          | (notched)   |

Specimen Details: Notched, V-Groove,  $K_t = 3.3$   
0.450-inch gross diameter  
0.400-inch net diameter  
0.010-inch root radius, r  
60° flank angle,  $\omega$

Surface Condition: Lathe turned to RMS 10

Reference: 2.3.1.3.8(b)

Test Parameters:  
Loading - Axial  
Frequency - 2000 to 2500 cpm  
Temperature - 800°F  
Atmosphere - Air

No. of Heat/Lots: 1

Equivalent Stress Equation:  
 $\log N_f = 7.31 - 2.01 \log (S_{eq} - 48.6)$   
 $S_{eq} = S_{max} (1 - R)^{0.92}$   
Std. Error of Estimate,  $\log (\text{Life}) = 0.60$   
Standard Deviation,  $\log (\text{Life}) = 1.14$   
 $R^2 = 72\%$

Sample Size = 9

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

VIEW INTERACTIVE GRAPH

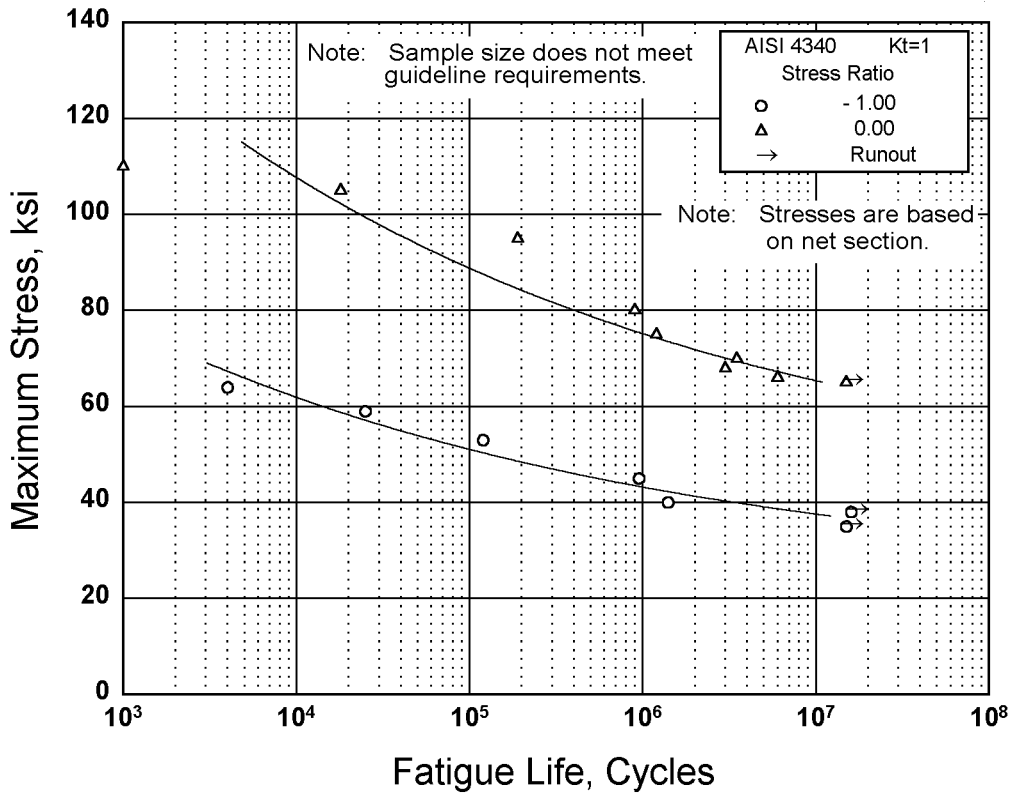


Figure 2.3.1.3.8(i). Best-fit S/N curves for unnotched AISI 4340 alloy steel bar at 1000°F,  $F_{tu} = 150$  ksi, longitudinal direction.

Correlative Information for Figure 2.3.1.3.8(i)

Product Form: Rolled bar, 1-1/8 inches diameter, air melted

| <u>Properties:</u> | <u>TUS, ksi</u> | <u>TYS, ksi</u> | <u>Temp., °F</u> |
|--------------------|-----------------|-----------------|------------------|
|                    | 158             | 147             | RT               |
|                    |                 |                 | (unnotched)      |
|                    | 81              | 63              | 1000°F           |
|                    |                 |                 | (unnotched)      |
|                    | 190             | —               | RT               |
|                    |                 |                 | (notched)        |
|                    | 98              | —               | 1000°F           |
|                    |                 |                 | (notched)        |

Specimen Details: Unnotched  
0.400-inch diameter

Surface Condition: Hand polished to RMS 10

Reference: 2.3.1.3.8(b)

Test Parameters:  
Loading - Axial  
Frequency - 2000 to 2500 cpm  
Temperature - 1000°F  
Atmosphere - Air

No. of Heat/Lots: 1

Equivalent Stress Equation:  
 $\log N_f = 16.85 - 7.02 \log (S_{eq} - 40.0)$   
 $S_{eq} = S_{max} (1 - R)^{0.80}$   
Std. Error of Estimate,  $\log (\text{Life}) = 0.42$   
Standard Deviation,  $\log (\text{Life}) = 1.20$   
 $R^2 = 88\%$

Sample Size = 13

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

[VIEW INTERACTIVE GRAPH](#)

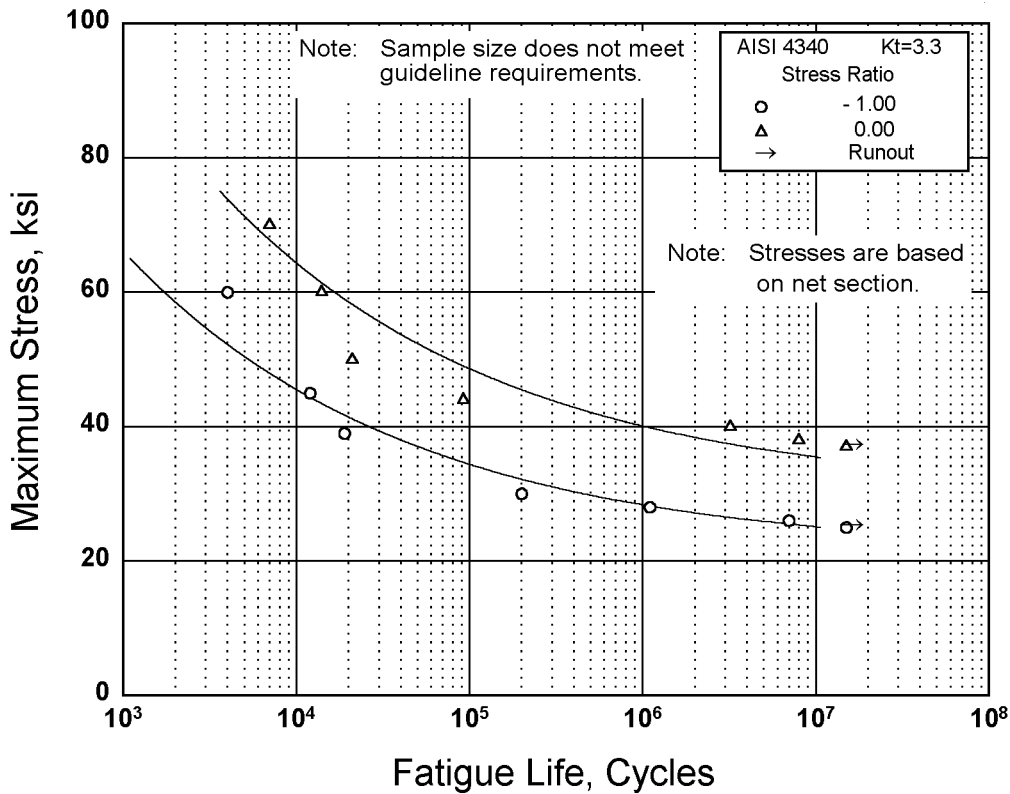


Figure 2.3.1.3.8(j). Best-fit S/N curves for notched,  $K_t = 3.3$ , AISI 4340 alloy steel bar at 1000°F,  $F_{tu} = 150$  ksi, longitudinal direction.

Correlative Information for Figure 2.3.1.3.8(j)

Product Form: Rolled bar, 1-1/8 inches diameter, air melted

|                    |                 |                 |                    |
|--------------------|-----------------|-----------------|--------------------|
| <u>Properties:</u> | <u>TUS, ksi</u> | <u>TYS, ksi</u> | <u>Temp., °F</u>   |
|                    | 158             | 147             | RT (unnotched)     |
|                    | 81              | 63              | 1000°F (unnotched) |
|                    | 190             | —               | RT (notched)       |
|                    | 98              | —               | 1000°F (notched)   |

Specimen Details: Notched, V-Groove,  $K_t = 3.3$   
0.450-inch gross diameter  
0.400-inch net diameter  
0.010-inch root radius, r  
60° flank angle,  $\omega$

Surface Condition: Lathe turned to RMS 10

Reference: 2.3.1.3.8(b)

Test Parameters:  
Loading - Axial  
Frequency - 2000 to 2500 cpm  
Temperature - 1000°F  
Atmosphere - Air

No. of Heat/Lots: 1

Equivalent Stress Equation:  
 $\log N_f = 9.76 - 3.75 \log (S_{eq} - 30.0)$   
 $S_{eq} = S_{max} (1 - R)^{0.50}$   
Std. Error of Estimate,  $\log (\text{Life}) = 0.40$   
Standard Deviation,  $\log (\text{Life}) = 1.22$   
 $R^2 = 89\%$

Sample Size = 12

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

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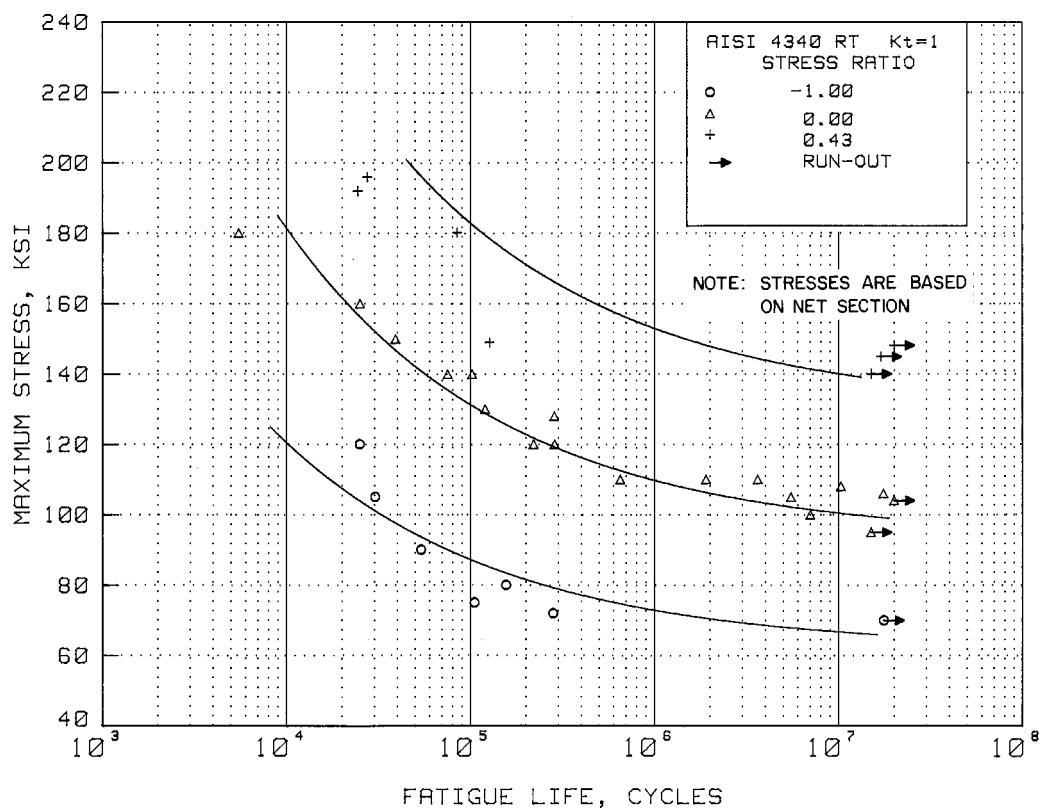


Figure 2.3.1.3.8(k). Best-fit S/N curves for unnotched AISI 4340 alloy steel bar and die forging,  $F_{tu} = 200$  ksi, longitudinal direction.

Correlative Information for Figure 2.3.1.3.8(k)

Product Form: Rolled bar, 1-1/8 inches diameter, air melted  
Die forging (landing gear-B36 aircraft), air melted

|                    |                 |                 |                  |
|--------------------|-----------------|-----------------|------------------|
| <u>Properties:</u> | <u>TUS, ksi</u> | <u>TYS, ksi</u> | <u>Temp., °F</u> |
|                    | 208, 221        | 189, 217        | RT (unnotched)   |
|                    | 251             | —               | RT (notched)     |

Specimen Details: Unnotched  
0.300 and 0.400-inch diameter

Surface Condition: Hand polished to RMS 5-10

References: 2.3.1.3.8(a) and (c)

Test Parameters:  
Loading - Axial  
Frequency - 2000 to 2500 cpm  
Temperature - RT  
Atmosphere - Air

No. of Heat/Lots: 2

Equivalent Stress Equation:  
 $\log N_f = 9.31 - 2.73 \log (S_{eq} - 93.4)$   
 $S_{eq} = S_{max} (1 - R)^{0.59}$   
Standard Error of Estimate = 0.49  
Standard Deviation in Life = 0.93  
 $R^2 = 72\%$

Sample Size = 26

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

[VIEW INTERACTIVE GRAPH](#)

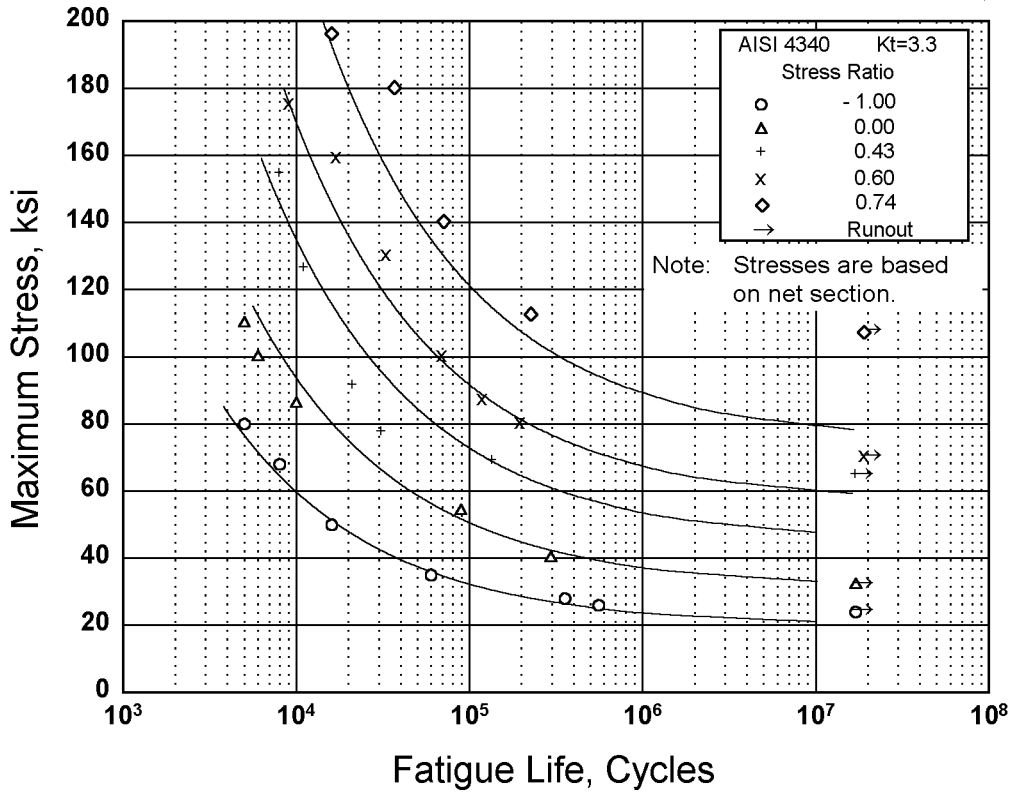


**Figure 2.3.1.3.8(I). Best-fit S/N curves for notched,  $K_t = 3.3$ , AISI 4340 alloy steel bar,  $F_{tu} = 200$  ksi, longitudinal direction.**

Correlative Information for Figure 2.3.1.3.8(I)

Product Form: Rolled bar, 1-1/8 inches diameter, air melted

|                    |                 |                 |                   |
|--------------------|-----------------|-----------------|-------------------|
| <u>Properties:</u> | <u>TUS, ksi</u> | <u>TYS, ksi</u> | <u>Temp., °F</u>  |
|                    | 208             | —               | RT<br>(unnotched) |
|                    | 251             | —               | RT<br>(notched)   |

Specimen Details: Notched, V-Groove,  $K_t = 3.3$   
0.450-inch gross diameter  
0.400-inch net diameter  
0.010-inch root radius,  $r$   
60° flank angle,  $\omega$

Surface Condition: Lathe turned to RMS 10

Reference: 2.3.1.3.8(a)

Test Parameters:

Loading - Axial  
Frequency - 2000 to 2500 cpm  
Temperature - RT  
Atmosphere - Air

No. of Heat/Lots: 1

Equivalent Stress Equation:

$\log N_f = 7.52 - 1.96 \log (S_{eq} - 31.2)$   
 $S_{eq} = S_{max} (1 - R)^{0.65}$   
Std. Error of Estimate,  $\log (\text{Life}) = 0.16$   
Standard Deviation,  $\log (\text{Life}) = 0.62$   
 $R^2 = 93\%$

Sample Size = 26

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

[VIEW INTERACTIVE GRAPH](#)

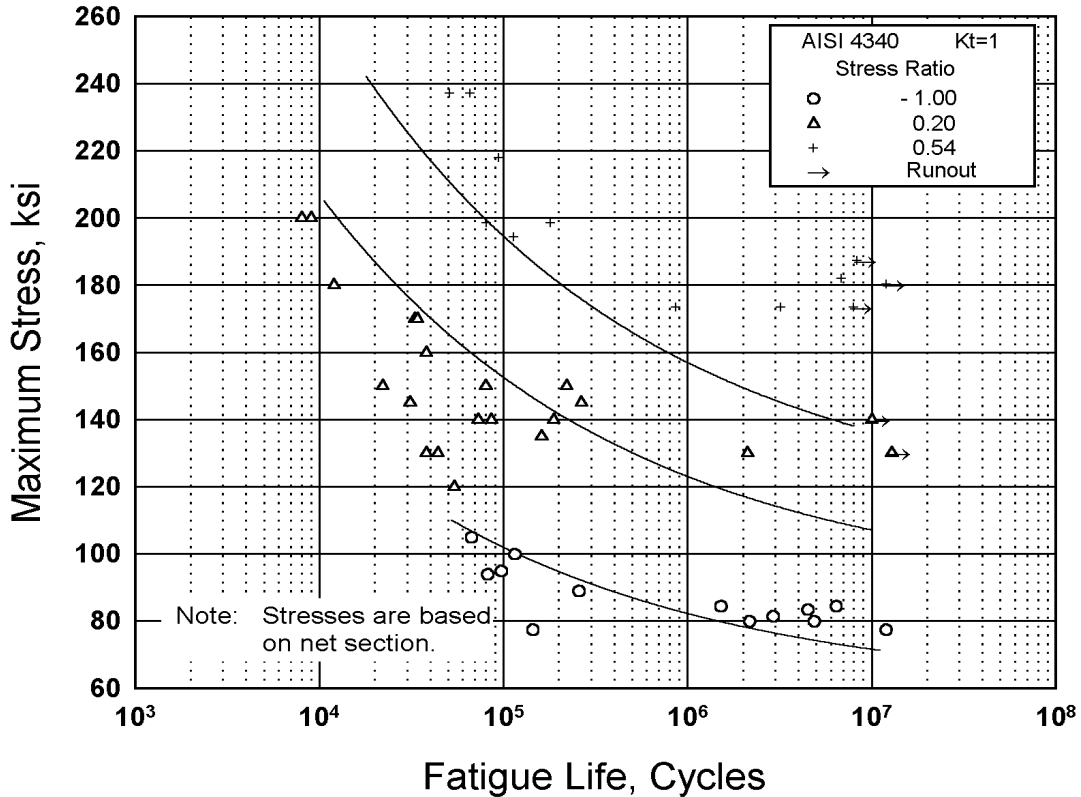


**Figure 2.3.1.3.8(m). Best-fit S/N curves for unnotched AISI 4340 alloy steel bar and billet,  $F_{tu} = 260$  ksi, longitudinal direction.**

Correlative Information for Figure 2.3.1.3.8(m)

Product Form: Rolled bar, 1-1/8 inches diameter, air melted  
Billet, 6 inches RCS air melted

Test Parameters:  
Loading - Axial  
Frequency - 1800 to 2500 cpm  
Temperature - RT  
Atmosphere - Air

Properties: TUS, ksi TYS, ksi Temp., °F  
266, 291 232 RT  
(unnotched)  
352 — RT  
(notched)

No. of Heat/Lots: 2

Equivalent Stress Equation:  
 $\log N_f = 11.62 - 3.75 \log (S_{eq} - 80.0)$   
 $S_{eq} = S_{max} (1-R)^{0.44}$   
Std. Error of Estimate,  $\log (\text{Life}) = 0.64$   
Standard Deviation,  $\log (\text{Life}) = 0.86$   
 $R^2 = 45\%$

Specimen Details: Unnotched  
0.200 and 0.400-inch diameter

Surface Condition: Hand polished to RMS 10

Sample Size = 41

References: 2.3.1.3.8(a) and (b)

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]



[VIEW INTERACTIVE GRAPH](#)

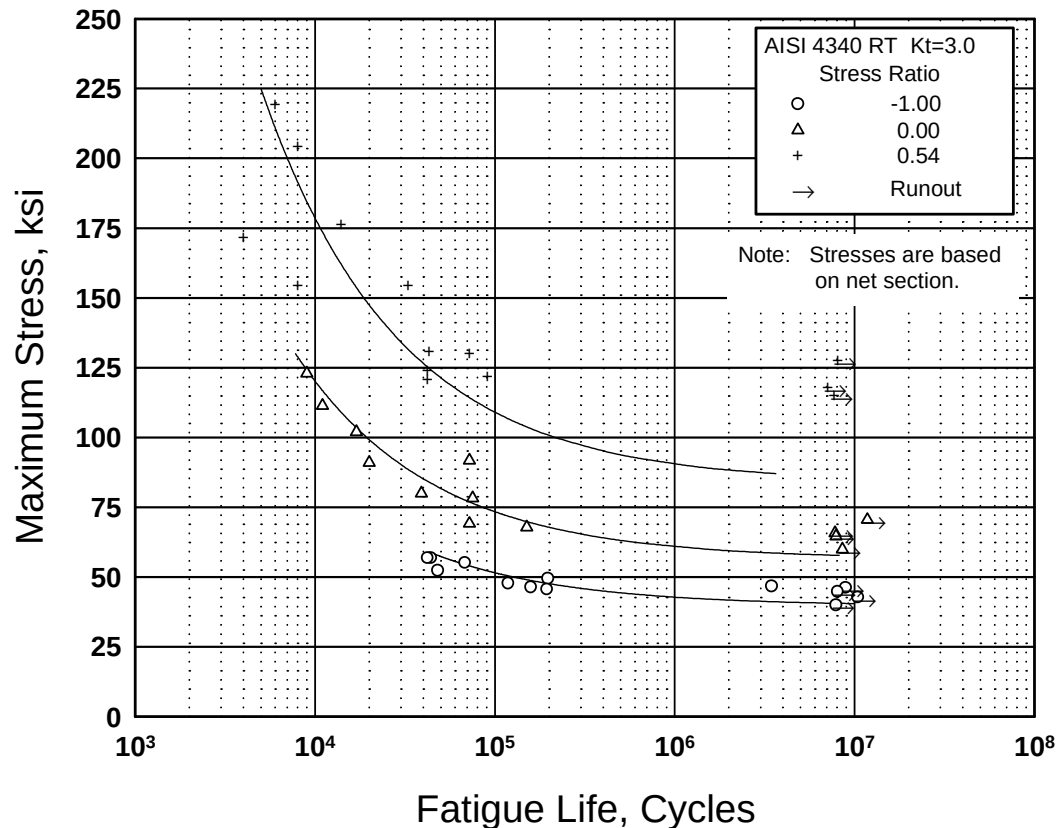


**Figure 2.3.1.3.8(o). Best-fit S/N curves for notched,  $K_t = 3.0$ , AISI 4340 alloy steel bar,  $F_{tu} = 260$  ksi, longitudinal direction.**

Correlative Information for Figure 2.3.1.3.8(o)

Product Form:  
Rolled bar, 1-1/8 inches diameter, air melted

Properties:    TUS, ksi    TYS, ksi    Temp., °F  
  
266        232        RT  
                              (unnotched)  
352        —        RT  
                              (notched)

Specimen Details: Notched, V-Groove,  $K_t = 3.0$   
0.270-inch gross diameter  
0.220-inch net diameter  
0.010-inch root radius, r  
60° flank angle,  $\omega$

Surface Condition: Lathe turned to RMS 10

Reference: 2.3.1.3.8(a)

Test Parameters:

Loading—Axial  
Frequency—2000 to 2500 cpm  
Temperature—RT  
Atmosphere—Air

No. of Heats/Lots: 1

Equivalent Stress Equation:

$\text{Log } N_f = 7.14 - 1.74 \log (S_{eq} - 56.4)$   
 $S_{eq} = S_{max} (1-R)^{0.51}$   
Std. Error of Estimate,  $\text{Log (Life)} = 0.32$   
Standard Deviation,  $\text{Log (Life)} = 0.59$   
 $R^2 = 71\%$

Sample Size = 29

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]



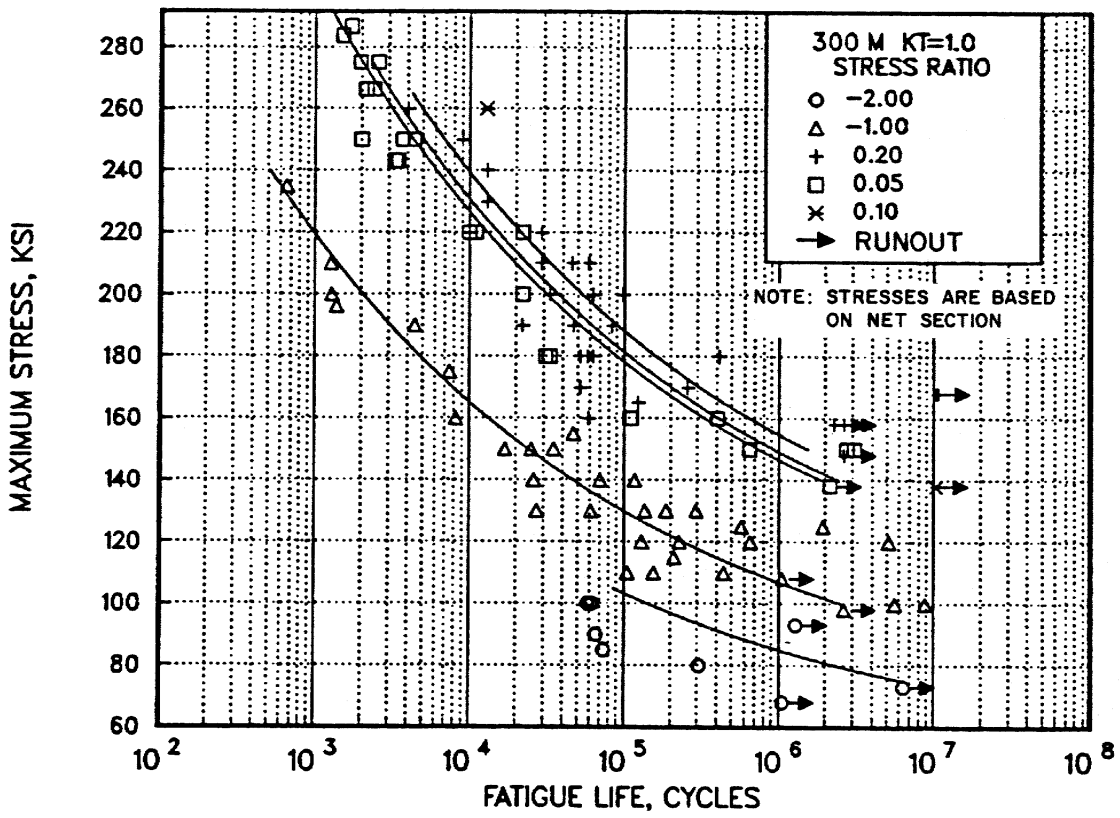


Figure 2.3.1.4.8(a). Best-fit S/N curves for unnotched 300M alloy forging,  $F_{tu} = 280$  ksi, longitudinal and transverse directions.

|                                                        |                                                                                                                                                    |                                                                                                                                                                                                                                                                     |
|--------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <u>Correlative Information for Figure 2.3.1.4.8(a)</u> |                                                                                                                                                    |                                                                                                                                                                                                                                                                     |
| <u>Product Forms:</u>                                  | Die forging, 10 x 20 inches<br>CEVM<br>Die forging, 6-1/2 x 20 inches<br>CEVM<br>RCS billet, 6 inches CEVM<br>Forged Bar, 1-1/4 x 8 inches<br>CEVM | <u>Test Parameters:</u><br>Loading - Axial<br>Frequency - 1800 to 2000 cpm<br>Temperature - RT<br>Atmosphere - Air<br><br><u>No. of Heat/Lots:</u> 6                                                                                                                |
| <u>Properties:</u>                                     | <u>TUS, ksi</u> <u>TYS, ksi</u> <u>Temp., °F</u><br><br>274-294    227-247    RT                                                                   | <u>Equivalent Stress Equation:</u><br>$\text{Log } N_f = 14.8 - 5.38 \text{ log } (S_{eq} - 63.8)$<br>$S_{eq} = S_a + 0.48 S_m$<br>Std. Error of Estimate, $\text{Log (Life)} = 55.7 (1/S_{eq})$<br>Standard Deviation, $\text{Log (Life)} = 1.037$<br>$R^2 = 82.0$ |
| <u>Specimen Details:</u>                               | Unnotched<br>0.200 - 0.250-inch diameter                                                                                                           | <u>Sample Size</u> = 104                                                                                                                                                                                                                                            |
| <u>Surface Condition:</u>                              | Heat treat and finish grind to a surface finish of RMS 63 or better with light grinding parallel to specimen length, stress relieve                | [Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]                                                                                                                                   |

References: 2.3.1.4.8(a), (c), (d), (e)

VIEW INTERACTIVE GRAPH

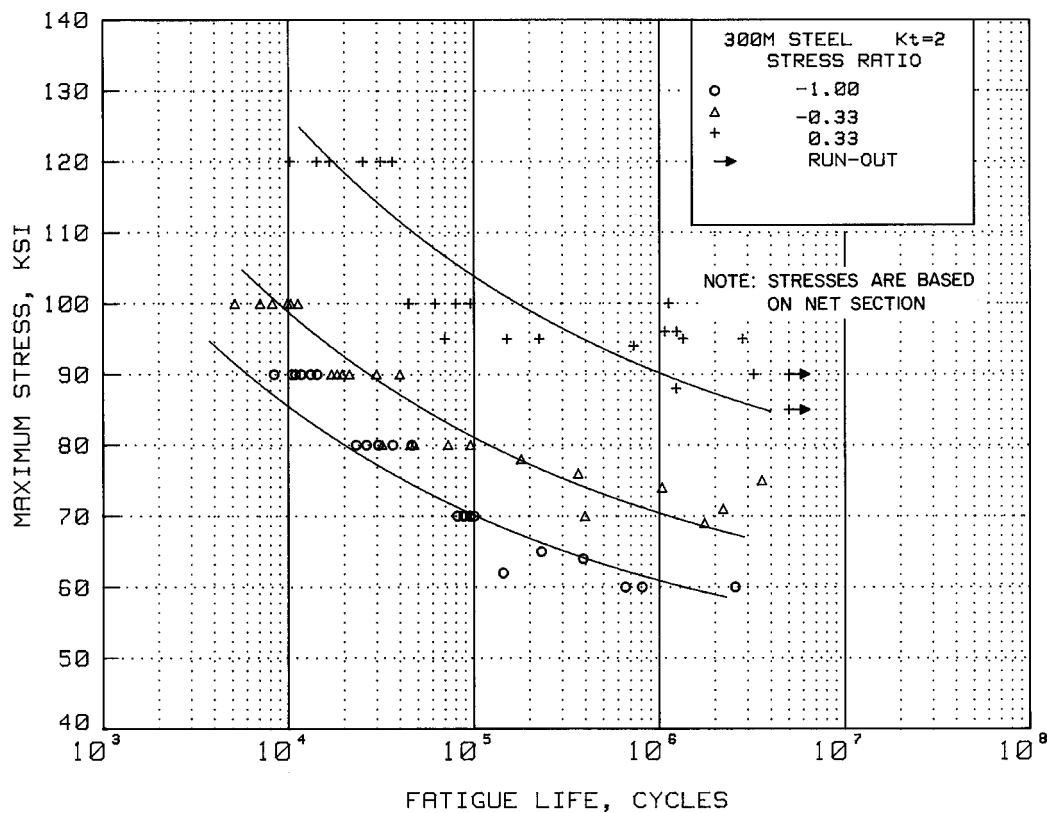


Figure 2.3.1.4.8(b). Best-fit S/N curves for unnotched,  $K_t = 2.0$ , 300M alloy forged billet,  $F_{tu} = 280$  ksi, longitudinal direction.

Correlative Information for Figure 2.3.1.4.8(b)

Product Form: Forged billet, unspecified size, CEVM

Properties: TUS, ksi 290 TYS, ksi 242 Temp., °F RT (unnotched)  
456 — RT (notched)

Specimen Details: Notched, 60° V-Groove,  $K_t = 2.0$   
0.500-inch gross diameter  
0.250-inch net diameter  
0.040-inch root radius,  $r$   
60° flank angle,  $\omega$

Surface Condition: Heat treat and finish grind notch to RMS  $63 \pm 5$ ; stress relieve

Reference: 2.3.1.4.8(b)

Test Parameters:  
Loading - Axial  
Frequency -  
Temperature - RT  
Atmosphere - Air

No. of Heats/Lots: 3

Equivalent Stress Equation:  
 $\log N_f = 12.87 - 5.08 \log (S_{eq} - 55.0)$   
 $S_{eq} = S_{max} (1 - R)^{0.36}$   
Standard Deviation in Life = 0.79  
 $R^2 = 79\%$

Sample Size = 70

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

VIEW INTERACTIVE GRAPH

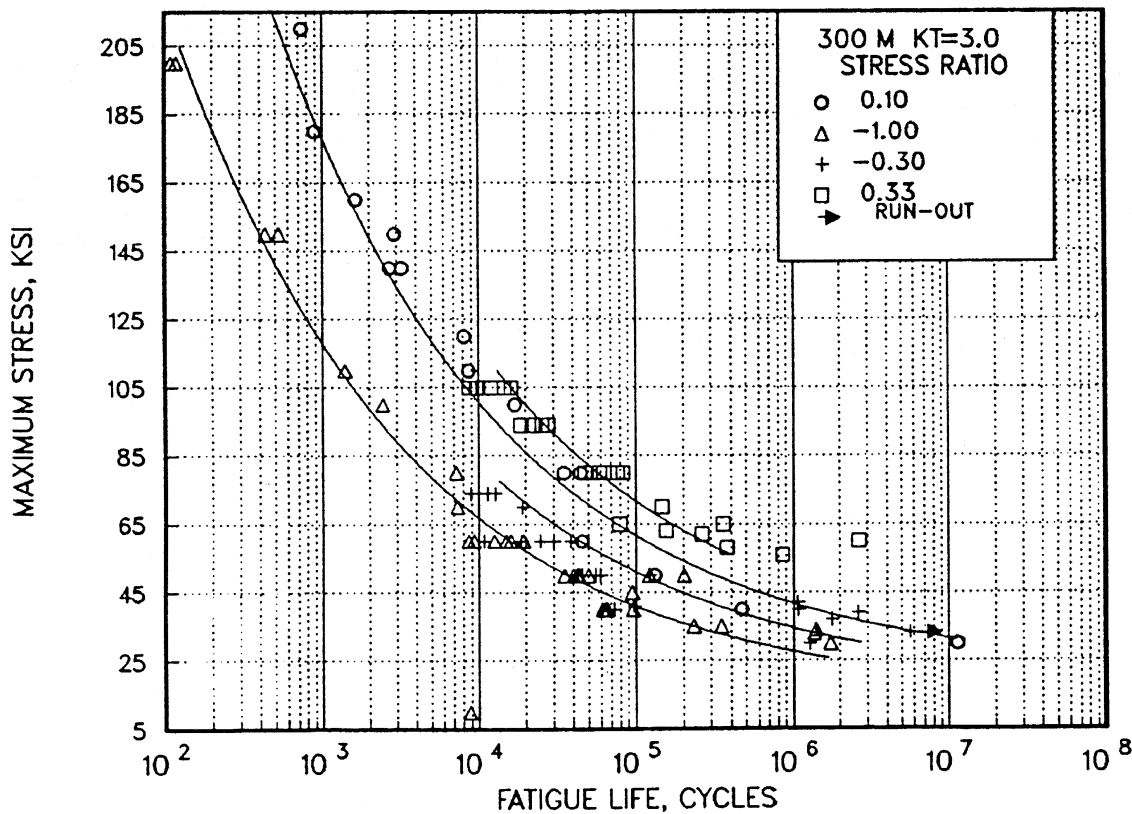


Figure 2.3.1.4.8(c). Best-fit S/N curves for notched,  $K_t = 3.0$ , 300M alloy forging,  $F_{tu} = 280$  ksi, longitudinal and transverse directions.

Correlative Information for Figure 2.3.1.4.8(c)

Product Forms: Forged billet, unspecified size,  
CEVM  
Die forging, 10 x 20 inches,  
CEVM  
Die forging, 6-1/2 x 20 inches,  
CEVM

Properties: TUS, ksi TYS, ksi Temp., °F  
290-292 242-247 RT  
(unnotched)  
435 — RT  
(notched)

Specimen Details: Notched 60° V-Groove,  
 $K_t = 3.0$   
0.500-inch gross diameter  
0.250-inch net diameter  
0.0145-inch root radius, r  
60° flank angle,  $\omega$

Surface Condition: Heat treat and finish grind  
notch to RMS 63 or better;  
stress relieve

References: 2.3.1.4.8(a), (b), (c)

Test Parameters:  
Loading - Axial  
Frequency -  
Temperature - RT  
Atmosphere - Air

No. of Heats/Lots: 5

Equivalent Stress Equation:  
 $\log N_f = 10.40 - 3.41 \log (S_{eq} - 20.0)$   
 $S_{eq} = S_{max} (1-R)^{0.51}$   
Std. Error of Estimate,  $\log (\text{Life}) = 18.3 (1/S_{eq})$   
Standard Deviation,  $\log (\text{Life}) = 2.100$   
 $R^2 = 97.4$

Sample Size = 99

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

1 December 1998

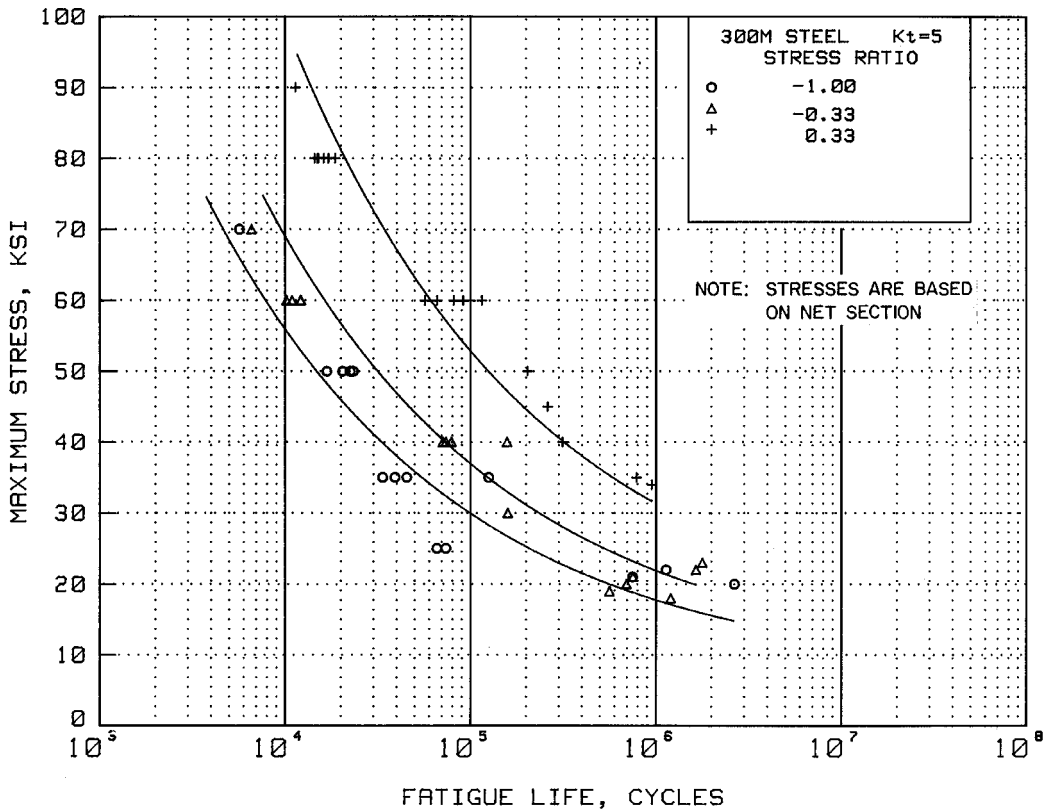
VIEW INTERACTIVE GRAPH

**Figure 2.3.1.4.8(d). Best-fit S/N curves for notched,  $K_t = 5.0$ , 300M alloy forged billet,  $F_{tu} = 280$  ksi, longitudinal direction.**

Correlative Information for Figure 2.3.1.4.8(d)

Product Forms: Forged billet, unspecified size,  
CEVM

Test Parameters:

Loading - Axial

Frequency -

Temperature - RT

Atmosphere - Air

Properties: TUS, ksi TYS, ksi Temp., °F  
290 242 RT  
(unnotched)  
379 — RT  
(notched)

No. of Heat/Lots: 2

Specimen Details: Notched, 60° V-Groove,  
 $K_t = 5.0$   
0.500-inch gross diameter  
0.250-inch net diameter  
0.0042-inch root radius,  $r$   
60° flank angle,  $\omega$

Equivalent Stress Equation:

$\log N_f = 9.61 - 3.04 \log (S_{eq} - 10.0)$

$S_{eq} = S_{max} (1-R)^{0.52}$

Standard Error of Estimate = 0.28

Standard Deviation in Life = 0.81

$R^2 = 88\%$

Surface Condition: Heat treat and finish grind  
notch to RMS 63 maximum;  
stress relieve

Sample Size = 48

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

Reference: 2.3.1.4.8(b)

[VIEW INTERACTIVE GRAPH](#)

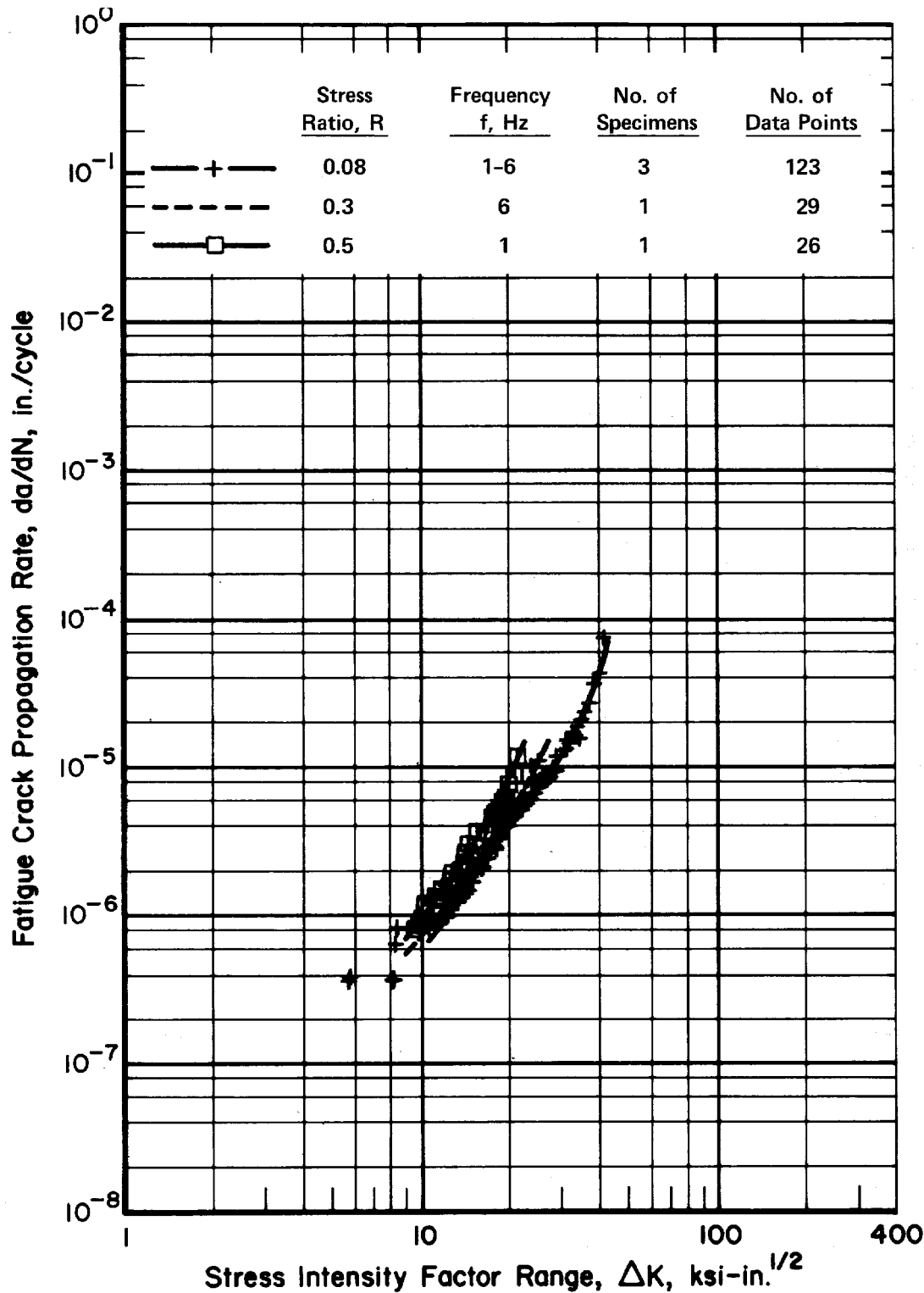


Figure 2.3.1.4.9. Fatigue-crack-propagation data for 3.00-inch hand forging and 1.80-inch thick, 300M steel alloy plate (TUS: 280-290 ksi.) [References - 2.3.1.4.9(a) and (b).]

|                     |                    |              |                  |
|---------------------|--------------------|--------------|------------------|
| Specimen Thickness: | 0.900-1.000 inches | Environment: | Low-humidity air |
| Specimen Width:     | 3.09-7.41 inches   | Temperature: | RT               |
| Specimen Type:      | CT                 | Orientation: | L-T and T-L      |

[VIEW INTERACTIVE GRAPH](#)

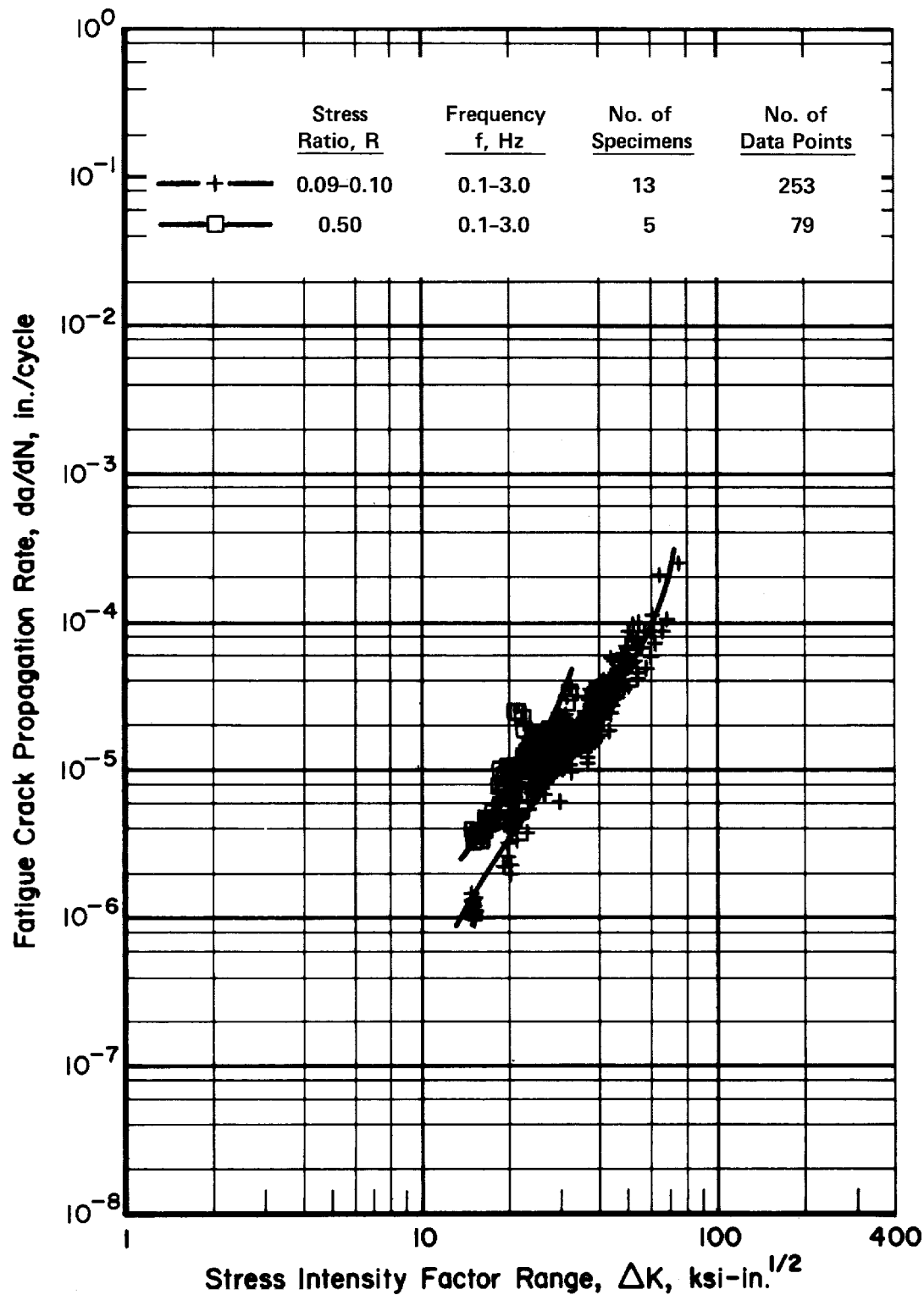


Figure 2.3.1.5.9. Fatigue-crack-propagation data for 0.80-inch D6AC steel alloy plate. Data include material both oil quenched and salt quenched (TUS: 230-240 ksi). [Reference - 2.3.1.5.9.]

|                     |                |              |                     |
|---------------------|----------------|--------------|---------------------|
| Specimen Thickness: | 0.70-0.75 inch | Environment: | Dry air and lab air |
| Specimen Width:     | 1.5-5.0 inches | Temperature: | RT                  |
| Specimen Type:      | CT             | Orientation: | L-T                 |

CHAPTER 3

ALUMINUM

3.1 GENERAL

This chapter contains the engineering properties and related characteristics of wrought and cast aluminum alloys used in aircraft and missile structural applications.

General comments on engineering properties and the considerations relating to alloy selection are presented in Section 3.1. Mechanical and physical property data and characteristics pertinent to specific alloy groups or individual alloys are reported in Sections 3.2 through 3.10. Element properties are presented in Section 3.11.

Aluminum is a lightweight, corrosion-resistant structural material that can be strengthened through alloying and, dependent upon composition, further strengthened by heat treatment and/or cold working [Reference 3.1(a)]. Among its advantages for specific applications are: low density, high strength-to-weight ratio, good corrosion resistance, ease of fabrication and diversity of form.

Wrought and cast aluminum and aluminum alloys are identified by a four-digit numerical designation, the first digit of which indicates the alloy group as shown in Table 3.1. For structural wrought aluminum alloys the last two digits identify the aluminum alloy. The second digit indicates modifications of the original alloy or impurity limits. For cast aluminum and aluminum alloys the second and third digits identify the aluminum alloy or indicate the minimum aluminum percentage. The last digit, which is to the right of the decimal point, indicates the product form: XXX.0 indicates castings, and XXX.1 and XXX.2 indicate ingot.

Table 3.1. Basic Designation for Wrought and Cast Aluminum Alloys  
[Reference 3.1(b)]

| Alloy Group | Major Alloying Elements        | Alloy Group | Major Alloying Groups                      |
|-------------|--------------------------------|-------------|--------------------------------------------|
|             | Wrought Alloys                 |             | Cast Alloys                                |
| 1XXX        | 99.00 percent minimum aluminum | 1XX.0       | 99.00 percent minimum aluminum             |
| 2XXX        | Copper                         | 2XX.0       | Copper                                     |
| 3XXX        | Manganese                      | 3XX.0       | Silicon with added copper and/or magnesium |
| 4XXX        | Silicon                        | 4XX.0       | Silicon                                    |
| 5XXX        | Magnesium                      | 5XX.0       | Magnesium                                  |
| 6XXX        | Magnesium and Silicon          | 6XX.0       | Unused Series                              |
| 7XXX        | Zinc                           | 7XX.0       | Zinc                                       |
| 8XXX        | Other Elements                 | 8XX.0       | Tin                                        |
| 9XXX        | Unused Series                  | 9XX.0       | Other Elements                             |

**Table 3.1.1. Aluminum Alloy Index**

| Section | Alloy Designation          | Section | Alloy Designation          |
|---------|----------------------------|---------|----------------------------|
| 3.2     | 2000 series wrought alloys | 3.6.3   | 6151                       |
| 3.2.1   | 2014                       | 3.7     | 7000 series wrought alloys |
| 3.2.2   | 2107                       | 3.7.1   | 7010                       |
| 3.2.3   | 2024                       | 3.7.2   | 7049/7149                  |
| 3.2.4   | 2025                       | 3.7.3   | 7050                       |
| 3.2.5   | 2090                       | 3.7.4   | 7075                       |
| 3.2.6   | 2124                       | 3.7.5   | 7150                       |
| 3.2.7   | 2219                       | 3.7.6   | 7175                       |
| 3.2.8   | 2519                       | 3.7.7   | 7249                       |
| 3.2.9   | 2618                       | 3.7.8   | 7475                       |
| 3.3     | 3000 series wrought alloys | 3.8     | 200.0 series cast alloys   |
| 3.4     | 4000 series wrought alloys | 3.8.1   | A201.0                     |
| 3.5     | 5000 series wrought alloys | 3.9     | 300.0 series cast alloys   |
| 3.5.1   | 5052                       | 3.9.1   | 354.0                      |
| 3.5.2   | 5083                       | 3.9.2   | 355.0                      |
| 3.5.3   | 5086                       | 3.9.3   | C355.0                     |
| 3.5.4   | 5454                       | 3.9.4   | 356.0                      |
| 3.5.5   | 5456                       | 3.9.5   | A356.0                     |
| 3.6     | 6000 series wrought alloys | 3.9.6   | A357.0                     |
| 3.6.1   | 6013                       | 3.9.7   | D357.0                     |
| 3.6.2   | 6061                       | 3.9.8   | 359.0                      |

**3.1.1 ALUMINUM ALLOY INDEX** — The layout of this chapter is in accordance with this four-digit number system for both wrought and cast alloys [Reference 3.1(b)]. Table 3.1.1 is the aluminum alloy index that illustrates both the general section layout as well as details of those specific aluminum alloys presently contained in this chapter. The wrought alloys are in Sections 3.2 through 3.7; whereas the cast alloys are in Sections 3.8 and 3.9.

**3.1.2 MATERIAL PROPERTIES** — The properties of the aluminum alloys are determined by the alloy content and method of fabrication. Some alloys are strengthened principally by cold work, while others are strengthened principally by solution heat treatment and precipitation hardening [Reference 3.1(a)]. The temper designations, shown in Table 3.1.2 (which is based on Reference 3.1.2), are indicative of the type of strengthening mechanism employed.

Among the properties presented herein, some, such as the room-temperature, tensile, compressive, shear and bearing properties, are either specified minimum properties or derived minimum properties related directly to the specified minimum properties. They may be directly useful in design. Data on the effect of temperature on properties are presented so that percentages may be applied directly to the room-temperature minimum properties. Other properties, such as the stress-strain curve, fatigue and fracture toughness data, and modulus of elasticity values, are presented as average or typical values, which may be used in assessing the usefulness of the material for certain applications. Comments on the effect of temperature on properties are given in Sections 3.1.2.1.7 and 3.1.2.1.8; comments on the corrosion resistance are given in Section 3.1.2.3; and comments on the effects of manufacturing practices on these properties are given in Section 3.1.3.



**Table 3.1.2. Temper Designation System for Aluminum Alloys**

| Temper Designation System <sup>ab</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | the period of natural aging is indicated: for example, W ½ hr.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>The temper designation system is used for all forms of wrought and cast aluminum and aluminum alloys except ingot. It is based on the sequences of basic treatments used to produce the various tempers. The temper designation follows the alloy designation, the two being separated by a hyphen. Basic temper designations consist of letters. Subdivisions of the basic tempers, where required, are indicated by one or more digits following the letter. These designate specific sequences of basic treatments, but only operations recognized as significantly influencing the characteristics of the product are indicated. Should some other variation of the same sequence of basic operations be applied to the same alloy, resulting in different characteristics, then additional digits are added to the designation.</p> | <p><b>T thermally treated to produce stable tempers other than F, O, or H.</b> Applies to products which are thermally treated, with or without supplementary strain-hardening, to produce stable tempers. The T is always followed by one or more digits.</p>                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>Basic Temper Designations</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | <b>Subdivisions of H Temper: Strain-hardened.</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <p><b>F as fabricated.</b> Applies to the products of shaping processes in which no special control over thermal conditions or strain-hardening is employed. For wrought products, there are no mechanical property limits.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | <p>The first digit following H indicates the specific combination of basic operations, as follows:</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <p><b>O annealed.</b> Applies to wrought products which are annealed to obtain the lowest strength temper, and to cast products which are annealed to improve ductility and dimensional stability. The O may be followed by a digit other than zero.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | <p><b>H1 strain-hardened only.</b> Applies to products which are strain-hardened to obtain the desired strength without supplementary thermal treatment. The number following this designation indicates the degree of strain-hardening.</p>                                                                                                                                                                                                                                                                                                                                                                                                               |
| <p><b>H strain-hardened (wrought products only).</b> Applies to products which have their strength increased by strain-hardening, with or without supplementary thermal treatments to produce some reduction in strength. The H is always followed by two or more digits.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | <p><b>H2 strain-hardened and partially annealed.</b> Applies to products which are strain-hardened more than the desired final amount and then reduced in strength to the desired level by partial annealing. For alloys that age-soften at room temperature, the H2 tempers have the same minimum ultimate tensile strength as the corresponding H3 tempers. For other alloys, the H2 tempers have the same minimum ultimate tensile strength as the corresponding H1 tempers and slightly higher elongation. The number following this designation indicates the degree of strain-hardening remaining after the product has been partially annealed.</p> |
| <p><b>W solution heat-treated.</b> An unstable temper applicable only to alloys which spontaneously age at room temperature after solution heat-treatment. This designation is specific only when</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | <p><b>H3 strain-hardened and stabilized.</b> Applies to products which are strain-hardened and whose mechanical properties are stabilized either by a low temperature thermal treatment or as a result</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                 |

a From reference 3.1.2.

b Temper designations conforming to this standard for wrought aluminum and wrought aluminum alloys, and aluminum alloy castings may be registered with the Aluminum Association provided: (1) the temper is used or is available for use by more than one user, (2) mechanical property limits are registered, (3) characteristics of the temper are significantly different from those of all other tempers which have the same sequence of basic treatments and for which designations already have been assigned for the same alloy and product, and (4) the following are also registered if characteristics other than mechanical properties are considered significant: (a) test methods and limits for the characteristics or (b) the specific practices used to produce the temper.

Table 3.1.2. Temper Designation System for Aluminum Alloys - Continued

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>of heat introduced during fabrication. Stabilization usually improves ductility. This designation is applicable only to those alloys which, unless stabilized, gradually age-soften at room temperature. The number following this designation indicates the degree of strain-hardening remaining after the stabilization treatment.</p> <p>The digit following the designations H1, H2, and H3 indicates the degree of strain hardening. Numeral 8 has been assigned to indicate tempers having an ultimate tensile strength equivalent to that achieved by a cold reduction (temperature during reduction not to exceed 120°F) of approximately 75 percent following a full anneal. Tempers between O (annealed) and 8 are designated by numerals 1 through 7. Material having an ultimate tensile strength about midway between that of the O temper and that of the 8 temper is designated by the numeral 4; about midway between the O and 4 tempers by the numeral 2; and about midway between 4 and 8 tempers by the numeral 6. Numeral 9 designates tempers whose minimum ultimate tensile strength exceeds that of the 8 temper by 2.0 ksi or more. For two-digit H tempers whose second digit is odd, the standard limits for ultimate tensile strength are exactly midway between those of the adjacent two digit H tempers whose second digits are even.</p> <p>NOTE: For alloys which cannot be cold reduced an amount sufficient to establish an ultimate tensile strength applicable to the 8 temper (75 percent cold reduction after full anneal), the 6 temper tensile strength may be established by a cold reduction of approximately 55 percent following a full anneal, or the 4 temper tensile strength may be established by a cold reduction of approximately 35 percent after a full anneal.</p> <p>The third digit<sup>c</sup>, when used, indicates a variation of a two-digit temper. It is used when the degree of control of temper or the mechanical properties or both differ from, but are close to, that (or those) for the two-digit H temper designation to which it is</p> | <p>added, or when some other characteristic is significantly affected.</p> <p>NOTE: The minimum ultimate tensile strength of a three-digit H temper must be at least as close to that of the corresponding two-digit H temper as it is to the adjacent two-digit H tempers. Products of the H temper whose mechanical properties are below H_1 shall be variations of H_1.</p> <p><b>Three-digit H Tempers</b></p> <p><b>H_11</b> Applies to products which incur sufficient strain hardening after the final anneal that they fail to qualify as annealed but not so much or so consistent an amount of strain hardening that they qualify as H_1.</p> <p><b>H112</b> Applies to products which may acquire some temper from working at an elevated temperature and for which there are mechanical property limits.</p> <p><b>Subdivisions of T Temper:<br/>Thermally Treated</b></p> <p>Numerals 1 through 10 following the T indicate specific sequences of basic treatments, as follows.<sup>d</sup></p> <p><b>T1 cooled from an elevated temperature shaping process and naturally aged to a substantially stable condition.</b> Applies to products which are not cold worked after cooling from an elevated temperature shaping process, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.</p> <p><b>T2 cooled from an elevated temperature shaping process, cold worked and naturally aged to a substantially stable condition.</b> Applies to products which are cold worked to improve strength after cooling from an elevated temperature shaping process, or in which the effect of</p> |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

c Numerals 1 through 9 may be arbitrarily assigned as the third digit and registered with The Aluminum Association for an alloy and product to indicate a variation of a two-digit H temper (see footnote b).

d A period of natural aging at room temperature may occur between or after the operations listed for the T tempers. Control of this period is exercised when it is metallurgically important.

**Table 3.1.2. Temper Designation System for Aluminum Alloys - Continued**

|                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                      |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| cold work in flattening or straightening is recognized in mechanical property limits.                                                                                                                                                                                                                                          | artificially aged after solution heat-treatment to provide dimensional and strength stability.                                                                                                                                                                                       |
| <b>T3 solution heat-treated<sup>e</sup>, cold worked, and naturally aged to a substantially stable condition.</b> Applies to products which are cold worked to improve strength after solution heat-treatment, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits. | <b>T8 solution heat-treated<sup>e</sup>, cold worked, and artificially aged.</b> Applies to products which are cold worked to improve strength, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.                      |
| <b>T4 solution heat-treated<sup>e</sup> and naturally aged to a substantially stable condition.</b> Applies to products which are not cold worked after solution heat-treatment, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.                       | <b>T9 solution heat-treated<sup>e</sup>, artificially aged, and cold worked.</b> Applies to products which are cold worked to improve strength.                                                                                                                                      |
| <b>T5 cooled from an elevated temperature shaping process and artificially aged.</b> Applies to products which are not cold worked after cooling from an elevated temperature shaping process, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.         | <b>T10 cooled from an elevated temperature shaping process, cold worked, and artificially aged.</b> Applies to products which are cold worked to improve strength, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.   |
| <b>T6 solution heat-treated<sup>e</sup> and artificially aged.</b> Applies to products which are not cold worked after solution heat-treatment or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.                                                         | Additional digits <sup>f</sup> , the first of which shall not be zero, may be added to designations T1 through T10 to indicate a variation in treatment which significantly alters the product characteristics <sup>g</sup> that are or would be obtained using the basic treatment. |
| <b>T7 solution heat-treated<sup>e</sup> and overaged/stabilized.</b> Applies to wrought products that are artificially aged after solution heat-treatment to carry them beyond a point of maximum strength to provide control of some significant characteristic. Applies to cast products that are                            | The following specific additional digits have been assigned for stress-relieved tempers of wrought products:<br><br><b>Stress Relieved by Stretching</b>                                                                                                                             |
|                                                                                                                                                                                                                                                                                                                                | <b>T_51</b> Applies to plate and rolled or cold-finished rod and bar when stretched the indicated amounts after solution heat-treatment or after cooling from an elevated temperature shaping process. The products receive no further straightening after stretching.               |

- e Solution heat treatment is achieved by heating cast or wrought products to a suitable temperature, holding at that temperature long enough to allow constituents to enter into solid solution and cooling rapidly enough to hold the constituents in solution. Some 6000 series alloys attain the same specified mechanical properties whether furnace solution heat-treated or cooled from an elevated temperature shaping process at a rate rapid enough to hold constituents in solution. In such cases the temper designations T3, T4, T6, T7, T8, and T9 are used to apply to either process and are appropriate designations.
- f Additional digits may be arbitrarily assigned and registered with the Aluminum Association for an alloy and product to indicate a variation of tempers T1 through T10 even though the temper representing the basic treatment has not been registered (see footnote b). Variations in treatment which do not alter the characteristics of the product are considered alternate treatments for which additional digits are not assigned.
- g For this purpose, characteristic is something other than mechanical properties. The test method and limit used to evaluate material for this characteristic are specified at the time of the temper registration.

Table 3.1.2. Temper Designation System for Aluminum Alloys - Continued

|                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                    |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Plate .... 1½ to 3% permanent set.<br>Rolled or Cold-Finished<br>Rod and Bar .... 1 to 3% permanent set.<br>Die or Ring Forgings<br>and Rolled Rings .... 1 to 5% permanent set.                                                                                                 | The following temper designations have been assigned for wrought product test material heat-treated from annealed (O, O1, etc.) or F temper. <sup>h</sup>                                                                                                                                                                                                                                          |
| <b>T_510</b> Applies to extruded rod, bar, shapes and tube and to drawn tube when stretched the indicated amounts after solution heat-treatment or after cooling from an elevated temperature shaping process. These products receive no further straightening after stretching. | <b>T42 Solution heat-treated from annealed or F temper and naturally aged to a substantially stable condition.</b>                                                                                                                                                                                                                                                                                 |
| Extruded Rod, Bar, Shapes<br>and Tube .... 1 to 3% permanent set.<br>Drawn Tube .... ½ to 3% permanent set.                                                                                                                                                                      | <b>T62 Solution heat-treated from annealed or F temper and artificially aged.</b>                                                                                                                                                                                                                                                                                                                  |
|                                                                                                                                                                                                                                                                                  | Temper designations T42 and T62 may also be applied to wrought products heat-treated from any temper by the user when such heat-treatment results in the mechanical properties applicable to these tempers.                                                                                                                                                                                        |
|                                                                                                                                                                                                                                                                                  | <b>Variations of O Temper: Annealed</b>                                                                                                                                                                                                                                                                                                                                                            |
|                                                                                                                                                                                                                                                                                  | A digit following the O, when used, indicates a product in the annealed condition have special characteristics. NOTE: As the O temper is not part of the strain-hardened (H) series, variations of O temper shall not apply to products which are strain-hardened after annealing and in which the effect of strain-hardening is recognized in the mechanical properties or other characteristics. |
|                                                                                                                                                                                                                                                                                  | <b>Assigned O Temper Variations</b>                                                                                                                                                                                                                                                                                                                                                                |
|                                                                                                                                                                                                                                                                                  | The following temper designation has been assigned for wrought products high temperature annealed to accentuate ultrasonic response and provide dimensional stability.                                                                                                                                                                                                                             |
|                                                                                                                                                                                                                                                                                  | <b>O1 Thermally treated at approximately same time and temperature required for solution heat treatment and slow cooled to room temperature. Applicable to products which are to be machined prior to solution heat treatment by the user. Mechanical Property limits are not applicable.</b>                                                                                                      |
|                                                                                                                                                                                                                                                                                  | <b>Designation of Unregistered Tempers</b>                                                                                                                                                                                                                                                                                                                                                         |
|                                                                                                                                                                                                                                                                                  | The letter P has been assigned to denote H, T and O temper variations that are negotiated between manufacturer and purchaser. The letter P immediately follows the temper designation that                                                                                                                                                                                                         |

<sup>h</sup> When the user requires capability demonstrations from T-temper, the seller shall note "capability compliance" adjacent to the specified ending tempers. Some examples are: "-T4 to -T6 Capability Compliance as for aging" or "-T351 to -T4 Capability Compliance as for resolution heat treating."

**Table 3.1.2. Temper Designation System for Aluminum Alloys - Continued**

|                                                                                                                                                                     |                                                                                                                                                                                 |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| most nearly pertains. Specific examples where such designation may be applied include the following:                                                                | The test conditions (sampling location, number of samples, test specimen configuration, etc.) are different from those required for registration with the Aluminum Association. |
| The use of the temper is sufficiently limited so as to preclude its registration. (Negotiated H temper variations were formerly indicated by the third digit zero.) | The mechanical property limits are not established on the same basis as required for registration with the Aluminum Association.                                                |

It should be recognized not all combinations of stress and environment have been investigated, and it may be necessary to evaluate an alloy under the specific conditions involved for certain critical applications.

**3.1.2.1.1 Strength (Tension, Compression, Shear, Bearing)** — The design strength properties at room temperature are listed at the beginning of the section covering the properties of an alloy. The effect of temperature on these properties is indicated in figures which follow the tables.

The A- and B-basis values for tensile properties for the direction associated with the specification requirements are based upon a statistical analysis of production quality control data obtained from specimens tested in accordance with procurement specification requirements. For sheet and plate of heat-treatable alloys, the specified minimum values are for the long-transverse (LT) direction, while for sheet and plate of nonheat treatable alloys and for rolled, drawn, or extruded products, the specified minimum values are for the longitudinal (L) direction. For forgings, the specified minimum values are stated for at least two directions. The design tensile properties in other directions and the compression, shear, and bearing properties are “derived” properties, based upon the relationships among the properties developed by tests of at least ten lots of material and applied to the appropriate established A, B, or S properties. All of these properties are representative of the regions from which production quality control specimens are taken, but may not be representative of the entire cross section of products appreciably thicker than the test specimen or products of complex cross sections.

Tensile and compressive strengths are given for the longitudinal, long-transverse, and short-transverse directions wherever data are available. Short-transverse strengths may be relatively low, and transverse properties should not be assumed to apply to the short-transverse direction unless so stated. In those instances where the direction in which the material will be used is not known, the lesser of the applicable longitudinal or transverse properties should be used.

Bearing strengths are given without reference to direction and may be assumed to be about the same in all directions, with the exception of plate, die forging, and hand forging. A reduction factor is used for edgewise bearing load in thick bare and clad plate of 2000 and 7000 series alloys. The results of bearing tests on longitudinal and long-transverse specimens taken edgewise from plate, die forging, and hand forging have shown that the edgewise bearing strengths are substantially lower than those of specimens taken parallel to the surface. The bearing specimen orientations in thick plate are shown in Figure 3.1.2.1.1(a). For plate, bearing specimens are oriented so that the width of the specimen is parallel to the surfaces of the plate (flatwise); consequently, in cases where the stress condition approximates that of the longitudinal or long-transverse edgewise orientations, the reductions in design values shown in Table 3.1.2.1.1 should be made.

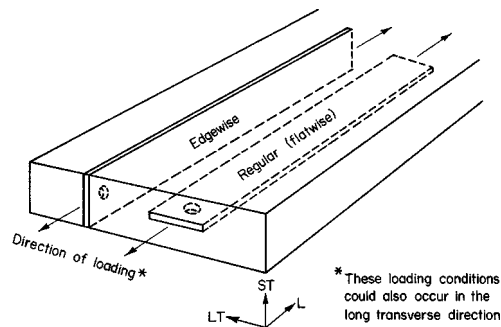


Figure 3.1.2.1.1(a). Bearing specimen orientation in thick plate.

Table 3.1.2.1.1. Bearing Property Reductions for Thick Plate of 2000 and 7000 Series Alloys.

| Thickness (in.) ...   | Bearing Property Reduction, percent |
|-----------------------|-------------------------------------|
|                       | 1.001-6.000                         |
| $F_{bru}$ (e/D = 1.5) | 15                                  |
| $F_{bru}$ (e/D = 2.0) | 10                                  |
| $F_{bry}$ (e/D = 1.5) | 5                                   |
| $F_{bry}$ (e/D = 2.0) | 5                                   |

It should be noted that in recent years, bearing data have been presented from tests made in accordance with ASTM E 238 which requires clean pins and specimens. See Reference 3.1.2.1.1 for additional information. Designers should consider a reduction factor in applying these values to structural analyses.

For die and hand forgings, bearing specimens are taken edgewise so that no reduction factor is necessary. In the case of die forgings, the location of bearing specimens is shown in Figures 3.1.2.1.1(b) and (c). For die forgings with cross-sectional shapes in the form of an I-beam or a channel, longitudinal bearing specimens are oriented so the width of the specimens is normal to the parting plane (edgewise). The specimens are positioned so the bearing test holes are midway between the parting plane and the top of the flange. The severity of metal flow at the parting plane near the flash can be expected to vary considerably for web-flange type die forgings; therefore, for consistency, the bearing test hole should not be located on the parting plane. However, in the case of large, bulky-type die forgings, with a cross-sectional shape similar to a square, rectangle, or trapezoid, as shown in Figure 3.1.2.1.1(c), longitudinal bearing specimens are oriented edgewise to the parting plane, but the specimens are positioned so the bearing test holes are located on the parting plane. Similarly, for hand forgings, bearing specimens are oriented edgewise and the specimens are positioned at the ½ thickness location.

Shear strengths also vary to some extent with plane of shear and direction of loading but the differences are not so consistent [Reference 3.1.2.1.1(c)]. The standard test method for the determination of shear strength of aluminum alloy products, 3/16 inch and greater in thickness, is contained in ASTM B 769.

Shear strength values are presented without reference to grain direction, except for hand forgings. For products other than hand forgings, the lowest shear strength exhibited by tests in the various grain

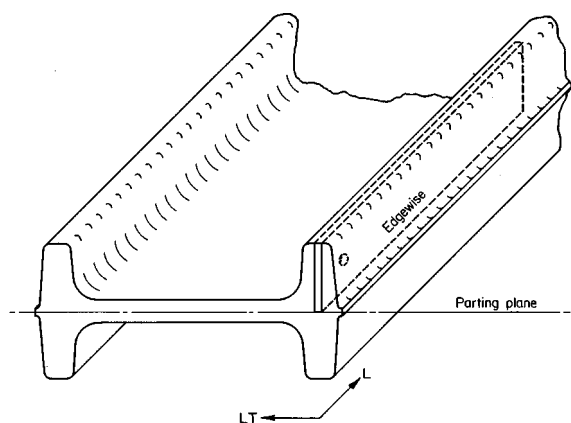


**Figure 3.1.2.1.1(b). Bearing specimen orientation for web-flange type die forging.**

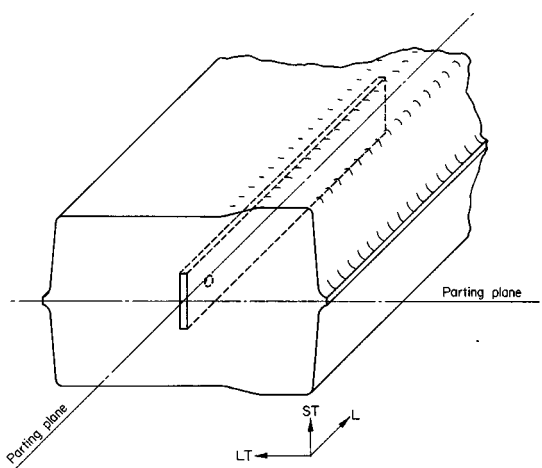


**Figure 3.1.2.1.1(c). Bearing specimen orientation for thick cross-section die forging.**

directions is the design value. For hand forgings, the shear strength in short-transverse direction may be significantly lower than for the other two grain directions. Consequently, the shear strength for hand forgings is presented for each grain direction.

For clad sheet and plate (i.e., containing thin surface layers of material of a different composition for added corrosion protection), the strength values are representative of the composite (i.e., the cladding and the core). For sheet and thin plate ( $\geq 0.499$  inch), the quality-control test specimens are of the full thickness, so that the guaranteed tensile properties and the associated derived values for these products directly represent the composite. For plate  $\geq .500$  inch in thickness, the quality-control test specimens are machined from the core so the guaranteed tensile properties in specifications reflect the core material only, not the composite. Therefore, the design tensile properties for the thicker material are obtained by adjustment of the specification tensile properties and the other related properties to represent the composite, using the nominal total cladding thickness and the typical tensile properties of the cladding material.

For clad aluminum sheet and plate products, it is also important to distinguish between primary and secondary modulus values. The initial, or primary, modulus represents an average of the elastic moduli of the core and cladding; it applies only up to the proportional limit of the cladding. For example, the primary modulus of 2024-T3 clad sheet applies only up to about 6 ksi. Similarly, the primary modulus of 7075-T6 clad sheet applies only up to approximately 12 ksi. A typical use of primary moduli is for low amplitude, high frequency fatigue.

**3.1.2.1.2 Elongation** — Elongation values are included in the tables of room-temperature mechanical properties. In some cases where the elongation is a function of material thickness, a supplemental table is provided. Short-transverse elongations may be relatively low, and long-transverse values should not be assumed to apply to the short-transverse direction.

**3.1.2.1.3 Stress-Strain Relationship** — The stress-strain relationships presented, which include elastic and compressive tangent moduli, are typical curves based on three or more lots of test data. Being typical, these curves will not correspond to yield strength data presented as design allowables (minimum values). However, the stress-strain relationships are no less useful, since there are well-known methods for using these curves in design by reducing them to a minimum curve affine to the typical curve or by using Ramberg-Osgood parameters obtained from the typical curves.

**3.1.2.1.4 Creep and Stress Rupture** — Sustained stressing at elevated temperature sufficient to result in appreciable amounts of creep deformation (e.g., more than 0.2 percent) may result in decreased strength and ductility. It may be necessary to evaluate an alloy under its stress-temperature environment for critical applications where sustained loading is anticipated (see Reference 3.1.2.1.4).

**3.1.2.1.5 Fatigue** — Fatigue S/N curves are presented for those alloys for which sufficient data are available. Data for both smooth and notched specimens are presented. The data from which the curves were developed were insufficient to establish scatter bands and do not have the statistical reliability of the room-temperature mechanical properties; the values should be considered to be representative for the respective alloys.

The fatigue strengths of aluminum alloys, with both notched and unnotched specimens, are at least as high or higher at subzero temperatures than at room temperature [References 3.1.2.1.5(a) through (c)]. At elevated temperatures, the fatigue strengths are somewhat lower than at room temperature, the difference increasing with increase in temperature.

The data presented do not apply directly to the design of structures because they do not take into account the effect of stress raisers such as reentrant corners, notches, holes, joints, rough surfaces, and other similar conditions which are present in fabricated parts. The localized high stresses induced in fabricated parts by such stress raisers are of much greater importance for repeated loading than they are for static loading and may reduce the fatigue life of fabricated parts far below that which would be predicted by comparing the smooth-specimen fatigue strength directly with the nominal calculated stresses for the parts in question. See References 3.1.2.1.5 (d) through (q) for information on how to use high-strength aluminum alloys, Reference 3.1.2.1.5(r) for details on the static and fatigue strengths of high-strength aluminum-alloy bolted joints, Reference 3.1.2.1.5(s) for single-rivet fatigue-test data, and Reference 1.4.9.3(b) for a general discussion of designing for fatigue. Fatigue-crack-growth data are presented in the various alloy sections.

**3.1.2.1.6 Fracture Toughness** — Typical values of plane-strain fracture toughness,  $K_{Ic}$ , [Reference 3.1.2.1.6(a)] for the high-strength aluminum alloy products are presented in Table 3.1.2.1.6. Minimum, average, and maximum values as well as coefficient of variation are presented for the alloys and tempers for which valid data are available [References 3.1.2.1.6(b) through (j)]. Although representative, these values do not have the statistical reliability of the room-temperature mechanical properties.

Graphic displays of the residual strength behavior of center-cracked tension panels are presented in the various alloy sections. The points denote the experimental data from which the curve of fracture toughness was derived.

**3.1.2.1.7 Cryogenic Temperatures** — In general, the strengths (including fatigue strengths) of aluminum alloys increase with decrease in temperature below room temperature [References 3.1.2.1.7(a) and (b)]. The increase is greatest over the range from about -100 to -423° F (liquid hydrogen temperature); the strengths at -452° F (liquid helium temperature) are nearly the same as at -423° F [References 3.1.2.1.7(c) and (d)]. For most alloys, elongation and various indices of toughness remain nearly constant or increase with decrease in temperature, while for the 7000 series, modest reductions are observed [References 3.1.2.1.7(d) and (e)]. None of the alloys exhibit a marked transition in fracture resistance over a narrow range of temperature indicative of embrittlement.



**Table 3.1.2.1.6. Values of Room-Temperature Plane-Strain Fracture Toughness of Aluminum Alloys<sup>a</sup>**

| Alloy/Temper <sup>b</sup> | Product Form | Orientation <sup>c</sup> | Product Thickness Range, inches | Number of Sources | Sample Size | Specimen Thickness Range, inches | K <sub>IC</sub> , ksi $\sqrt{\text{in.}}$ |      |      |                          |                             |
|---------------------------|--------------|--------------------------|---------------------------------|-------------------|-------------|----------------------------------|-------------------------------------------|------|------|--------------------------|-----------------------------|
|                           |              |                          |                                 |                   |             |                                  | Max.                                      | Avg. | Min. | Coefficient of Variation | Minimum Specification Value |
| 2014-T651                 | Plate        | L-T                      | $\geq 0.5$                      | 1                 | 24          | 0.5-1.0                          | 25                                        | 22   | 19   | 8.4                      |                             |
| 2014-T651                 | Plate        | T-L                      | $\geq 0.5$                      | 2                 | 34          | 0.5-1.0                          | 23                                        | 21   | 18   | 6.5                      |                             |
| 2014-T652                 | Hand Forging | L-T                      | $\geq 0.5$                      | 2                 | 15          | 0.8-2.0                          | 48                                        | 31   | 24   | 21.8                     |                             |
| 2014-T652                 | Hand Forging | T-L                      | $\geq 0.8$                      | 2                 | 15          | 0.8-2.0                          | 30                                        | 21   | 18   | 14.4                     |                             |
| 2024-T351                 | Plate        | L-T                      | $\geq 1.0$                      | 2                 | 11          | 0.8-2.0                          | 43                                        | 31   | 27   | 16.5                     |                             |
| 2024-T851                 | Plate        | L-S                      | 1.4-3.0                         | 4                 | 11          | 0.5-0.8                          | 32                                        | 25   | 20   | 17.8                     |                             |
| 2024-T851                 | Plate        | L-T                      | $\geq 0.5$                      | 11                | 102         | 0.4-1.4                          | 32                                        | 23   | 15   | 10.1                     |                             |
| 2024-T851                 | Plate        | T-L                      | 0.4-4.0                         | 9                 | 80          | 0.4-1.4                          | 25                                        | 20   | 18   | 8.8                      |                             |
| 2024-T852                 | Forging      | T-L                      | 2.0-7.0                         | 3                 | 20          | 0.7-2.0                          | 25                                        | 19   | 15   | 15.5                     |                             |
| 2024-T852                 | Hand Forging | L-T                      | ----                            | 4                 | 35          | 0.8-2.0                          | 38                                        | 28   | 19   | 18.4                     |                             |
| 2024-T852                 | Hand Forging | T-L                      | ----                            | 2                 | 17          | 0.7-2.0                          | 22                                        | 18   | 14   | 14.4                     |                             |
| 2124-T851                 | Plate        | L-T                      | $\geq 0.8$                      | 13                | 497         | 0.5-2.5                          | 38                                        | 29   | 18   | 10.4                     | 24                          |
| 2124-T851                 | Plate        | T-L                      | 0.6-6.0                         | 10                | 509         | 0.5-2.0                          | 32                                        | 25   | 19   | 9.7                      | 20                          |
| 2124-T851                 | Plate        | S-L                      | $\geq 0.5$                      | 6                 | 489         | 0.3-1.5                          | 27                                        | 21   | 16   | 9.8                      | 18                          |
| 2219-T851                 | Plate        | L-T                      | ----                            | 4                 | 67          | 1.0-2.5                          | 38                                        | 33   | 30   | 7.2                      |                             |
| 2219-T851                 | Plate        | T-L                      | $\geq 1.0$                      | 6                 | 108         | 0.8-2.5                          | 37                                        | 29   | 20   | 10.1                     |                             |
| 2219-T851                 | Plate        | S-L                      | $\geq 0.8$                      | 3                 | 24          | 0.5-1.5                          | 26                                        | 22   | 20   | 9.6                      |                             |
| 2219-T851                 | Forging      | S-L                      | ----                            | 1                 | 85          | 1.0-1.5                          | 34                                        | 25   | 19   | 12.1                     |                             |
| 2219-T851 1               | Extrusion    | T-L                      | ----                            | 1                 | 19          | 1.8-2.0                          | 34                                        | 29   | 23   | 12.3                     |                             |
| 2219-T852                 | Forging      | S-L                      | ----                            | 2                 | 60          | 0.8-2.0                          | 35                                        | 25   | 20   | 12.1                     |                             |
| 2219-T852                 | Hand Forging | L-T                      | ----                            | 2                 | 32          | 1.5-2.5                          | 46                                        | 38   | 30   | 9.7                      |                             |
| 2219-T852                 | Hand Forging | T-L                      | $\geq 1.5$                      | 2                 | 28          | 1.5-2.5                          | 30                                        | 27   | 22   | 8.4                      |                             |
| 2219-T87                  | Plate        | L-T                      | $\geq 1.5$                      | 3                 | 11          | 0.8-2.0                          | 34                                        | 27   | 25   | 9.3                      |                             |
| 2219-T87                  | Plate        | T-L                      | ----                            | 1                 | 11          | 1.0                              | 22                                        | 22   | 19   | 3.9                      | 31                          |
| 7040-T7451                | Plate        | L-T                      | 3-4                             | 1                 | 16          | 2                                | 39                                        | 37   | 34   | 5.2                      | 26                          |
| 7040-T7451                | Plate        | T-L                      | 3-4                             | 1                 | 16          | 2                                | 31                                        | 30   | 28   | 2.8                      | 24                          |
| 7040-T7451                | Plate        | S-L                      | 3-4                             | 1                 | 14          | 2                                | 33                                        | 31   | 29   | 4.2                      | 30                          |
| 7040-T7451                | Plate        | L-T                      | 4-5                             | 1                 | 17          | 2                                | 34                                        | 32   | 31   | 2.0                      | 25                          |
| 7040-T7451                | Plate        | T-L                      | 4-5                             | 1                 | 17          | 2                                | 27                                        | 26   | 26   | 1.5                      | 24                          |
| 7040-T7451                | Plate        | S-L                      | 4-5                             | 1                 | 17          | 2                                | 28                                        | 26   | 26   | 2.2                      | 29                          |
| 7040-T7451                | Plate        | L-T                      | 5-6                             | 1                 | 17          | 2                                | 34                                        | 32   | 30   | 2.7                      | 23                          |
| 7040-T7451                | Plate        | T-L                      | 5-6                             | 1                 | 14          | 2                                | 28                                        | 25   | 25   | 3.5                      | 24                          |
| 7040-T7451                | Plate        | S-L                      | 5-6                             | 1                 | 16          | 2                                | 28                                        | 27   | 26   | 2.7                      | 27                          |
| 7040-T7451                | Plate        | L-T                      | 6-7                             | 1                 | 21          | 2                                | 37                                        | 34   | 30   | 5.9                      | 22                          |
| 7040-T7451                | Plate        | T-L                      | 6-7                             | 1                 | 21          | 2                                | 29                                        | 27   | 25   | 2.8                      | 23                          |
| 7040-T7451                | Plate        | S-L                      | 6-7                             | 1                 | 21          | 2                                | 30                                        | 29   | 27   | 4.0                      | 26                          |
| 7040-T7451                | Plate        | L-T                      | 7-8                             | 1                 | 18          | 2                                | 33                                        | 32   | 30   | 3.2                      | 22                          |
| 7040-T7451                | Plate        | T-L                      | 7-8                             | 1                 | 16          | 2                                | 29                                        | 28   | 26   | 2.7                      |                             |

a These values are for information only.

b Products that do not receive a mechanical stress-relieving process (e.g. -T73 & -T74 tempers) have the potential for induced residual stresses. As a result, care must be taken to prevent fracture toughness properties from bias resulting from residual stresses.

c Refer to Figure 1.4.12.3 for definition of symbols.

d Varies with thickness.

**Table 3.1.2.1.6. Values of Room-Temperature Plane-Strain Fracture Toughness of Aluminum Alloys<sup>a</sup>—Continued**

| Alloy/Temper <sup>b</sup> | Product Form | Orientation <sup>c</sup> | Product Thickness Range, inches | Number of Sources | Sample Size | Specimen Thickness Range, inches | K <sub>IC</sub> , ksi√in. |      |      |                          |                             |
|---------------------------|--------------|--------------------------|---------------------------------|-------------------|-------------|----------------------------------|---------------------------|------|------|--------------------------|-----------------------------|
|                           |              |                          |                                 |                   |             |                                  | Max.                      | Avg. | Min. | Coefficient of Variation | Minimum Specification Value |
| 7040-T7451                | Plate        | S-L                      | 7-8                             | 1                 | 13          | 2                                | 31                        | 29   | 26   | 4.6                      | 23                          |
| 7040-T7451                | Plate        | L-T                      | 8-8.5                           | 1                 | 17          | 2                                | 34                        | 31   | 28   | 4.6                      | 26                          |
| 7040-T7451                | Plate        | T-L                      | 8-8.5                           | 1                 | 13          | 2                                | 26                        | 24   | 23   | 5.0                      | 22                          |
| 7040-T7451                | Plate        | S-L                      | 8-8.5                           | 1                 | 17          | 2                                | 27                        | 26   | 25   | 2.1                      | 22                          |
| 7049-T73                  | Die Forging  | L-T                      | 1.4                             | 3                 | 21          | 0.5-1.0                          | 34                        | 30   | 27   | 7.4                      |                             |
| 7049-T73                  | Die Forging  | S-L                      | ≥0.5                            | 3                 | 46          | 0.5-1.0                          | 26                        | 22   | 18   | 9.7                      |                             |
| 7049-T73                  | Hand Forging | L-T                      | ≥0.5                            | 2                 | 28          | 0.5-1.0                          | 37                        | 30   | 23   | 12.1                     |                             |
| 7049-T73                  | Hand Forging | T-L                      | 2.0-7.1                         | 2                 | 27          | 1.0                              | 28                        | 22   | 18   | 12.5                     |                             |
| 7049-T73                  | Hand Forging | S-L                      | 1.0                             | 2                 | 24          | 0.8-1.0                          | 22                        | 19   | 14   | 14.2                     |                             |
| 7050-T7351                | Plate        | L-T                      | 1.0-6.0                         | 2                 | 31          | 1.0-2.0                          | 43                        | 35   | 28   | 11.3                     |                             |
| 7050-T7351                | Plate        | T-L                      | 2.0-6.0                         | 1                 | 29          | 1.5-2.0                          | 35                        | 30   | 25   | 8.5                      |                             |
| 7050-T7351                | Plate        | S-L                      | 2.0-6.0                         | 1                 | 30          | 0.8-1.5                          | 30                        | 28   | 25   | 4.6                      |                             |
| 7050-T74                  | Die Forging  | S-L                      | 0.6-7.1                         | 3                 | 12          | 0.6-2.0                          | 27                        | 24   | 21   | 8.8                      |                             |
| 7050-T7451                | Plate        | L-T                      | ----                            | 13                | 96          | 1.0-2.0                          | 39                        | 32   | 25   | 11.7                     | d                           |
| 7050-T7451                | Plate        | T-L                      | ≥1.0                            | 9                 | 97          | 0.5-2.0                          | 38                        | 28   | 21   | 15.6                     | d                           |
| 7050-T7451                | Plate        | S-L                      | ≥1.0                            | 6                 | 44          | 0.7-2.0                          | 28                        | 23   | 21   | 6.3                      | d                           |
| 7050-T7452                | Hand Forging | L-T                      | 3.5-5.5                         | 1                 | 11          | 1.5                              | 34                        | 31   | 26   | 8.0                      | d                           |
| 7050-T7452                | Hand Forging | T-L                      | 3.5-7.5                         | 1                 | 13          | 1.5                              | 22                        | 21   | 18   | 6.7                      | d                           |
| 7050-T7452                | Hand Forging | S-L                      | 3.5-7.5                         | 1                 | 17          | 0.8-1.5                          | 21                        | 19   | 16   | 7.5                      | d                           |
| 7050-T76511               | Extrusion    | L-T                      | ----                            | 2                 | 38          | 0.6-2.0                          | 40                        | 31   | 27   | 7.8                      | d                           |
| 7075-T651                 | Plate        | L-T                      | ≥0.6                            | 7                 | 99          | 0.5-2.0                          | 30                        | 26   | 20   | 7.6                      | d                           |
| 7075-T651                 | Plate        | T-L                      | ≥0.5                            | 5                 | 135         | 0.4-2.0                          | 27                        | 22   | 18   | 8.9                      |                             |
| 7075-T651                 | Plate        | S-L                      | ----                            | 2                 | 37          | 0.5-1.5                          | 22                        | 18   | 14   | 10.4                     |                             |
| 7075-T6510                | Extrusion    | L-T                      | 0.7-3.5                         | 1                 | 26          | 0.5-1.2                          | 32                        | 27   | 23   | 7.8                      |                             |
| 7075-T6510                | Extrusion    | T-L                      | 0.7-3.5                         | 1                 | 25          | 0.5-1.2                          | 28                        | 24   | 21   | 8.0                      |                             |
| 7075-T6510                | Forged Bar   | L-T                      | 0.7-5.0                         | 1                 | 13          | 0.6-2.0                          | 35                        | 29   | 24   | 11.6                     |                             |
| 7075-T6510                | Forged Bar   | T-L                      | 0.7-5.0                         | 1                 | 13          | 0.5-2.5                          | 24                        | 21   | 17   | 8.2                      |                             |
| 7075-T73                  | Die Forging  | T-L                      | ≥0.5                            | 1                 | 22          | 0.5-0.8                          | 25                        | 21   | 18   | 9.9                      |                             |
| 7075-T73                  | Hand Forging | L-T                      | ----                            | 2                 | 10          | 1.0-1.5                          | 39                        | 31   | 29   | 8.8                      |                             |
| 7075-T73                  | Hand Forging | T-L                      | ≥1.0                            | 2                 | 14          | 1.0-1.5                          | 27                        | 23   | 20   | 9.0                      |                             |
| 7075-T7351                | Plate        | L-T                      | ≥1.0                            | 8                 | 65          | 0.5-2.0                          | 36                        | 30   | 25   | 8.2                      |                             |
| 7075-T7351                | Plate        | T-L                      | ≥0.5                            | 6                 | 56          | 0.5-2.0                          | 47                        | 27   | 21   | 20.1                     |                             |
| 7075-T7351                | Plate        | S-L                      | ≥0.5                            | 3                 | 20          | 0.5-1.5                          | 38                        | 22   | 17   | 32.5                     |                             |
| 7075-T73511               | Extrusion    | T-L                      | 1.0-7.0                         | 1                 | 19          | 0.9-1.0                          | 22                        | 20   | 19   | 3.7                      |                             |
| 7075-T73511               | Extrusion    | L-T                      | ≥0.9                            | 3                 | 28          | 0.7-2.0                          | 43                        | 35   | 31   | 9.4                      |                             |

<sup>a</sup> These values are for information only.

<sup>b</sup> Products that do not receive a mechanical stress-relieving process (e.g. -T73 & -T74 tempers) have the potential for induced residual stresses. As a result, care must be taken to prevent fracture toughness properties from bias resulting from residual stresses.

<sup>c</sup> Refer to Figure 1.4.12.3 for definition of symbols.

**Table 3.1.2.1.6. Values of Room-Temperature Plane-Strain Fracture Toughness of Aluminum Alloys<sup>a</sup>—Continued**

| Alloy/Temper <sup>b</sup> | Product Form | Orientation <sup>c</sup> | Product Thickness Range, inches | Number of Sources | Sample Size | Specimen Thickness Range, inches | K <sub>IC</sub> , ksi√in. |      |      |                          |                             |
|---------------------------|--------------|--------------------------|---------------------------------|-------------------|-------------|----------------------------------|---------------------------|------|------|--------------------------|-----------------------------|
|                           |              |                          |                                 |                   |             |                                  | Max.                      | Avg. | Min. | Coefficient of Variation | Minimum Specification Value |
| 7075-T73511               | Extrusion    | T-L                      | ≥0.7                            | 3                 | 35          | 0.5-1.8                          | 35                        | 23   | 12   | 20.3                     |                             |
| 7075-T73511               | Extrusion    | S-L                      | ≥0.5                            | 3                 | 15          | 0.4-1.0                          | 22                        | 20   | 17   | 9.0                      |                             |
| 7075-T7352                | Hand Forging | L-T                      | ----                            | 2                 | 27          | 0.8-2.0                          | 39                        | 33   | 30   | 9.2                      |                             |
| 7075-T7352                | Hand Forging | T-L                      | ≥0.8                            | 3                 | 20          | 0.8-2.0                          | 33                        | 26   | 23   | 9.9                      |                             |
| 7075-T7651                | Plate        | L-T                      | ≥0.8                            | 6                 | 82          | 0.5-2.0                          | 43                        | 29   | 22   | 17.8                     |                             |
| 7075-T7651                | Plate        | T-L                      | ≥0.5                            | 7                 | 96          | 0.5-2.0                          | 28                        | 23   | 20   | 7.6                      |                             |
| 7075-T7651                | Plate        | S-L                      | ≥0.5                            | 5                 | 28          | 0.4-0.8                          | 20                        | 18   | 15   | 7.7                      |                             |
| 7075-T7651                | Clad Plate   | L-T                      | 0.5-0.6                         | 2                 | 30          | 0.5-0.6                          | 30                        | 25   | 22   | 7.1                      |                             |
| 7075-T7651                | Clad Plate   | T-L                      | 0.5-0.6                         | 2                 | 56          | 0.5-0.6                          | 28                        | 24   | 21   | 7.7                      |                             |
| 7075-T76511               | Extrusion    | L-T                      | 1.3-7.0                         | 4                 | 11          | 1.2-2.0                          | 41                        | 35   | 31   | 11.0                     |                             |
| 7075-T76511               | Extrusion    | T-L                      | 1.2                             | 3                 | 42          | 0.6-2.0                          | 36                        | 23   | 20   | 15.5                     |                             |
| 7175-T6/T6511             | Extrusion    | T-L                      | ----                            | 2                 | 25          | 0.8-1.0                          | 24                        | 21   | 18   | 7.9                      |                             |
| 7175-T651                 | Plate        | L-T                      | ----                            | 1                 | 17          | 0.7-0.8                          | 30                        | 26   | 24   | 9.2                      |                             |
| 7175-T651                 | Plate        | T-L                      | ----                            | 1                 | 10          | 0.7-0.8                          | 26                        | 22   | 20   | 9.8                      |                             |
| 7175-T6511                | Extrusion    | L-T                      | ----                            | 2                 | 14          | 0.8-1.0                          | 36                        | 32   | 24   | 13.8                     |                             |
| 7175-T7351                | Plate        | L-T                      | ----                            | 2                 | 30          | 0.7-1.6                          | 36                        | 33   | 32   | 3.3                      |                             |
| 7175-T7351                | Plate        | T-L                      | ----                            | 2                 | 32          | 0.7-1.6                          | 30                        | 27   | 25   | 4.5                      |                             |
| 7175-T73511               | Extrusion    | L-T                      | ≥0.7                            | 5                 | 43          | 0.5-1.5                          | 47                        | 33   | 23   | 16.0                     | 30                          |
| 7175-T73511               | Extrusion    | T-L                      | ≥0.5                            | 5                 | 43          | 0.5-1.5                          | 35                        | 25   | 20   | 10.9                     | 22                          |
| 7175-T74                  | Die Forging  | L-T                      | ≥0.5                            | 3                 | 14          | 0.5-1.0                          | 38                        | 30   | 22   | 15.0                     | 27                          |
| 7175-T74                  | Die Forging  | T-L                      | ≥0.5                            | 2                 | 13          | 0.5-1.0                          | 33                        | 24   | 21   | 15.7                     | 21                          |
| 7175-T74                  | Die Forging  | S-L                      | ≥0.5                            | 4                 | 41          | 0.5-0.8                          | 31                        | 26   | 20   | 8.6                      | 21                          |
| 7175-T74                  | Hand Forging | T-L                      | 3.0-5.0                         | 2                 | 10          | 1.0-1.5                          | 29                        | 26   | 24   | 4.8                      | 25                          |
| 7175-T7651                | Clad Plate   | L-T                      | ----                            | 1                 | 53          | 1.5                              | 33                        | 32   | 30   | 4.3                      |                             |
| 7175-T7651                | Clad Plate   | T-L                      | ----                            | 1                 | 50          | 0.6                              | 28                        | 27   | 25   | 3.1                      |                             |
| 7175-T7651                | Plate        | L-T                      | ----                            | 1                 | 12          | 1.5                              | 32                        | 32   | 31   | 1.7                      |                             |
| 7175-T7651                | Plate        | T-L                      | ----                            | 1                 | 11          | 1.5                              | 26                        | 25   | 24   | 3.3                      |                             |
| 7175-T76511               | Extrusion    | L-T                      | 1.4-3.8                         | 2                 | 48          | 0.6-2.0                          | 39                        | 33   | 27   | 10.7                     |                             |
| 7175-T76511               | Extrusion    | T-L                      | ≥0.6                            | 4                 | 49          | 0.6-1.8                          | 31                        | 22   | 20   | 9.8                      |                             |
| 7475-T651                 | Plate        | L-T                      | ----                            | 3                 | 34          | 0.9-2.0                          | 49                        | 38   | 33   | 9.2                      | 30                          |
| 7475-T651                 | Plate        | T-L                      | 0.6-2.0                         | 2                 | 143         | 0.6-2.0                          | 43                        | 34   | 27   | 9.8                      | 28                          |
| 7475-T651                 | Plate        | S-L                      | ≥0.6                            | 1                 | 23          | 0.5-1.0                          | 36                        | 28   | 20   | 14.9                     |                             |
| 7475-T7351                | Plate        | L-T                      | 1.3-4.0                         | 8                 | 151         | 1.3-3.0                          | 60                        | 47   | 34   | 10.4                     | d                           |
| 7475-T7351                | Plate        | T-L                      | ≥1.3                            | 7                 | 132         | 0.7-3.0                          | 50                        | 37   | 29   | 10.4                     | d                           |
| 7475-T7351                | Plate        | S-L                      | ≥0.7                            | 7                 | 74          | 0.5-1.5                          | 36                        | 30   | 25   | 8.7                      | 25                          |
| 7475-T7651                | Plate        | L-T                      | 1.0-2.0                         | 4                 | 10          | 1.0-2.0                          | 46                        | 41   | 36   | 6.2                      | 33                          |
| 7475-T7651                | Plate        | T-L                      | ≥1.0                            | 2                 | 15          | 0.9-2.0                          | 50                        | 36   | 29   | 14.5                     | 30                          |

<sup>a</sup> These values are for information only.

<sup>b</sup> Products that do not receive a mechanical stress-relieving process (e.g. -T73 & -T74 tempers) have the potential for induced residual stresses. As a result, care must be taken to prevent fracture toughness properties from bias resulting from residual stresses.

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The tensile and shear moduli of aluminum alloys also increase with decreasing temperature so that at -100, -320, and -423°F, they are approximately 5, 12, and 16 percent, respectively, above the room temperature values [Reference 3.1.2.1.7(f)].

**3.1.2.1.8 Elevated Temperatures** — In general, the strengths of aluminum alloys decrease and toughness increases with increase in temperature and with time at temperature above room temperature; the effect is generally greatest over the temperature range from 212 to 400°F. Exceptions to the general trends are tempers developed by solution heat treatment without subsequent aging, for which the initial elevated temperature exposure results in some age hardening and reduction in toughness; further time at temperature beyond that required to achieve peak hardness results in the aforementioned decrease in strength and increase in toughness [Reference 3.1.2.1.8].

**3.1.2.2 Physical Properties**— Where available from the literature, the average values of certain physical properties are included in the room-temperature tables for each alloy. These properties include density,  $\omega$ , in lb/in.<sup>3</sup>; the specific heat,  $C$ , in Btu/(lb)(°F); the thermal conductivity,  $K$ , in Btu/[(hr)(ft<sup>2</sup>)(°F)/ft]; and the mean coefficient of thermal expansion,  $\alpha$ , in in./in./°F. Where more extensive data are available to show the effect of temperature on these physical properties, graphs of physical property as a function of temperature are presented for the applicable alloys.

**3.1.2.3 Corrosion Resistance —**

**3.1.2.3.1 Resistance to Stress-Corrosion Cracking** [see References 3.1.2.3.1(a) through (d)] — In-service stress-corrosion cracking failures can be caused by stresses produced from a wide variety of sources, including solution heat treatment, straightening, forming, fit-up, clamping, and sustained service loads. These stresses may be tensile or compressive, and the stresses due to Poisson effects should not be ignored because SCC failures can be caused by sustained shear stresses. Pin-hole flaws in some corrosion protection coatings may also be sufficient to allow SCC to occur. The high-strength heat treatable wrought aluminum alloys in certain tempers are susceptible to stress-corrosion cracking, depending upon product, section size, direction and magnitude of stress. These alloys include 2014, 2025, 2618, 7075, 7150, 7175, and 7475 in the T6-type tempers and 2014, 2024, 2124, and 2219 in the T3 and T4-type tempers. Other alloy-temper combinations, notably 2024, 2124, 2219, and 2519 in the T6- or T8-type tempers and 7010, 7049, 7050, 7075, 7149, 7175, and 7475 in the T73-type tempers, are decidedly more resistant and sustained tensile stresses of 50 to 75 percent of the minimum yield strength may be permitted without concern about stress corrosion cracking. The T74 and T76 tempers of 7010, 7075, 7475, 7049, 7149, and 7050 provide an intermediate degree of resistance to stress-corrosion cracking, i.e., superior to that of the T6 temper, but not as good as that of the T73 temper of 7075. To assist in the selection of materials, letter ratings indicating the relative resistance to stress-corrosion cracking of various mill product forms of the wrought 2000, 6000, and 7000 series heat-treated aluminum alloys are presented in Table 3.1.2.3.1(a). This table is based upon ASTM G 64 which contains more detailed information regarding this rating system and the procedure for determining the ratings. In addition, more quantitative information in the form of the maximum specified tension stresses at which test specimens will not fail when subjected to the alternate immersion stress-corrosion test described in ASTM G 47 are shown in Tables 3.1.2.3.1(b) through (e) for various heat-treated aluminum product forms, alloys, and tempers.

Where short times at elevated temperatures of 150 to 500°F may be encountered, the precipitation heat-treated tempers of 2024 and 2219 alloys are recommended over the naturally aged tempers.

Alloys 5083, 5086, and 5456 should not be used under high constant applied stress for continuous service at temperatures exceeding 150°F, because of the hazard of developing susceptibility to stress-corrosion cracking. In general, the H34 through H38 tempers of 5086, and the H32 through H38 tempers

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**Table 3.1.2.3.1(a). Resistance to Stress-Corrosion Ratings<sup>a</sup> for High-Strength Aluminum Alloy Products**

| Alloy and Temper <sup>b</sup> | Test Direction <sup>c</sup> | Rolled Plate   | Rod and Bar <sup>d</sup> | Extruded Shapes | Forging        |
|-------------------------------|-----------------------------|----------------|--------------------------|-----------------|----------------|
| 2014-T6                       | L                           | A              | A                        | A               | B              |
|                               | LT                          | B <sup>e</sup> | D                        | B <sup>e</sup>  | B <sup>e</sup> |
|                               | ST                          | D              | D                        | D               | D              |
| 2024-T3, T4                   | L                           | A              | A                        | A               | f              |
|                               | LT                          | B <sup>e</sup> | D                        | B <sup>e</sup>  | f              |
|                               | ST                          | D              | D                        | D               | f              |
| 2024-T6                       | L                           | f              | A                        | f               | A              |
|                               | LT                          | f              | B                        | f               | A <sup>e</sup> |
|                               | ST                          | f              | B                        | f               | D              |
| 2024-T8                       | L                           | A              | A                        | A               | A              |
|                               | LT                          | A              | A                        | A               | A              |
|                               | ST                          | B              | A                        | B               | C              |
| 2124-T8                       | L                           | A              | f                        | f               | f              |
|                               | LT                          | A              | f                        | f               | f              |
|                               | ST                          | B              | f                        | f               | f              |
| 2219-T351X, T37               | L                           | A              | f                        | A               | f              |
|                               | LT                          | B              | f                        | B               | f              |
|                               | ST                          | D              | f                        | D               | f              |
| 2219-T6                       | L                           | A              | A                        | A               | A              |
|                               | LT                          | A              | A                        | A               | A              |
|                               | ST                          | A              | A                        | A               | A              |
| 2219-T85XX, T87               | L                           | A              | f                        | A               | A              |
|                               | LT                          | A              | f                        | A               | A              |
|                               | ST                          | A              | f                        | A               | A              |
| 6061-T6                       | L                           | A              | A                        | A               | A              |
|                               | LT                          | A              | A                        | A               | A              |
|                               | ST                          | A              | A                        | A               | A              |
| 7040-T7451                    | L                           | A              | f                        | f               | f              |
|                               | LT                          | A              | f                        | f               | f              |
|                               | ST                          | B              | f                        | f               | f              |
| 7049-T73                      | L                           | A              | f                        | A               | A              |
|                               | LT                          | A              | f                        | A               | A              |
|                               | ST                          | A              | f                        | B               | A              |
| 7049-T76                      | L                           | f              | f                        | A               | f              |
|                               | LT                          | f              | f                        | A               | f              |
|                               | ST                          | f              | f                        | C               | f              |
| 7050-T74                      | L                           | A              | f                        | A               | A              |
|                               | LT                          | A              | f                        | A               | A              |
|                               | ST                          | B              | f                        | B               | B              |
| 7050-T76                      | L                           | A              | A                        | A               | f              |
|                               | LT                          | A              | B                        | A               | f              |
|                               | ST                          | C              | B                        | C               | f              |
| 7075-T6                       | L                           | A              | A                        | A               | A              |
|                               | LT                          | B <sup>e</sup> | D                        | B <sup>e</sup>  | B <sup>e</sup> |
|                               | ST                          | D              | D                        | D               | D              |
| 7075-T73                      | L                           | A              | A                        | A               | A              |
|                               | LT                          | A              | A                        | A               | A              |
|                               | ST                          | A              | A                        | A               | A              |

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**Table 3.1.2.3.1(a). Resistance to Stress-Corrosion Ratings<sup>a</sup> for High-Strength Aluminum Alloy Products—Continued**

| Alloy and Temper <sup>b</sup> | Test Direction <sup>c</sup> | Rolled Plate   | Rod and Bar <sup>d</sup> | Extruded Shapes | Forging |
|-------------------------------|-----------------------------|----------------|--------------------------|-----------------|---------|
| 7075-T74                      | L                           | f              | f                        | f               | A       |
|                               | LT                          | f              | f                        | f               | A       |
|                               | ST                          | f              | f                        | f               | B       |
| 7075-T76                      | L                           | A              | f                        | A               | f       |
|                               | LT                          | A              | f                        | A               | f       |
|                               | ST                          | C              | f                        | C               | f       |
| 7149-T73                      | L                           | f              | f                        | A               | A       |
|                               | LT                          | f              | f                        | A               | A       |
|                               | ST                          | f              | f                        | B               | A       |
| 7175-T74                      | L                           | f              | f                        | f               | A       |
|                               | LT                          | f              | f                        | f               | A       |
|                               | ST                          | f              | f                        | f               | B       |
| 7475-T6                       | L                           | A              | f                        | f               | f       |
|                               | LT                          | B <sup>e</sup> | f                        | f               | f       |
|                               | ST                          | D              | f                        | f               | f       |
| 7475-T73                      | L                           | A              | f                        | f               | f       |
|                               | LT                          | A              | f                        | f               | f       |
|                               | ST                          | A              | f                        | f               | f       |
| 7475-T76                      | L                           | A              | f                        | f               | f       |
|                               | LT                          | A              | f                        | f               | f       |
|                               | ST                          | C              | f                        | f               | f       |

<sup>a</sup> Ratings were determined from stress corrosion tests performed on at least ten random lots for which test results showed 90% conformance with 95% confidence when tested at the following stresses.

- A - Equal to or greater than 75% of the specified minimum yield strength. A very high rating. SCC not anticipated in general applications if the total sustained tensile stress\* is less than 75% of the minimum specified yield stress for the alloy, heat treatment, product form, and orientation.
- B - Equal to or greater than 50% of the specified minimum yield strength. A high rating. SCC not anticipated if the total sustained tensile stress\* is less than 50% of the specified minimum yield stress.
- C - Equal to or greater than 25% of the specified minimum yield stress or 14.5 ksi, whichever is higher. An intermediate rating. SCC not anticipated if the total sustained tensile stress\* is less than 25% of the specified minimum yield stress. This rating is designated for the short transverse direction in improved products used primarily for high resistance to exfoliation corrosion in relatively thin structures where applicable short transverse stresses are unlikely.
- D - Fails to meet the criterion for the rating C. A low rating. SCC failures have occurred in service or would be anticipated if there is any sustained tensile stress\* in the designated test direction. This rating currently is designated only for the short transverse direction in certain materials.

NOTE - The above stress levels are not to be interpreted as “threshold” stresses, and are not recommended for design. Other documents, such as MIL-STD-1568, NAS SD-24, and MSFC-SPEC-522A, should be consulted for design recommendations.

\* The sum of all stresses, including those from service loads (applied), heat treatment, straightening, forming, etc.

**Table 3.1.2.3.1(a). Resistance to Stress-Corrosion Ratings™ for High Strength Aluminum Alloy Products - Continued**

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- b The ratings apply to standard mill products in the types of tempers indicated, including stress-relieved tempers, and could be invalidated in some cases by application of nonstandard thermal treatments or mechanical deformation at room temperature by the user.
  - c Test direction refers to orientation of the stressing direction relative to the directional grain structure typical of wrought materials, which in the case of extrusions and forgings may not be predictable from the geometrical cross section of the product.  
L—Longitudinal: parallel to the direction of principal metal extension during manufacture of the product.  
LT—Long Transverse: perpendicular to direction of principal metal extension. In products whose grain structure clearly shows directionality (width to thickness ratio greater than two) it is that perpendicular direction parallel to the major grain dimension.  
ST—Short Transverse: perpendicular to direction of principal metal extension and parallel to minor dimension of grains in products with significant grain directionality.
  - d Sections with width-to-thickness ratio equal to or less than two for which there is no distinction between LT and ST.
  - e Rating is one class lower for thicker sections: extrusion, 1 inch and over; plate and forgings, 1.5 inches and over.
  - f Ratings not established because the product is not offered commercially.

NOTE: This table is based upon ASTM G 64.

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**Table 3.1.2.3.1(b). Maximum Specified Tension Stress at Which Test Specimens Will Not Fail in 3½% NaCl Alternate Immersion Test<sup>a</sup> for Various Stress Corrosion Resistant Aluminum Alloy Plate**

| Alloy and Temper        | Test Direction | Thickness, inches | Stress, ksi     | Referenced Specifications              |
|-------------------------|----------------|-------------------|-----------------|----------------------------------------|
| 2024-T851               | ST             | 1.001-4.000       | 28 <sup>b</sup> | Company specification                  |
|                         |                | 4.001-6.000       | 27 <sup>b</sup> |                                        |
| 2090-T81 <sup>c</sup>   | ST             | 0.750-1.500       | 20              | AMS 4303                               |
| 2124-T851               | ST             | 1.500-1.999       | 28 <sup>b</sup> | AMS 4101                               |
|                         |                | 2.000-4.000       | 28 <sup>b</sup> | AMS-QQ-A-0025/29, ASTM B 209, AMS 4101 |
|                         |                | 4.001-6.000       | 27 <sup>b</sup> |                                        |
| 2124-T8151 <sup>c</sup> | ST             | 1.500-3.000       | 30 <sup>b</sup> | AMS 4221                               |
|                         |                | 3.001-5.000       | 29 <sup>b</sup> |                                        |
|                         |                | 5.001-6.000       | 28 <sup>b</sup> |                                        |
| 2219-T851               | ST             | 0.750-2.000       | 34 <sup>d</sup> | AMS-QQ-A-250/30                        |
|                         |                | 2.001-4.000       | 33 <sup>d</sup> |                                        |
|                         |                | 4.001-5.000       | 32 <sup>d</sup> |                                        |
|                         |                | 5.001-6.000       | 31 <sup>d</sup> |                                        |
| 2219-T87                | ST             | 0.750-3.000       | 38 <sup>d</sup> | AMS-QQ-A-250/30                        |
|                         |                | 3.001-4.000       | 37 <sup>d</sup> |                                        |
|                         |                | 4.001-5.000       | 36 <sup>d</sup> |                                        |
| 2519-T87                | ST             | 0.750-4.000       | 43 <sup>d</sup> | MIL-A-46192                            |
| 7010-T7351 <sup>c</sup> | ST             | 0.750-3.000       | 41 <sup>d</sup> | AMS 4203                               |
|                         |                | 3.001-5.000       | 40 <sup>d</sup> |                                        |
|                         |                | 5.001-5.500       | 39 <sup>d</sup> |                                        |
| 7010-T7451              | ST             | 0.750-3.000       | 31 <sup>b</sup> | AMS 4205                               |
|                         |                | 3.001-5.500       | 35              |                                        |
| 7010-T7651              | ST             | 0.750-5.500       | 25              | AMS 4204                               |
| 7049-T7351              | ST             | 0.750-5.000       | 45              | AMS 4200                               |
| 7050-T7451              | ST             | 0.750-6.000       | 35              | AMS 4050                               |
| 7050-T7651              | ST             | 0.750-3.000       | 25              | AMS 4201                               |
| 7075-T7351              | ST             | 0.750-2.000       | 42 <sup>d</sup> | AMS-QQ-A-250/12, AMS 4078, ASTM B 209  |
|                         |                | 2.001-2.500       | 39 <sup>d</sup> |                                        |
|                         |                | 2.501-4.000       | 36 <sup>d</sup> |                                        |
| 7075-T7651              | ST             | 0.750-1.000       | 25              | AMS-QQ-A-00250/24, ASTM B 209          |
| Clad 7075-T7651         | ST             | 0.750-1.000       | 25              | AMS-QQ-A-00250/25, ASTM B 209          |
| 7150-T7751              | ST             | 0.750-3.000       | 25              | AMS 4252                               |
| 7475-T7351              | ST             | 0.750-4.000       | 40              | AMS 4202                               |
| 7475-T7651              | ST             | 0.750-1.500       | 25              | AMS 4089                               |

a Most specifications reference ASTM G 47, which requires exposures of 10 days for 2XXX alloys and 20 days for 7XXX alloys in ST test direction.

b 50% of specified minimum long transverse yield strength.

c Design values are not included in MIL-HDBK-5.

d 75% of specified minimum long transverse yield strength.

**DO NOT USE STRESS VALUES FOR DESIGN**



**Table 3.1.2.3.1(c). Maximum Specified Tension Stress at Which Test Specimens Will Not Fail in 3½% NaCl Alternate Immersion Test<sup>a</sup> for Various Stress Corrosion Resistant Aluminum Alloy Rolled Bars, Rods, and Extrusions**

| Alloy and Temper         | Product Form       | Test Direction | Thickness, inches | Stress, ksi       | Referenced Specifications                   |
|--------------------------|--------------------|----------------|-------------------|-------------------|---------------------------------------------|
| 7075-T73-T7351           | Rolled Bar and Rod | ST             | 0.750-3.000       | 42 <sup>b</sup>   | AMS-QQ-A-225/9, AMS 4124, ASTM B211         |
| 2219-T8511               | Extrusion          | ST             | 0.750-3.000       | 30                | AMS 4162, AMS 4163                          |
| 7049-T73511              | Extrusion          | ST             | 0.750-2.999       | 41 <sup>c</sup>   | AMS 4157                                    |
|                          |                    |                | 3.000-5.000       | 40 <sup>c</sup>   |                                             |
| 7049-T76511 <sup>d</sup> | Extrusion          | ST             | 0.750-5.000       | 20                | AMS 4159                                    |
| 7050-T73511              | Extrusion          | ST             | 0.750-5.000       | 45                | AMS 4341                                    |
| 7050-T74511              | Extrusion          | ST             | 0.750-5.000       | 35                | AMS 4342                                    |
| 7050-T76511              | Extrusion          | ST             | 0.750-5.000       | 17                | AMS 4340                                    |
| 7075-T73-T73510-T73511   | Extrusion          | ST             | 0.750-1.499       | 45 <sup>b</sup>   | AMS-QQ-A-200/11, AMS 4166, AMS 4167, ASTM B |
|                          |                    |                | 1.500-2.999       | 44 <sup>b</sup>   | 211                                         |
|                          |                    |                | 3.000-4.999       | 42 <sup>b</sup>   |                                             |
|                          |                    |                | 3.000-4.999       | 41 <sup>b,e</sup> |                                             |
| 7075-T76-T76510-T76511   | Extrusion          | ST             | 0.750-1.000       | 25                |                                             |
| 7149-T73511 <sup>d</sup> | Extrusion          | ST             | 0.750-2.999       | 41 <sup>c</sup>   | AMS-QQ-A-200/15, ASTM B 221                 |
|                          |                    |                | 3.000-5.000       | 40 <sup>c</sup>   | AMS 4543                                    |
| 7150-T77511              | Extrusion          | ST             | 0.750-2.000       | 25                |                                             |
| 7175-T73511              | Extrusion          | ST             | 0.750-2.000       | 44                | AMS 4345                                    |
|                          |                    |                |                   |                   | AMS 4344                                    |

a Most specifications reference ASTM G 47, which requires exposures of 10 days for 2XXX alloys and 20 days for 7XXX alloys in ST test direction.

b 75% of specified minimum longitudinal yield strength.

c 65% of specified minimum longitudinal yield strength.

d Design values are not included in MIL-HDBK-5.

e Over 20 square inches cross-sectional area.

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**Table 3.1.2.3.1(d). Maximum Specified Tension Stress at Which Test Specimens Will Not Fail in 3½% NaCl Alternate Immersion Test<sup>a</sup> for Various Stress Corrosion Resistant Aluminum Die Forgings**

| Alloy and Temper        | Test Direction | Thickness, inches | Stress, ksi     | Referenced Specifications                   |
|-------------------------|----------------|-------------------|-----------------|---------------------------------------------|
| 7049-T73                | ST             | 0.750-2.000       | 46 <sup>b</sup> | QQ-A-367, AMS 4111, ASTM B 247              |
|                         |                | 2.001-5.000       | 45 <sup>b</sup> |                                             |
| 7050-T74                | ST             | 0.750-6.000       | 35              | AMS 4107                                    |
| 7050-T7452              | ST             | 0.750-4.000       | 35              | AMS 4333                                    |
| 7075-T73                | ST             | 0.750-3.000       | 42 <sup>b</sup> | MIL-A-22771, QQ-A-367                       |
|                         |                | 3.001-4.000       | 41 <sup>b</sup> | AMS 4241, ASTM B 247                        |
|                         |                | 4.001-5.000       | 39 <sup>b</sup> | AMS 4141                                    |
|                         |                | 5.001-6.000       | 38 <sup>b</sup> |                                             |
| 7075-T7352              | ST             | 0.750-4.000       | 42 <sup>b</sup> | MIL-A-22771, QQ-A-367, AMS 4147, ASTM B 247 |
|                         |                | 3.001-4.000       | 39 <sup>b</sup> |                                             |
| 7075-T7354 <sup>c</sup> | ST             | 0.750-3.000       | 42              | Company Specification                       |
| 7075-T74 <sup>c</sup>   | ST             | 0.750-3.000       | 35              | AMS 4131                                    |
|                         |                | 3.001-4.000       | 31 <sup>d</sup> |                                             |
|                         |                | 4.001-5.000       | 30 <sup>d</sup> |                                             |
|                         |                | 5.001-6.000       | 29 <sup>d</sup> |                                             |
| 7149-T73                | ST             | 0.750-2.000       | 46 <sup>b</sup> | AMS 4320                                    |
|                         |                | 2.001-5.000       | 45 <sup>b</sup> |                                             |
| 7175-T74                | ST             | 0.750-3.000       | 35              | AMS 4149, ASTM B 247                        |
|                         |                | 3.001-4.000       | 31 <sup>d</sup> | AMS 4149                                    |
|                         |                | 4.001-5.000       | 30 <sup>d</sup> |                                             |
|                         |                | 5.001-6.000       | 29 <sup>d</sup> |                                             |
| 7175-T7452 <sup>c</sup> | ST             | 0.750-3.000       | 35              | AMS 4179                                    |

a Most specifications Reference ASTM G 47, which requires 20 days of exposure for 7XXX alloys in ST test direction.

b 75% of specified minimum longitudinal yield strength.

c Design values are not included in MIL-HDBK-5.

d 50% of specified minimum longitudinal yield strength.

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**Table 3.1.2.3.1(e). Maximum Specified Tension Stress at Which Test Specimens Will Not Fail in 3½% NaCl Alternate Immersion Test<sup>a</sup> for Various Stress Corrosion Resistant Aluminum Hand Forgings**

| Alloy and Temper        | Test Direction | Thickness, inches | Stress, ksi     | Referenced Specifications         |
|-------------------------|----------------|-------------------|-----------------|-----------------------------------|
| 7049-T73                | ST             | 2.001-3.000       | 45 <sup>b</sup> | QQ-A-367, AMS 4111, ASTM B 247    |
|                         |                | 3.001-4.000       | 44 <sup>b</sup> |                                   |
|                         |                | 4.001-5.000       | 42 <sup>b</sup> |                                   |
| 7049-T7352 <sup>c</sup> | ST             | 0.750-3.000       | 44 <sup>b</sup> | AMS 4247                          |
|                         |                | 3.001-4.000       | 43 <sup>b</sup> |                                   |
|                         |                | 4.001-5.000       | 40 <sup>b</sup> |                                   |
| 7050-T7452              | ST             | 0.750-8.000       | 35              | AMS 4108                          |
| 7075-T73                | ST             | 0.750-3.000       | 42 <sup>b</sup> | MIL-A-22771, QQ-A-367, ASTM B 247 |
|                         |                | 3.001-4.000       | 41 <sup>b</sup> |                                   |
|                         |                | 4.001-4.000       | 39 <sup>b</sup> |                                   |
|                         |                | 5.001-6.000       | 38 <sup>b</sup> |                                   |
| 7075-T7352              | ST             | 0.750-3.000       | 39 <sup>d</sup> | AMS 4147                          |
|                         |                | 3.001-4.000       | 37 <sup>d</sup> |                                   |
|                         |                | 4.001-5.000       | 36 <sup>d</sup> |                                   |
|                         |                | 5.001-6.000       | 34 <sup>d</sup> |                                   |
| 7075-T74 <sup>c</sup>   | ST             | 0.750-3.000       | 35              | AMS 4131                          |
|                         |                | 3.001-4.000       | 30 <sup>e</sup> |                                   |
|                         |                | 4.001-5.000       | 28 <sup>e</sup> |                                   |
|                         |                | 5.001-6.000       | 27 <sup>e</sup> |                                   |
| 7075-T7452 <sup>c</sup> | ST             | 0.750-2.000       | 35              | AMS 4323                          |
|                         |                | 2.001-3.000       | 29 <sup>f</sup> |                                   |
|                         |                | 3.001-4.000       | 28 <sup>f</sup> |                                   |
|                         |                | 4.001-5.000       | 26 <sup>f</sup> |                                   |
| 7149-T73                | ST             | 5.001-6.000       | 24 <sup>f</sup> | AMS 4320                          |
|                         |                | 2.000-3.000       | 44 <sup>d</sup> |                                   |
|                         |                | 3.001-4.000       | 43 <sup>d</sup> |                                   |
|                         |                | 4.001-5.000       | 42 <sup>d</sup> |                                   |
| 7175-T74                | ST             | 0.750-3.000       | 35              | AMS 4149                          |
|                         |                | 3.001-4.000       | 29 <sup>f</sup> |                                   |
|                         |                | 4.001-5.000       | 28 <sup>f</sup> |                                   |
|                         |                | 4.001-6.000       | 26 <sup>f</sup> |                                   |
| 7175-T7452              | ST             | 0.750-3.000       | 35              | AMS 4179                          |
|                         |                | 3.001-4.000       | 27 <sup>f</sup> |                                   |
|                         |                | 4.001-5.000       | 26 <sup>f</sup> |                                   |
|                         |                | 5.001-6.000       | 24 <sup>f</sup> |                                   |

a Most specifications Reference ASTM G 47, which requires 20 days of exposure for 7XXX alloys in ST test direction.

b 75% of specified minimum longitudinal yield strength.

c Design values are not included in MIL-HDBK-5.

d 75% of specified minimum long transverse yield strength.

e 50% of specified minimum longitudinal yield strength.

f 50% of specified minimum long transverse yield strength.

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of 5083 and 5456 are not recommended, because these tempers can become susceptible to stress-corrosion cracking.

For the cold forming of 5083 sheet and plate in the H112, H321, H323, and H343 tempers and 5456 sheet and plate in the H112 and H321 tempers, a minimum bend radius of 5T should be used. Hot forming of the O temper for alloys 5083 and 5456 is recommended, and is preferred to the cold worked tempers to avoid excessive cold work and high residual stress. If the cold worked tempers are heat-treatable alloys are heated for hot forming, a slight decrease in mechanical properties, particularly yield strength, may result.

**3.1.2.3.2 Resistance to Exfoliation [Reference 3.1.2.3.2]** —The high-strength wrought aluminum alloys in certain tempers are susceptible to exfoliation corrosion, dependent upon product and section size. Generally those alloys and tempers that have the lowest resistance to stress-corrosion cracking also have the lowest resistance to exfoliation. The tempers that provide improved resistance to stress-corrosion cracking also provide improved resistance or immunity to exfoliation. For example, the T76 temper of 7075, 7049, 7050, and 7475 provides a very high resistance to exfoliation, i.e., decidedly superior to the T6 temper, and almost the immunity provided by the T73 temper of 7075 alloy (see Reference 3.1.2.3.2).

### **3.1.3 MANUFACTURING CONSIDERATIONS**

**3.1.3.1 Avoiding Stress-Corrosion Cracking** — In order to avoid stress-corrosion cracking (see Section 3.1.2.3), practices, such as the use of press or shrink fits; taper pins; clevis joints in which tightening of the bolt imposes a bending load on female lugs; and straightening or assembly operations; which result in sustained surface tensile stresses (especially when acting in the short-transverse grain orientation), should be avoided in these high-strength alloys: 2014-T451, T4, T6, T651, T652; 2024-T3, T351, T4; 7075-T6, T651, T652; 7150-T6151, T61511; and 7475-T6, T651.

Where straightening or forming is necessary, it should be performed when the material is in the freshly quenched condition or at an elevated temperature to minimize the residual stress induced. Where elevated temperature forming is performed on 2014-T4 T451, or 2024-T3 T351, a subsequent precipitation heat treatment to produce the T6 or T651, T81 or T851 temper is recommended.

It is good engineering practice to control sustained short-transverse tensile stress at the surface of structural parts at the lowest practicable level. Thus, careful attention should be given in all stages of manufacturing, starting with design of the part configuration, to choose practices in the heat treatment, fabrication, and assembly to avoid unfavorable combinations of end grain microstructure and sustained tensile stress. The greatest danger arises when residual, assembly, and service stress combine to produce high sustained tensile stress at the metal surface. Sources of residual and assembly stress have been the most contributory to stress-corrosion-cracking problems because their presence and magnitude were not recognized. In most cases, the design stresses (developed by functional loads) are not continuous and would not be involved in the summation of sustained tensile stress. It is imperative that, for materials with low resistance to stress-corrosion cracking in the short-transverse grain orientation, every effort be taken to keep the level of sustained tensile stress close to zero.

**3.1.3.2 Cold-Formed Heat-Treatable Aluminum Alloys** — Cold working such as stretch forming of aluminum alloy prior to solution heat treatment may result in recrystallization or grain growth during heat treatment. The resulting strength, particularly yield strength, may be significantly below the specified minimum values. For critical applications, the strength should be determined on the part after forming and heat treating including straightening operations. To minimize recrystallization during heat treatment, it is recommended that forming be done after solution heat treatment in the as-quenched condition whenever possible, but this may result in compressive yield strength in the direction of stretching being lower than MIL-HDBK-5 design allowables for user heat treat tempers.

**3.1.3.3 Dimensional Changes** — The dimensional changes that occur in aluminum alloy during thermal treatment generally are negligible, but in a few instances these changes may have to be considered in manufacturing. Because of many variables involved, there are no tabulated values for these dimensional changes. In the artificial aging of alloy 2219 from the T42, T351, and T37 tempers to the T62, T851, and T87 tempers, respectively, a net dimensional growth of 0.00010 to 0.0015 in./in. may be anticipated. Additional growth of as much as 0.0010 in./in. may occur during subsequent service of a year or more at 300°F or equivalent shorter exposures at higher temperatures. The dimensional changes that occur during the artificial aging of other wrought heat-treatable alloys are less than one-half that for alloy 2219 under the same conditions.

**3.1.3.4 Welding** — The ease with which aluminum alloys may be welded is dependent principally upon composition, but the ease is also influenced by the temper of the alloy, the welding process, and the filler metal used. Also, the weldability of wrought and cast alloys is generally considered separately.

Several weldability rating systems are established and may be found in publications by the Aluminum Association, American Welding Society, and the American Society for Metals. Handbooks from these groups can be consulted for more detailed information. Specification AA-R-566 also contains useful information. This document follows most of these references in adopting a four level rating system. An “A” level, or readily weldable, means that the alloy (and temper) is routinely welded by the indicated process using commercial procedures. A “B” level means that welding is accomplished for many applications, but special techniques are required, and the application may require preliminary trials to develop procedures and tests to demonstrate weld performance. A “C” level refers to limited weldability because crack sensitivity, loss of corrosion resistance, and/or loss of mechanical properties may occur. A “D” level indicates that the alloy is not commercially weldable.

The weldability of aluminum alloys is rated by alloy, temper, and welding process (arc or resistance). Tables 3.1.3.4(a) and (b) list the ratings in the alloy section number order in which they appear in Chapter 3.

When heat-treated or work-hardened materials of most systems are welded, a loss of mechanical properties generally occurs. The extent of the loss (if not reheat treated) over the table strength allowables will have to be established for each specific situation.

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**Table 3.1.3.4(a). Fabrication Weldability of Wrought Aluminum Alloys**

| MIL-HDBK-5<br>Section No. | Alloy | Tempers                                                                                | Weldability <sup>a,b</sup>         |                                 |
|---------------------------|-------|----------------------------------------------------------------------------------------|------------------------------------|---------------------------------|
|                           |       |                                                                                        | Inert Gas Metal<br>or Tungsten Arc | Resistance<br>Spot <sup>c</sup> |
| 3.2.1                     | 2014  | O<br>T6, T62, T651, T652, T6510, T6511                                                 | C<br>B                             | D<br>B                          |
| 3.2.2                     | 2017  | T4, T42, T451                                                                          | C                                  | B                               |
| 3.2.3                     | 2024  | O<br>T3, T351, T361, T4, T42<br>T6, T62, T81, T851, T861<br>T8510, T8511, T3510, T3511 | D<br>C<br>C<br>C<br>C              | D<br>B<br>B<br>B<br>B           |
| 3.2.4                     | 2025  | T6                                                                                     | C                                  | B                               |
| 3.2.5                     | 2090  | T83                                                                                    | B                                  | B                               |
| 3.2.6                     | 2124  | T851                                                                                   | C                                  | B                               |
| 3.2.7                     | 2219  | O<br>T62, T81, T851, T87, T8510, T8511                                                 | A<br>A                             | B-D<br>A                        |
| 3.2.8                     | 2618  | T61                                                                                    | C                                  | B                               |
| 3.2.9                     | 2519  | T87                                                                                    | A                                  | ...                             |
| 3.5.1                     | 5052  | O<br>H32, H34, H36, H38                                                                | A<br>A                             | B<br>A                          |
| 3.5.2                     | 5083  | O<br>H321, H323, H343, H111, H112                                                      | A<br>A                             | B<br>A                          |
| 3.5.3                     | 5086  | O<br>H32, H34, H36, H38, H111, H112                                                    | A<br>A                             | B<br>A                          |
| 3.5.4                     | 5454  | O<br>H32, H34, H111, H112                                                              | A<br>A                             | B<br>A                          |
| 3.5.5                     | 5456  | O<br>H111, H321, H112                                                                  | A<br>A                             | B<br>A                          |
| 3.6.1                     | 6013  | T6                                                                                     | A                                  | A                               |
| 3.6.2                     | 6061  | O<br>T4, T42, T451, T4510, T4511, T6<br>T62, T651, T652, T6510, T6511                  | A<br>A<br>A                        | B<br>A<br>A                     |
| 3.6.3                     | 6151  | T6                                                                                     | A                                  | A                               |
| 3.7.1                     | 7010  | All                                                                                    | C                                  | B                               |
| 3.7.2                     | 7040  | All                                                                                    | C                                  | B                               |
| 3.7.3                     | 7049  | All                                                                                    | C                                  | B                               |
|                           | 7149  |                                                                                        |                                    |                                 |
| 3.7.4                     | 7050  | All                                                                                    | C                                  | B                               |
| 3.7.5                     | 7055  |                                                                                        |                                    |                                 |
| 3.7.6                     | 7075  | All                                                                                    | C                                  | B                               |
| 3.7.7                     | 7150  | All                                                                                    | C                                  | B                               |
| 3.7.8                     | 7175  | All                                                                                    | C                                  | B                               |
| 3.7.9                     | 7249  |                                                                                        |                                    |                                 |
| 3.7.10                    | 7475  | All                                                                                    | C                                  | B                               |

a Ratings A through D are relative ratings defined as follows:

A - Generally weldable by all commercial procedures and methods.

B - Weldable with special techniques or for specific applications which justify preliminary trials or testing to develop welding procedures and weld performance.

C - Limited weldability because of crack sensitivity or loss in resistance to corrosion and mechanical properties.

D - No commonly used welding methods have been developed.

b When using filler wire, the wire should contain less than 0.0008 percent beryllium to avoid toxic fumes.

c See MIL-W-6858 for permissible combinations.

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**1 December 1998**

**Table 3.1.3.4(b). Fabrication Weldability<sup>a</sup> of Cast Alumimun Alloys**

| MIL-HDBK-5<br>Section No. | Alloy  | Weldability <sup>b,c</sup>         |                 |
|---------------------------|--------|------------------------------------|-----------------|
|                           |        | Inert Gas Metal or<br>Tungsten Arc | Resistance Spot |
| 3.8.1                     | A201.0 | C                                  | C               |
| 3.9.1                     | 354.0  | B                                  | B               |
| 3.9.2                     | 355.0  | B                                  | B               |
| 3.9.3                     | C355.0 | B                                  | B               |
| 3.9.4                     | 356.0  | A                                  | A               |
| 3.9.5                     | A356.0 | A                                  | A               |
| 3.9.6                     | A357.0 | A                                  | B               |
| 3.9.7                     | D357.0 | A                                  | A               |
| 3.9.8                     | 359.0  | A                                  | B               |

- a Weldability related to joining a casting to another part of same composition. The weldability ratings are not applicable to minor weld repairs. Such repairs shall be governed by the contractors procedure for in-process welding of castings, after approval by the procuring agency.
- b Ratings A through D are relative ratings defined as follows:
- A - Generally weldable by all commercial procedures and methods.
  - B - Weldable with special techniques or for specific applications which justify preliminary trials or testing to develop welding procedure and weld performance.
  - C - Limited weldability because of crack sensitivity or loss in resistance to corrosion and mechanical properties.
  - D - No commonly used welding methods have been developed.
- c When using filler wire, the wire should contain less than 0.0008 percent beryllium to avoid toxic fumes.

# MAGNESIUM ALLOYS

## 4.1 GENERAL

This chapter contains the engineering properties and characteristics of wrought and cast magnesium alloys used in aircraft and missile applications. Magnesium is a lightweight structural metal that can be strengthened greatly by alloying, and in some cases by heat treatment or cold work or by both.

**4.1.1 ALLOY INDEX**— The magnesium alloys in this chapter are listed in alphanumeric sequence in each of two parts, the first one being wrought forms of magnesium and the second cast forms. These sections and the alloys covered under each are shown in Table 4.1.

Table 4.1. Magnesium Alloy Index

| Section | Designation                     |
|---------|---------------------------------|
| 4.2     | <b>Magnesium-Wrought Alloys</b> |
| 4.2.1   | AZ31B                           |
| 4.2.2   | AZ61A                           |
| 4.2.3   | ZK60A                           |
| 4.3     | <b>Magnesium-Cast Alloys</b>    |
| 4.3.1   | AM100A                          |
| 4.3.2   | AZ91C/AZ91E                     |
| 4.3.3   | AZ92A                           |
| 4.3.4   | EZ33A                           |
| 4.3.5   | QE22A                           |
| 4.3.6   | ZE41A                           |

## 4.1.2 MATERIAL PROPERTIES

**4.1.2.1 Mechanical Properties** — The mechanical properties are given either as design values or for information purposes. The tensile strength ( $F_{tu}$ ), tensile yield strength ( $F_{ty}$ ), elongation ( $e$ ), and sometimes the compressive yield strength ( $F_{cy}$ ) are guaranteed by procurement specifications. The properties obtained reflect the location of sample, type of test specimen and method of testing required by the product specification. The remaining design values are “derived” values; that is, sufficient tests have been made to ascertain that if a given material meets the requirements of the product specification, the material will have the compression ( $F_{cy}$ ), shear ( $F_{su}$ ) and bearing ( $F_{bru}$  and  $F_{bry}$ ) strengths listed.

**4.1.2.1.1 Tension Testing** — Room-temperature tension tests are made according to ASTM E 8. The yield strength ( $F_{ty}$ ) is obtained by the “offset method” using an offset of 0.2 percent. The speed of testing for room-temperature tests has a small effect on the strength and elongation values obtained on most magnesium alloys. The rate of stressing generally specified to the yield strength is less than 100,000 psi per



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minute and the rate of straining from the yield strength to fracture is less than 0.5 in./in./min. It can be expected that the speed of testing used for room-temperature tension tests will approach the maximum permitted.

Elevated-temperature tension tests are made according to ASTM E 21. The speed of testing has a considerable effect on the results obtained and no one standard rate of straining is given in ASTM E 21. The strain rates most commonly used on magnesium are 0.005 in./in./min. to the yield and 0.10 in./in./min. from yield to fracture [see References 4.1.2.1(a) to (d)].

**4.1.2.1.2 Compression Testing** — Compression test methods used for magnesium are specified in ASTM E 9. The values given for the compressive yield strength ( $F_{cy}$ ), are taken at an offset of 0.2 percent. References 4.1.2.1.2(a) and (b) provide information on test techniques.

**4.1.2.1.3 Bearing Testing** — Bearing tests of magnesium alloys are made according to ASTM E 238. The size of pin used has a significant effect on the values obtained, especially the bearing ultimate strength ( $F_{bru}$ ). On tests made to obtain the data on magnesium alloys shown in this document, pin diameters of 0.187 and 0.250 inch were used. For pin diameters significantly larger than 0.250 inch lower values may be obtained. Additional information on bearing testing is given in References 4.1.2.1.3(a) and (b). Bearing values in the property tables are considered to be “dry pin” values in accordance with the discussion in Section 1.4.7.1.

**4.1.2.1.4 Shear Testing** — The shear strength values used in this document were obtained by the “double shear” method using a pin-type specimen, the “punch shear” method and the “tension shear” method as applicable. Just as tensile ultimate strength ( $F_u$ ) values vary with location and direction of sample in relation to the method of fabrication, the shear strength ( $F_{su}$ ) may be expected to reflect the effect of orientation, either as a function of the sampling or the maximum stresses imposed by the method of test. Information on shear testing is given in Reference 4.1.2.1.4.

**4.1.2.1.5 Stress Raisers** — The effect of notches, holes, and stress raisers on the static properties of magnesium alloys is described in References 4.1.2.1.5(a) through (c). Additional data on the strength properties of magnesium alloys are presented in References 4.1.2.1.5(d) through (h).

**4.1.2.1.6 Creep** — Some creep data on magnesium alloys are summarized in Reference 4.1.2.1.6.

**4.1.2.1.7 Fatigue** — Room-temperature axial load fatigue data for several magnesium alloys are presented in appropriate alloy sections. References 4.1.2.1.7(a) and (b) provide additional data on fatigue of magnesium alloys.

**4.1.3 PHYSICAL PROPERTIES** — Selected experimental data from the literature were used in determining values for physical properties. In other cases, enough information was available to calculate the constants. Estimated values of some of the remaining constants were also included. Estimated values are noted.

**4.1.4 ENVIRONMENTAL CONSIDERATIONS** — Corrosion protection must be considered for all magnesium applications. Protection can be provided by anodic films, chemical conversion coatings, paint systems, platings, or a combination of these methods. Proper drainage must be provided to prevent entrapment of water or other fluids. Dissimilar metal joints must be properly and completely insulated, including barrier strips and sealants.

Strain-hardened or age-hardened alloys may be annealed or overaged by prolonged exposure to elevated temperatures, with a resulting decrease in strength. Maximum recommended temperatures for prolonged service are reported, where available, for specific alloys.

**4.1.5 ALLOY AND TEMPER DESIGNATIONS**— Standard ASTM nomenclature is used for the alloys listed. Temper designations are given in ASTM B 296. A summary of the temper designations is given in Table 4.1.5.

**4.1.6 JOINING METHODS** — Most magnesium alloys may be welded; refer to “Comments and Properties” in individual alloy sections. Adhesive bonding and brazing may be used to join magnesium to itself or other alloys. All types of mechanical fasteners may be used to join magnesium. Refer to Section 4.1.4 when using mechanical fasteners or joining of dissimilar materials with magnesium alloys.

Table 4.1.5 Temper Designation System for Magnesium Alloys

| Temper Designation System <sup>a</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                           |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>This temper designation system is used for all forms of wrought and cast magnesium and magnesium alloy products except ingots. It is based on the sequence of basic treatments used to produce the various tempers. The temper designation follows the alloy designation, the two being separated by a hyphen. Basic temper designations consist of letters. Subdivisions of the basic tempers, where required, are indicated by one or more digits following the letter. These designate specific sequences of basic treatments, but only operations recognized as significantly influencing the characteristics of the product are indicated. Should some other variation of the same sequence of basic operations be applied to the same alloy, resulting in different characteristics, then additional digits are added to the designation.</p> <p>NOTE—In material specifications containing reference to two or more tempers of the same alloy which result in identical mechanical properties, the distinction between the tempers should be covered in suitable explanatory notes.</p> |                                                                                                                                                                                                                                                                                                                                                           |
| Basic Temper Designations                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                           |
| F                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | <b>as fabricated.</b> Applies to the products of shaping processes in which no special control over thermal conditions or strain-hardening is employed.                                                                                                                                                                                                   |
| O                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | <b>annealed recrystallized (wrought products only).</b> Applies to wrought products which are annealed to obtain the lowest strength temper.                                                                                                                                                                                                              |
| H                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | <b>strain-hardened (wrought products only).</b> Applies to products which have their strength increased by strain-hardening, with or without supplementary thermal treatments to produce some reduction in strength. The H is always followed by two or more digits.                                                                                      |
| W                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | <b>solution heat-treated.</b> An unstable temper applicable only to alloys which spontaneously age at room temperature after solution heat-treatment. This designation is specific only when the period of natural aging is indicated: for example, W ½ hr.                                                                                               |
| T                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | <b>thermally treated to product stable tempers other than F, O, or H.</b> Applies to products which are thermally treated, with or without supplementary strain-hardening, to product stable tempers. The T is always followed by one or more digits.                                                                                                     |
| Subdivisions of H Temper: Strain-Hardened                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                           |
| The first digit following H indicates the specific combination of basic operations, as follows:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                           |
| H1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | <b>strain-hardened only.</b> Applies to products which are strain-hardened to obtain the desired strength without supplementary thermal treatment. The number following this designation indicates the degree of strain-hardening.                                                                                                                        |
| H2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | <b>strain-hardened and partially annealed.</b> Applies to products which are strain-hardened more than the desired final amount and then reduced in strength to the desired level by partial annealing. The number following this designation indicates the degree of strain-hardening remaining after the product has been partially annealed.           |
| H3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | <b>strain-hardened and stabilized.</b> Applies to products which are strain-hardened and whose mechanical properties are stabilized by a low temperature thermal treatment to slightly lower strength and increase ductility. The number following this designation indicates the degree of strain-hardening remaining after the stabilization treatment. |
| The digit following the designations H1, H2, and H3 indicates the final degree of strain hardening. Tempers between 0 (annealed) and 8 (full-hard) are designated by numerals 1 through 7. Material having an ultimate tensile strength about midway between                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                           |

a From ASTM B 296.

**Table 4.1.5 Temper Designation System for Magnesium Alloys (Continued)**

that of the 0 temper and that of the 8 temper is designated by the numeral 4; about midway between the 0 and 4 tempers by the numeral 2; and about midway between 4 and 8 tempers by the numeral 6, etc. Numeral 9 designates tempers whose minimum ultimate tensile strength exceeds that of the 8 temper.

The third digit, when used, indicates a variation of a two-digit temper. It is used when the degree of control of temper or the mechanical properties or both differ from, but are close to, that (or those) for the two-digit H temper designation to which it is added. Numerals 1 through 9 may be arbitrarily assigned as the third digit for an alloy and product to indicate a specific degree of control of temper or special mechanical property limits.

**Subdivisions of T Temper:  
Thermally Treated**

Numerals 1 through 10 following the T indicate specific sequences of basic treatments, as follows.

- T1**    **cooled from an elevated temperature shaping process and naturally aged to a substantially stable condition.** Applies to products for which the rate of cooling from an elevated temperature shaping process, such as casting or extrusion, is such that their strength is increased by room temperature aging.
- T2**    **annealed (castings only).** Applies to a type of annealing treatment used to improve ductility and increase stability.
- T3**    **solution heat-treated and cold worked.** Applies to products which are cold worked to improve strength after solution heat-treatment, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.
- T4**    **solution heat-treated and naturally aged to a substantially stable condition.** Applies to products which are not cold worked after solution heat-treatment, or in which the effect of cold work in flattening or straight-

ening may not be recognized in mechanical property limits.

- T5**    **cooled from an elevated temperature shaping process and artificially aged.** Applies to products which are cooled from an elevated temperature shaping process, such as casting or extrusion, and artificially aged to improve mechanical properties or dimensional stability or both.
  - T6**    **solution heat-treated and artificially aged.** Applies to products which are not cold worked after solution heat-treatment, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.
  - T7**    **solution heat-treated and stabilized.** Applies to products that are stabilized after solution heat-treatment to carry them beyond a point of maximum strength to provide control of some special characteristic.
  - T8**    **solution heat-treated, cold worked, and artificially aged.** Applies to products which are cold worked to improve strength, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.
  - T9**    **solution heat-treated, artificially aged, and cold worked.** Applies to products which are cold worked to improve strength.
  - T10**    **cooled from an elevated temperature shaping process, artificially aged, and cold worked.** Applies to products which are artificially aged after cooling from an elevated temperature shaping process, such as extrusion, and cold worked to further improve strength.
- Additional digits, the first of which shall not be zero, may be added to designations T1 through T10 to indicate a variation in treatment which significantly alters the product characteristics<sup>b</sup> that are or would be obtained using the basic treatment.

<sup>b</sup> For this purpose, characteristic is something other than mechanical properties.

4.2 MAGNESIUM-WROUGHT ALLOYS

4.2.1 AZ31B

**4.2.1.0 Comments and Properties** — AZ31B is a wrought magnesium-base alloy containing aluminum and zinc. It is available in the form of sheet, plate, extruded sections, forgings, and tubes. AZ31B has good room-temperature strength and ductility and is used primarily for applications where the temperature does not exceed 300°F. Increased strength is obtained in the sheet and plate form by strain hardening with a subsequent partial anneal (H24 and H26 temper). No treatments are available for increasing the strength of this alloy after fabrication.

Forming of AZ31B must be done at elevated temperatures if small radii or deep draws are required. If the temperatures used are too high or the times too great, H24 and H26 temper material will be softened. This alloy is readily welded but must be stress relieved after welding to prevent stress corrosion cracking.

Material specifications covering AZ31B wrought products are given in Table 4.2.1.0(a). Room-temperature mechanical and physical properties are shown in Tables 4.2.1.0(b) through (d). The effect of temperature on physical properties is shown in Figure 4.2.1.0.

**Table 4.2.1.0(a). Material Specifications for AZ31B Magnesium Alloy**

| Specification | Form            |
|---------------|-----------------|
| AMS 4375      | Sheet and plate |
| AMS 4376      | Plate           |
| AMS 4377      | Sheet and plate |
| ASTM B 107    | Extrusion       |
| ASTM B 91     | Forging         |

The temper index for AZ31B is as follows:

| <u>Section</u> | <u>Temper</u> |
|----------------|---------------|
| 4.2.1.1        | O             |
| 4.2.1.2        | H24           |
| 4.2.1.3        | H26           |
| 4.2.1.4        | F             |

**4.2.1.1 AZ31B-O Temper** — Effect of temperature on the tensile modulus of sheet and plate is presented in Figure 4.2.1.1.4. Typical room-temperature stress-strain and tangent-modulus curves are presented in Figure 4.2.1.1.6.

**4.2.1.2 AZ31B-H24 Temper** — Effect of temperature on the mechanical properties of sheet and plate is shown in Figures 4.2.1.2.1 through 4.2.1.2.4, and 4.2.1.2.6. Typical room-temperature tension and compression stress-strain and tangent-modulus curves for sheet are shown in Figure 4.2.1.2.6.

**4.2.1.3 AZ31B-H26 Temper**

**4.2.1.4 AZ31B-F Temper** — Figures 4.2.1.4.8 (a) and (b) contain fatigue data for forged disk at room temperature.

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 4.2.1.0(b). Design Mechanical and Physical Properties of AZ31B Magnesium Alloy Sheet and Plate**

| Specification . . . . .                  | AMS 4375           |             |             |             |             | AMS 4377    |             |             |             |             |             |             |
|------------------------------------------|--------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Form . . . . .                           | Sheet              |             | Plate       |             |             | Sheet       |             | Plate       |             |             |             |             |
| Temper . . . . .                         | 0                  |             |             |             |             | H24         |             |             |             |             |             |             |
| Thickness, in. . . . .                   | 0.016-0.060        | 0.061-0.249 | 0.250-0.500 | 0.501-2.000 | 2.001-3.000 | 0.016-0.062 | 0.063-0.249 | 0.250-0.374 | 0.375-0.500 | 0.501-1.000 | 1.001-2.000 | 2.001-3.000 |
| Basis . . . . .                          | S                  | S           | S           | S           | S           | S           | S           | S           | S           | S           | S           | S           |
| Mechanical Properties:                   |                    |             |             |             |             |             |             |             |             |             |             |             |
| $F_{tu}$ , ksi:                          |                    |             |             |             |             |             |             |             |             |             |             |             |
| L . . . . .                              | 32                 | 32          | 32          | 32          | 32          | 39          | 39          | 38          | 37          | 36          | 34          | 34          |
| LT . . . . .                             | ...                | ...         | ...         | ...         | ...         | 40          | 40          | 39          | 38          | 37          | 35          | ...         |
| $F_{ty}$ , ksi:                          |                    |             |             |             |             |             |             |             |             |             |             |             |
| L . . . . .                              | 18                 | 15          | 15          | 15          | 15          | 29          | 29          | 26          | 24          | 22          | 20          | 18          |
| LT . . . . .                             | ...                | ...         | ...         | ...         | ...         | 32          | 32          | 29          | 27          | 25          | 23          | ...         |
| $F_{cy}$ , ksi:                          |                    |             |             |             |             |             |             |             |             |             |             |             |
| L . . . . .                              | ...                | 12          | 10          | 10          | 8           | ...         | 24          | 20          | 16          | 13          | 10          | 9           |
| LT <sup>a</sup> . . . . .                | ...                | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         | ...         |
| $F_{su}$ , ksi . . . . .                 | 17                 | 17          | 17          | ...         | ...         | 18          | 18          | 18          | 18          | ...         | ...         | ...         |
| $F_{bru}^b$ , ksi:                       |                    |             |             |             |             |             |             |             |             |             |             |             |
| (e/D = 1.5) . . . . .                    | 50                 | 50          | 50          | ...         | ...         | 58          | 58          | 56          | 54          | ...         | ...         | ...         |
| (e/D = 2.0) . . . . .                    | 60                 | 60          | 60          | ...         | ...         | 68          | 68          | 65          | 63          | ...         | ...         | ...         |
| $F_{bry}^b$ , ksi:                       |                    |             |             |             |             |             |             |             |             |             |             |             |
| (e/D = 1.5) . . . . .                    | 29                 | 29          | 27          | ...         | ...         | 43          | 43          | 38          | 34          | ...         | ...         | ...         |
| (e/D = 2.0) . . . . .                    | 29                 | 29          | 27          | ...         | ...         | 43          | 43          | 38          | 34          | ...         | ...         | ...         |
| e, percent . . . . .                     |                    |             |             |             |             |             |             |             |             |             |             |             |
| L . . . . .                              | 12                 | 12          | 12          | 10          | 9           | 6           | 6           | 8           | 8           | 8           | 8           | 8           |
| $E$ , 10 <sup>3</sup> ksi . . . . .      | 6.5                |             |             |             |             |             |             |             |             |             |             |             |
| $E_c$ , 10 <sup>3</sup> ksi . . . . .    | 6.5                |             |             |             |             |             |             |             |             |             |             |             |
| $G$ , 10 <sup>3</sup> ksi . . . . .      | 2.4                |             |             |             |             |             |             |             |             |             |             |             |
| $\mu$ . . . . .                          | 0.35               |             |             |             |             |             |             |             |             |             |             |             |
| Physical Properties:                     |                    |             |             |             |             |             |             |             |             |             |             |             |
| $\omega$ , lb/in. <sup>3</sup> . . . . . | 0.0639             |             |             |             |             |             |             |             |             |             |             |             |
| C, K, and $\alpha$ . . . . .             | See Figure 4.2.1.0 |             |             |             |             |             |             |             |             |             |             |             |

a  $F_{cy}$ (LT) allowables are equal to or greater than  $F_{cy}$ (L) allowables.  
b Bearing values are “dry pin” values per Section 1.4.7.1.

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 4.2.1.0(c). Design Mechanical and Physical Properties of AZ31B Magnesium Alloy Plate**

|                                      |                    |                 |                 |                 |                 |                 |                 |
|--------------------------------------|--------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Specification .....                  | AMS 4376           |                 |                 |                 |                 |                 |                 |
| Form .....                           | Plate              |                 |                 |                 |                 |                 |                 |
| Temper .....                         | H26                |                 |                 |                 |                 |                 |                 |
| Thickness <sup>a</sup> , in. ....    | 0.250-<br>0.375    | 0.376-<br>0.438 | 0.439-<br>0.500 | 0.501-<br>0.750 | 0.751-<br>1.000 | 1.001-<br>1.500 | 1.501-<br>2.000 |
| Basis .....                          | S                  | S               | S               | S               | S               | S               | S               |
| Mechanical Properties:               |                    |                 |                 |                 |                 |                 |                 |
| $F_{tu}$ , ksi:                      |                    |                 |                 |                 |                 |                 |                 |
| L .....                              | 39                 | 38              | 38              | 37              | 37              | 35              | 35              |
| LT .....                             | 40                 | 39              | 39              | 38              | 38              | 36              | 36              |
| $F_{ty}$ , ksi:                      |                    |                 |                 |                 |                 |                 |                 |
| L .....                              | 27                 | 26              | 26              | 25              | 23              | 22              | 21              |
| LT .....                             | 30                 | 29              | 29              | 28              | 26              | 25              | 24              |
| $F_{cy}$ , ksi:                      |                    |                 |                 |                 |                 |                 |                 |
| L .....                              | 22                 | 21              | 18              | 17              | 16              | 15              | 14              |
| LT <sup>a</sup> .....                | ...                | ...             | ....            | ...             | ...             | ...             | ...             |
| $F_{su}$ , ksi .....                 | 18                 | 18              | 18              | ...             | ...             | ...             | ...             |
| $F_{bru}^b$ , ksi:                   |                    |                 |                 |                 |                 |                 |                 |
| (e/D = 1.5) .....                    | 58                 | 56              | 56              | ...             | ...             | ...             | ...             |
| (e/D = 2.0) .....                    | 68                 | 65              | 65              | ...             | ...             | ...             | ...             |
| $F_{bry}^b$ , ksi:                   |                    |                 |                 |                 |                 |                 |                 |
| (e/D = 1.5) .....                    | 40                 | 39              | 36              | ...             | ...             | ...             | ...             |
| (e/D = 2.0) .....                    | 40                 | 39              | 36              | ...             | ...             | ...             | ...             |
| $e$ , percent:                       |                    |                 |                 |                 |                 |                 |                 |
| L .....                              | 6                  | 6               | 6               | 6               | 6               | 6               | 6               |
| $E$ , 10 <sup>3</sup> ksi .....      | 6.5                |                 |                 |                 |                 |                 |                 |
| $E_c$ , 10 <sup>3</sup> ksi .....    | 6.5                |                 |                 |                 |                 |                 |                 |
| $G$ , 10 <sup>3</sup> ksi .....      | 2.4                |                 |                 |                 |                 |                 |                 |
| $\mu$ .....                          | 0.35               |                 |                 |                 |                 |                 |                 |
| Physical Properties:                 |                    |                 |                 |                 |                 |                 |                 |
| $\omega$ , lb/in. <sup>3</sup> ..... | 0.0639             |                 |                 |                 |                 |                 |                 |
| $C$ , $K$ , and $\alpha$ .....       | See Figure 4.2.1.0 |                 |                 |                 |                 |                 |                 |

a  $F_{cy}$ (LT) allowables are equal to or greater than  $F_{cy}$ (L) values.  
b Bearing values are "dry pin" values per Section 1.4.7.1.

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 4.2.1.0(d). Design Mechanical and Physical Properties of AZ31B Magnesium Alloy Extrusion and Forging**

| Specification . . . . .                              | ASTM B 107                          |             |             |             |                        |                          |                          | ASTM B 91 |
|------------------------------------------------------|-------------------------------------|-------------|-------------|-------------|------------------------|--------------------------|--------------------------|-----------|
| Form . . . . .                                       | Extruded bar, rod, and solid shapes |             |             |             | Extruded hollow shapes | Extruded tube            |                          | Forging   |
| Temper . . . . .                                     | F                                   |             |             |             |                        |                          |                          |           |
| Thickness <sup>a</sup> , in. . . . .                 | ≤0.249                              | 0.250-1.499 | 1.500-2.499 | 2.500-4.999 | All                    | 0.028-0.250 <sup>b</sup> | 0.251-0.750 <sup>b</sup> | ...       |
| Basis . . . . .                                      | S                                   | S           | S           | S           | S                      | S                        | S                        | S         |
| Mechanical Properties:                               |                                     |             |             |             |                        |                          |                          |           |
| <i>F<sub>tu</sub></i> , ksi:                         |                                     |             |             |             |                        |                          |                          |           |
| L . . . . .                                          | 35                                  | 35          | 34          | 32          | 32                     | 32                       | 32                       | 34        |
| LT . . . . .                                         | ...                                 | ...         | ...         | ...         | ...                    | ...                      | ...                      | ...       |
| <i>F<sub>ty</sub></i> , ksi:                         |                                     |             |             |             |                        |                          |                          |           |
| L . . . . .                                          | 21                                  | 22          | 22          | 20          | 16                     | 16                       | 16                       | 19        |
| LT . . . . .                                         | ...                                 | ...         | ...         | ...         | ...                    | ...                      | ...                      | ...       |
| <i>F<sub>cy</sub></i> , ksi:                         |                                     |             |             |             |                        |                          |                          |           |
| L . . . . .                                          | ...                                 | 12          | 12          | 10          | 10                     | 10                       | 10                       | ...       |
| LT . . . . .                                         | ...                                 | ...         | ...         | ...         | ...                    | ...                      | ...                      | ...       |
| <i>F<sub>su</sub></i> , ksi . . . . .                | 17                                  | 17          | 17          | ...         | ...                    | ...                      | ...                      | ...       |
| <i>F<sub>bru</sub></i> <sup>c</sup> , ksi:           |                                     |             |             |             |                        |                          |                          |           |
| (e/D = 1.5) . . . . .                                | 36                                  | 36          | 36          | ...         | ...                    | ...                      | ...                      | ...       |
| (e/D = 2.0) . . . . .                                | 45                                  | 45          | 45          | ...         | ...                    | ...                      | ...                      | ...       |
| <i>F<sub>bry</sub></i> <sup>c</sup> , ksi:           |                                     |             |             |             |                        |                          |                          |           |
| (e/D = 1.5) . . . . .                                | 23                                  | 23          | 23          | ...         | ...                    | ...                      | ...                      | ...       |
| (e/D = 2.0) . . . . .                                | 23                                  | 23          | 23          | ...         | ...                    | ...                      | ...                      | ...       |
| <i>e</i> , percent:                                  |                                     |             |             |             |                        |                          |                          |           |
| L . . . . .                                          | 7                                   | 7           | 7           | 7           | 8                      | 8                        | 4                        | 6         |
| <i>E</i> , 10 <sup>3</sup> ksi . . . . .             | 6.5                                 |             |             |             |                        |                          |                          |           |
| <i>E<sub>c</sub></i> , 10 <sup>3</sup> ksi . . . . . | 6.5                                 |             |             |             |                        |                          |                          |           |
| <i>G</i> , 10 <sup>3</sup> ksi . . . . .             | 2.4                                 |             |             |             |                        |                          |                          |           |
| μ . . . . .                                          | 0.35                                |             |             |             |                        |                          |                          |           |
| Physical Properties:                                 |                                     |             |             |             |                        |                          |                          |           |
| ω, lb/in. <sup>3</sup> . . . . .                     | 0.0639                              |             |             |             |                        |                          |                          |           |
| <i>C</i> , <i>K</i> , and α . . . . .                | See Figure 4.2.1.0                  |             |             |             |                        |                          |                          |           |

a Wall thickness for tube.  
b For outside diameter ≤6.000 inches.  
c Bearing values are “dry pin” values per Section 1.4.7.1.



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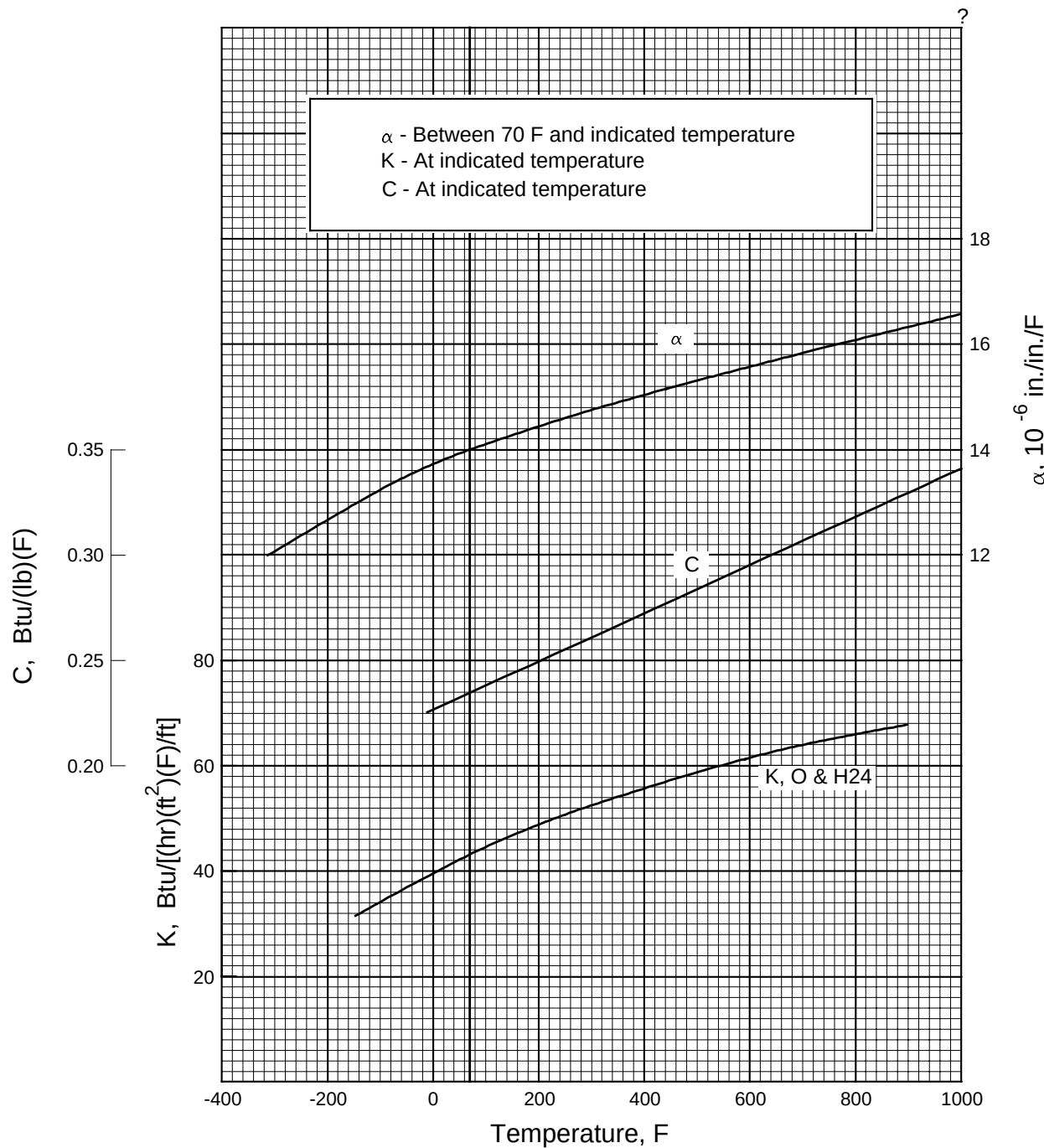


Figure 4.2.1.0. Effect of temperature on the physical properties of AZ31B.

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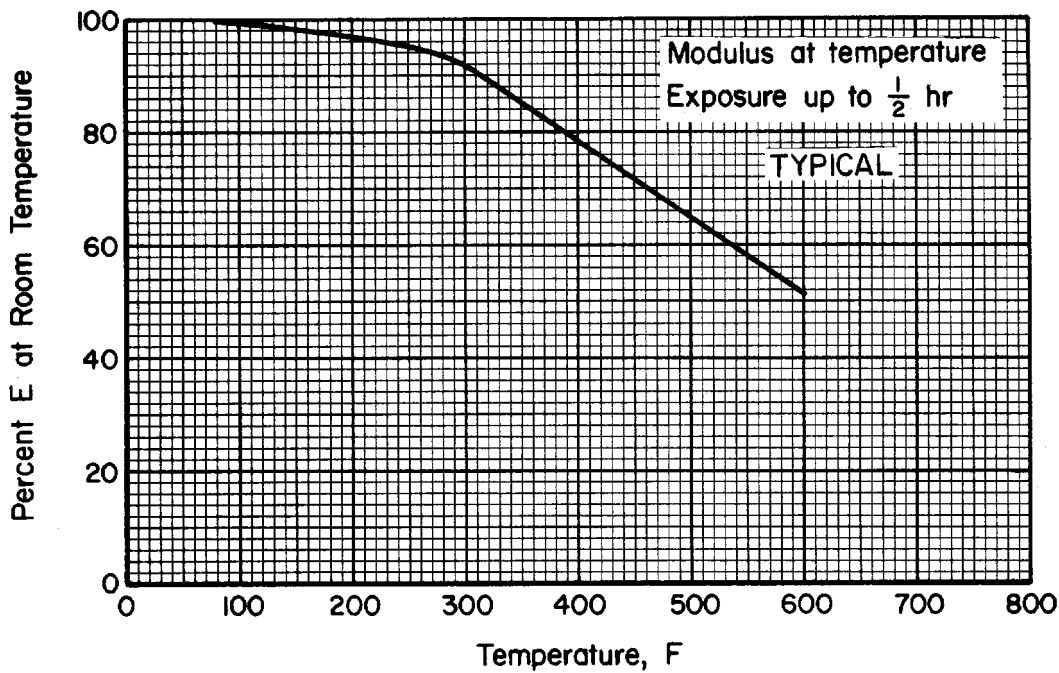


Figure 4.2.1.1.4. Effect of temperature on the tensile modulus (E) of AZ31B-O sheet and plate.

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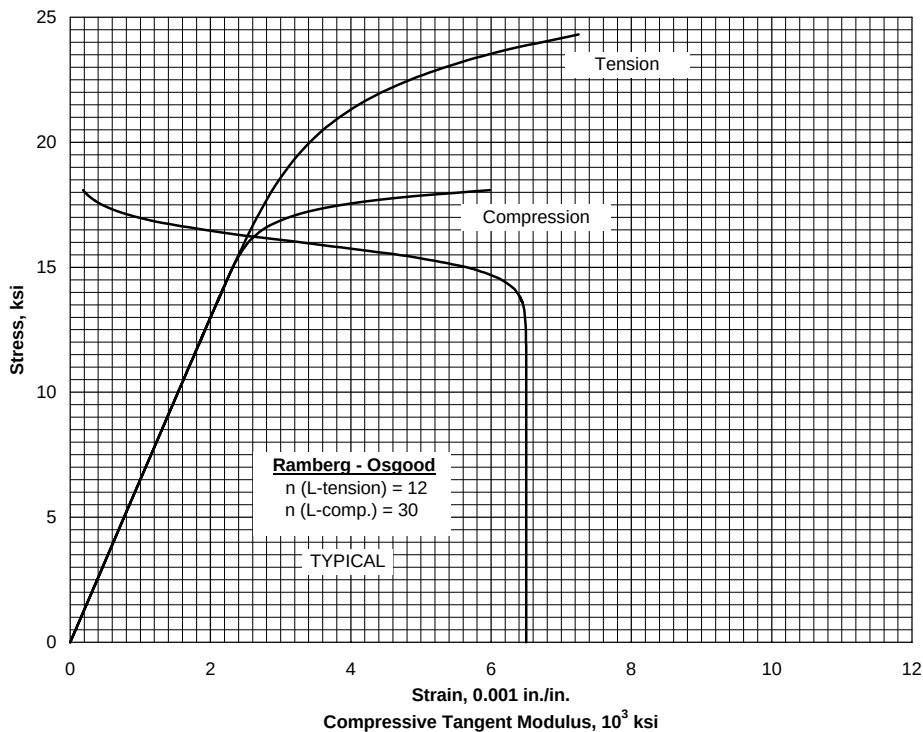


Figure 4.2.1.1.6. Typical tensile and compressive stress-strain and compressive tangent-modulus curves for AZ31B-O sheet and plate at room temperature.

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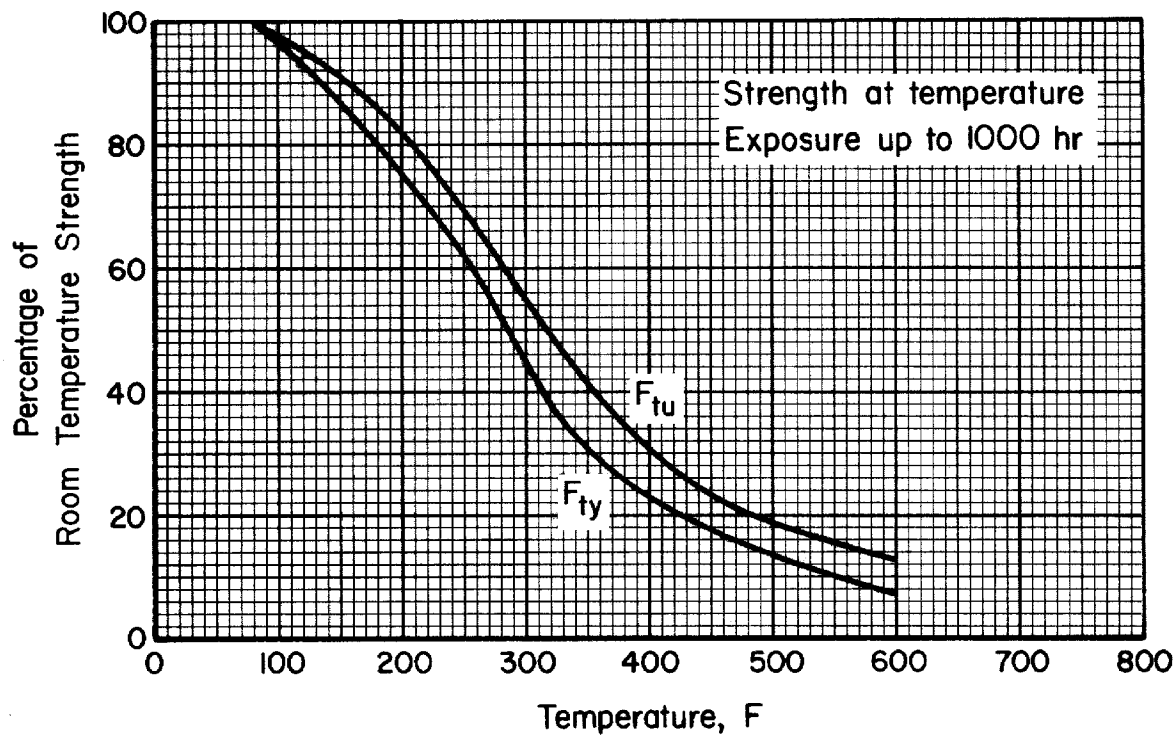


Figure 4.2.1.2.1. Effect of temperature on the tensile ultimate strength ( $F_{tu}$ ) and the tensile yield strength ( $F_{ty}$ ) of AZ31B-H24 sheet and plate.

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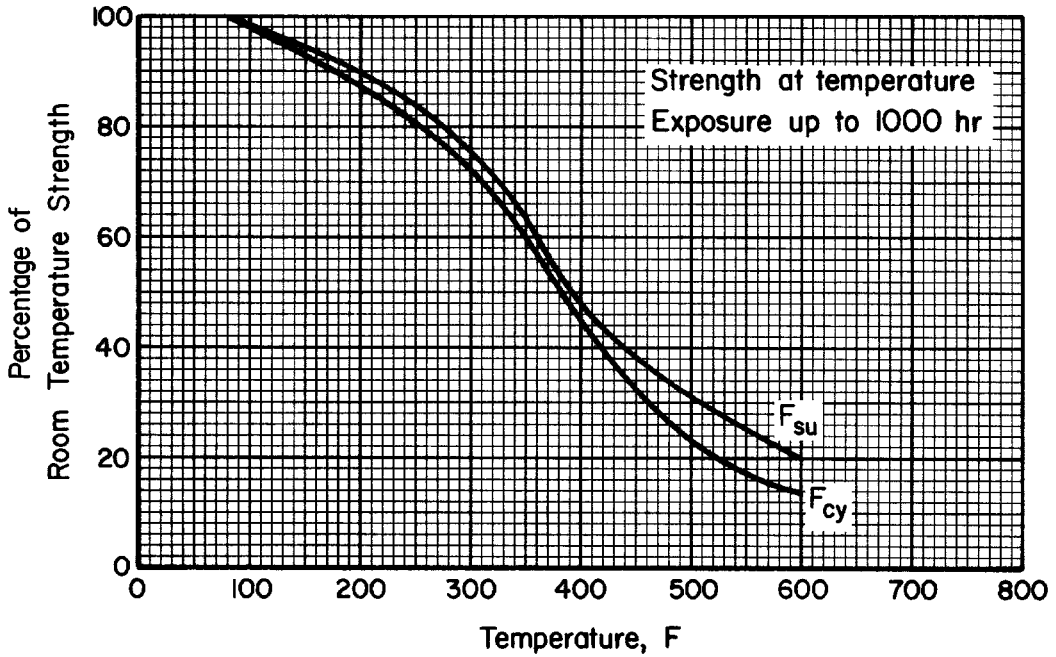


Figure 4.2.1.2.2. Effect of temperature on the compressive yield strength ( $F_{cy}$ ) and the tensile ultimate strength ( $F_{su}$ ) of AZ31B-H24 sheet and plate.

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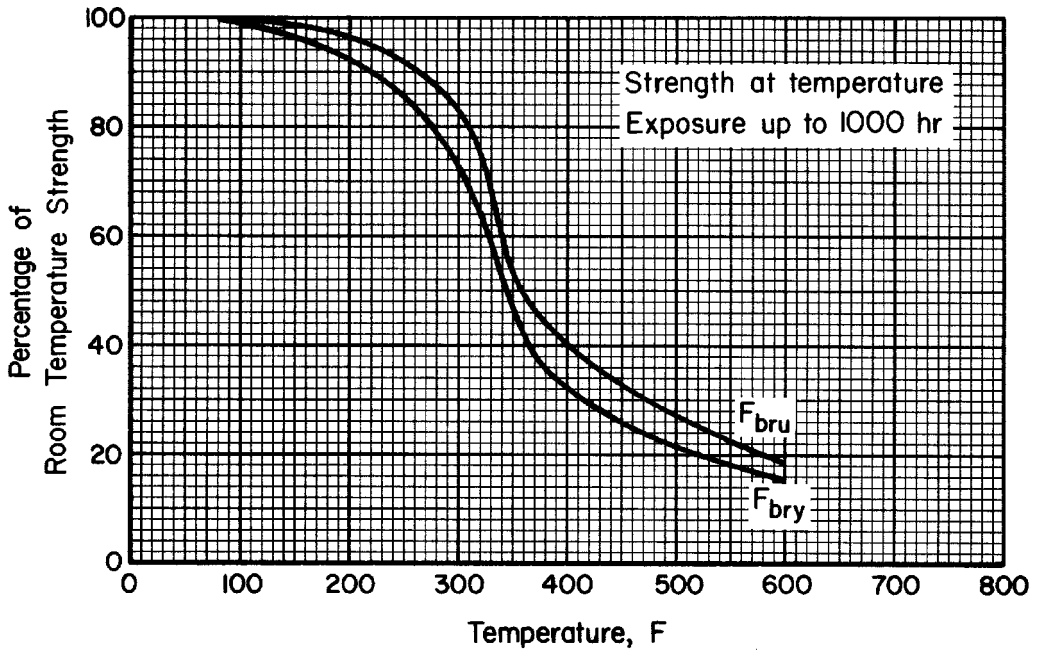


Figure 4.2.1.2.3. Effect of temperature on the bearing ultimate strength ( $F_{bru}$ ) and the bearing yield strength ( $F_{bry}$ ) of AZ31B-H24 sheet and plate.

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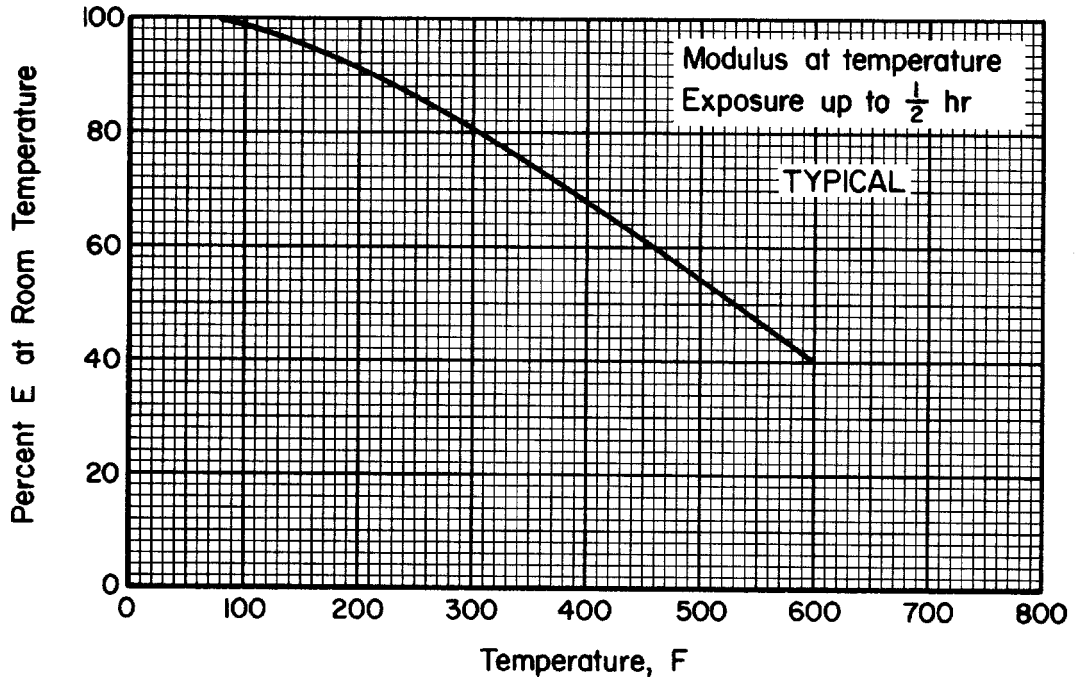


Figure 4.2.1.2.4. Effect of temperature on the tensile modulus (E) of AZ31B-H24 sheet and plate.

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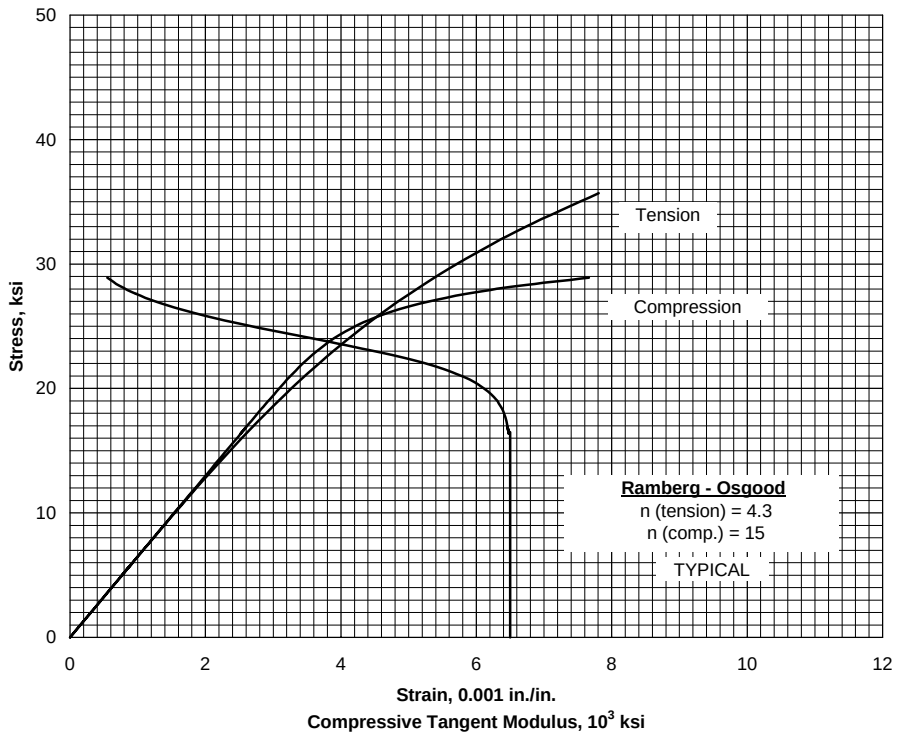


Figure 4.2.1.2.6. Typical tensile and compressive stress-strain and compressive tangent-modulus curves for AZ31B-H24 sheet at room temperature.

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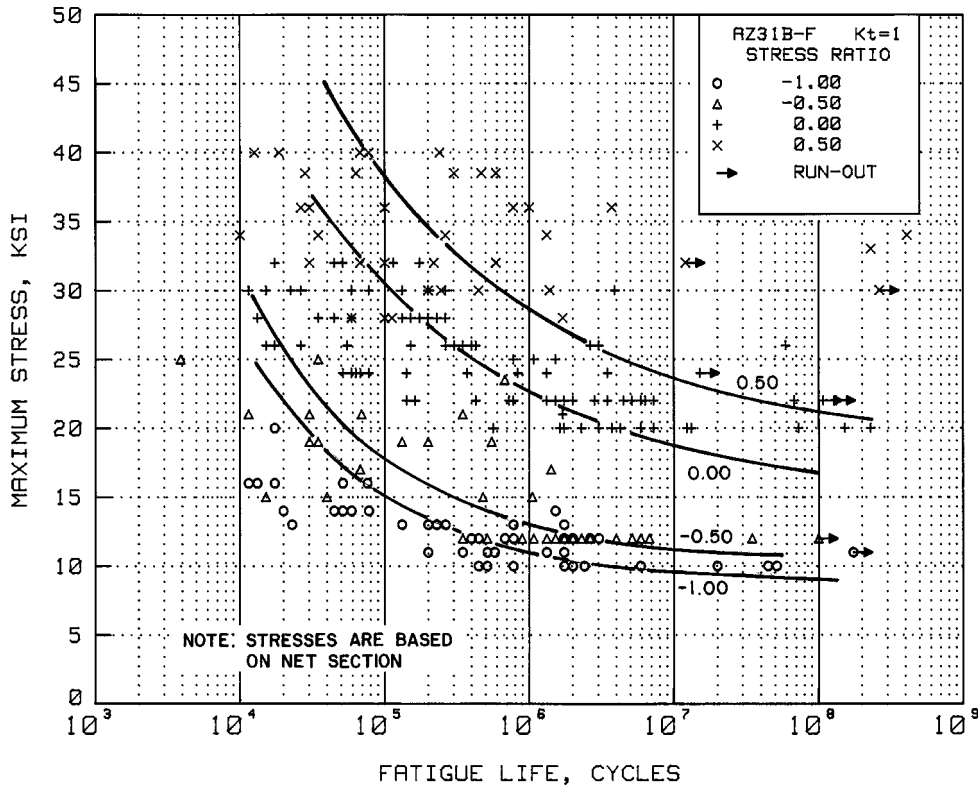
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**Figure 4.2.1.4.8(a). Best-fit S/N curves for unnotched AZ31B-F magnesium alloy forges disk, transverse direction.**

Correlative Information for Figure 4.2.1.4.8(a)

Product Form: Forged disk, 1-inch thick

No. of Heats/Lots: 1

Properties: TUS, ksi TYS, ksi Temp., °F

Equivalent Stress Equation:

38 26 RT

For R values between -1.0 and -0.50

$$\log N_f = 7.13 - 2.20 \log (S_{eq} - 12.9)$$

$$S_{eq} = S_{max}(1-R)^{0.56}$$

Standard Error of Estimate = 0.613

Standard Deviation in Life = 0.916

$$R^2 = 55.2\%$$

Specimen Details: Unnotched  
0.75-inch gross diameter  
0.30-inch net diameter

Surface Condition:

Polished sequentially with No. 320 aluminum oxide cloth, No. 0, 00, and 000 emery paper and finally No. 600 aluminum oxide powder in water

For R values between 0.0 and 0.50

$$\log N_f = 8.87 - 3.26 \log (S_{eq} - 15.0)$$

$$S_{eq} = S_{max}(1-R)^{0.33}$$

Standard Error of Estimate = 0.829

Standard Deviation in Life = 1.014

$$R^2 = 33.2\%$$

References: 4.2.1.1.8

Sample Size = 194

Test Parameters:

Loading - Axial  
Frequency - 1500 cpm  
Temperature - RT  
Environment - Air

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

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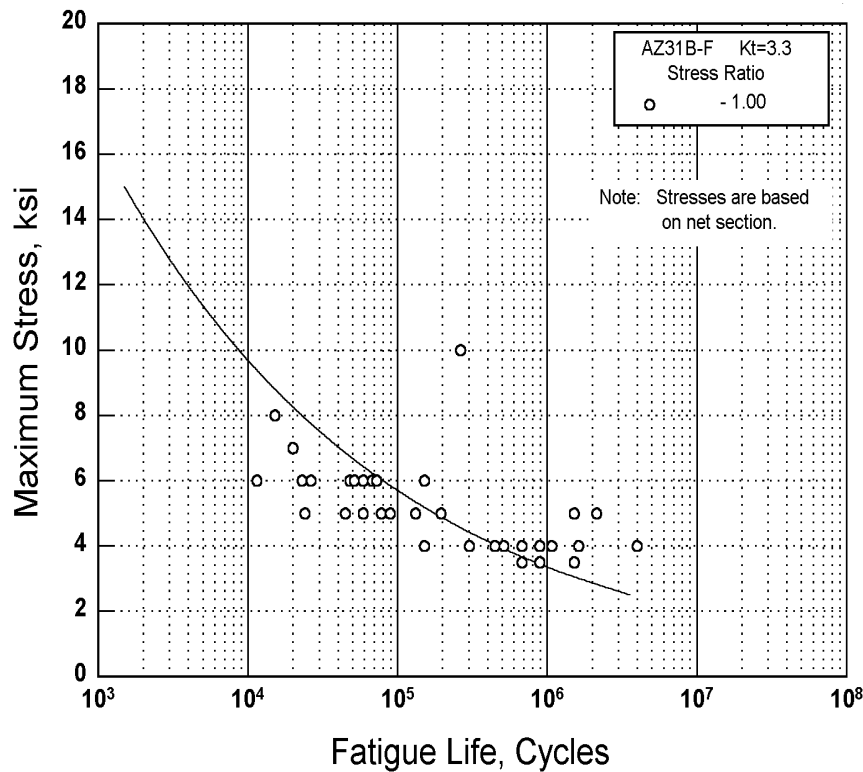


**Figure 4.2.1.4.8(b). Best-fit S/N curves for notched,  $K_t = 3.3$ , AZ31B-F magnesium alloy forged disk, transverse direction.**

Correlative Information for Figure 4.2.1.4.8(b)

Product Form: Forged disk, 1-inch thick

Properties:      TUS, ksi    TYS, ksi    Temp., °F  
                         38            26            RT

Specimen Details: Notched,  $K_t = 3.3$   
0.350-inch gross diameter  
0.280-inch net diameter  
0.01-inch root radius, r  
60° flank angle,  $\omega$

Reference:        4.2.1.1.8

Test Parameters:

Loading - Axial  
Frequency - 1500 cpm  
Temperature - RT  
Environment - Air

No. of Heats/Lots: 1

Maximum Stress Equation:

$\log N_f = 8.28 - 4.34 \log (S_{\max})$   
Std. Error of Estimate,  $\log (\text{Life}) = 0.534$   
Standard Deviation,  $\log (\text{Life}) = 0.707$   
 $R^2 = 43\%$

Sample Size = 34

4.2.2 AZ61A

**4.2.2.0 Comments and Properties** — AZ61A is a wrought magnesium-base alloy containing aluminum and zinc. It is available in the form of extruded sections, tubes, and forgings in the as-fabricated (F) temper. AZ61A is much like AZ31B in general characteristics. The increased aluminum content increases the strength and decreases the ductility slightly.

Severe forming must be done at elevated temperatures. This alloy is readily welded but must be stress relieved after welding to prevent stress corrosion cracking.

Material specifications covering AZ61A are given in Table 4.2.2.0(a). Room-temperature mechanical and physical properties are shown in Table 4.2.2.0(b).

**Table 4.2.2.0(a). Material Specifications for AZ61A Magnesium Alloy**

| Specification | Form      |
|---------------|-----------|
| AMS 4350      | Extrusion |
| ASTM B 91     | Forging   |



[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 4.2.2.0(b). Design Mechanical and Physical Properties of AZ61A Magnesium Alloy Extrusion and Forging**

| Specification .....                          | AMS 4350                            |             |                          |               |                          | ASTM B 91 |
|----------------------------------------------|-------------------------------------|-------------|--------------------------|---------------|--------------------------|-----------|
|                                              | Extruded bar, rod, and solid shapes |             | Extruded hollow shapes   | Extruded tube | Forging                  |           |
|                                              | F                                   |             |                          |               |                          |           |
|                                              | ≤0.249                              | 0.250-2.499 | 2.500-4.499 <sup>a</sup> | All           | 0.028-0.750 <sup>b</sup> | ...       |
| Basis .....                                  | S                                   | S           | S                        | S             | S                        | S         |
| Mechanical Properties:                       |                                     |             |                          |               |                          |           |
| $F_{tu}$ , ksi:                              |                                     |             |                          |               |                          |           |
| L .....                                      | 38                                  | 40          | 40                       | 36            | 36                       | 38        |
| LT .....                                     | ...                                 | ...         | ...                      | ...           | ...                      | ...       |
| $F_{ty}$ , ksi:                              |                                     |             |                          |               |                          |           |
| L .....                                      | 21                                  | 24          | 22                       | 16            | 16                       | 22        |
| LT .....                                     | ...                                 | ...         | ...                      | ...           | ...                      | ...       |
| $F_{cy}$ , ksi:                              |                                     |             |                          |               |                          |           |
| L .....                                      | 14                                  | 14          | 14                       | 11            | 11                       | 14        |
| LT .....                                     | ...                                 | ...         | ...                      | ...           | ...                      | ...       |
| $F_{su}$ , ksi .....                         | 19                                  | 19          | ...                      | ...           | ...                      | 19        |
| $F_{bru}^c$ , ksi:                           |                                     |             |                          |               |                          |           |
| (e/D = 1.5) .....                            | 45                                  | 45          | ...                      | ...           | ...                      | 50        |
| (e/D = 2.0) .....                            | 55                                  | 55          | ...                      | ...           | ...                      | 60        |
| $F_{bry}^c$ , ksi:                           |                                     |             |                          |               |                          |           |
| (e/D = 1.5) .....                            | 28                                  | 28          | ...                      | ...           | ...                      | 28        |
| (e/D = 2.0) .....                            | 32                                  | 32          | ...                      | ...           | ...                      | 32        |
| $e$ , percent:                               |                                     |             |                          |               |                          |           |
| L .....                                      | 8                                   | 9           | 7                        | 7             | 7                        | 6         |
| $E$ , 10 <sup>3</sup> ksi .....              | 6.3                                 |             |                          |               |                          |           |
| $E_c$ , 10 <sup>3</sup> ksi .....            | 6.3                                 |             |                          |               |                          |           |
| $G$ , 10 <sup>3</sup> ksi .....              | 2.4                                 |             |                          |               |                          |           |
| $\mu$ .....                                  | 0.31                                |             |                          |               |                          |           |
| Physical Properties:                         |                                     |             |                          |               |                          |           |
| $\omega$ , lb/in. <sup>3</sup> .....         | 0.0647                              |             |                          |               |                          |           |
| $C$ , Btu/(lb)(°F) .....                     | 0.25 (at 78°F) <sup>d</sup>         |             |                          |               |                          |           |
| $K$ , Btu/[(hr)(ft <sup>2</sup> )(°F)/ft]    | 46 (212 to 572°F)                   |             |                          |               |                          |           |
| $\alpha$ , 10 <sup>-6</sup> in./in./°F ..... | 14 (65 to 212°F)                    |             |                          |               |                          |           |

a For cross-sectional area ≤25 square inches.  
b Wall thickness for outside diameters ≤6.000 inches.  
c Bearing values are “dry pin” values per Section 1.4.7.1.  
d Estimated.

4.2.3 ZK60A

**4.2.3.0 Comments and Properties**— ZK60A is a wrought magnesium-base alloy containing zinc and zirconium. It is available as extruded sections, tubes, and forgings. Increased strength is obtained by artificial aging (T5) from the as-fabricated (F) temper. ZK60A has the best combination of high room-temperature strength and ductility of the wrought magnesium-base alloys. It is used primarily at temperatures below 300 °F.

ZK60A has good ductility as compared with other high-strength magnesium alloys and can be formed or bent cold into shapes not possible with those alloys having less ductility. It is not considered a weldable alloy.

Material specifications for ZK60A are given in Table 4.2.3.0(a). Room-temperature mechanical and physical properties are shown in Tables 4.2.3.0(b) and (c). Elevated temperature curves for physical properties are shown in Figures 4.2.3.0.

**Table 4.2.3.0(a). Material Specifications for ZK60A  
Magnesium Alloy**

| Specification | Form                  |
|---------------|-----------------------|
| ASTM B 107    | Extrusion             |
| AMS 4352      | Extrusion             |
| AMS 4362      | Die and hand forgings |

The temper index for ZK60A is as follows:

| <u>Section</u> | <u>Temper</u> |
|----------------|---------------|
| 4.2.3.1        | F             |
| 4.2.3.2        | T5            |

4.2.3.1 ZK60A-F Temper

**4.2.3.2 ZK60A-T5 Temper** — Typical room-temperature tension and compression stress-strain curves for extrusions are shown in Figures 4.2.3.2.6(a) and (b). Fatigue curves are presented in Figure 4.2.3.2.8(a) through (c).

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 4.2.3.0(b). Design Mechanical and Physical Properties of ZK60A Magnesium Alloy Extrusion**

|                                                  |                                     |             |             |              |                        |                  |
|--------------------------------------------------|-------------------------------------|-------------|-------------|--------------|------------------------|------------------|
| Specification .....                              | ASTM B 107                          |             |             |              |                        |                  |
| Form .....                                       | Extruded rod, bar, and solid shapes |             |             |              | Extruded hollow shapes | Extruded tube    |
| Temper .....                                     | F                                   |             |             |              |                        |                  |
| Cross-sectional area, in. <sup>2</sup> .....     | <2.000                              | 2.000-2.999 | 3.000-4.999 | 5.000-39.999 | All                    | ≤3.000 in. O.D.  |
| Thickness, in. ....                              | All                                 | All         | All         | All          | All                    | 0.028-0.750 wall |
| Basis .....                                      | S                                   | S           | S           | S            | S                      | S                |
| Mechanical Properties:                           |                                     |             |             |              |                        |                  |
| <i>F<sub>tu</sub></i> , ksi:                     |                                     |             |             |              |                        |                  |
| L .....                                          | 43                                  | 43          | 43          | 43           | 40                     | 40               |
| LT .....                                         | ...                                 | ...         | ...         | ...          | ...                    | ...              |
| <i>F<sub>ty</sub></i> , ksi:                     |                                     |             |             |              |                        |                  |
| L .....                                          | 31                                  | 31          | 31          | 31           | 28                     | 28               |
| LT .....                                         | ...                                 | ...         | ...         | ...          | ...                    | ...              |
| <i>F<sub>cy</sub></i> , ksi:                     |                                     |             |             |              |                        |                  |
| L .....                                          | 27                                  | 26          | 25          | 20           | 20                     | 20               |
| LT .....                                         | ...                                 | ...         | ...         | ...          | ...                    | ...              |
| <i>F<sub>su</sub></i> , ksi .....                | 22                                  | 22          | 22          | ...          | ...                    | ...              |
| <i>F<sub>bru</sub></i> <sup>a</sup> , ksi:       |                                     |             |             |              |                        |                  |
| (e/D = 1.5) .....                                | ...                                 | ...         | ...         | ...          | ...                    | ...              |
| (e/D = 2.0) .....                                | 70                                  | 70          | 70          | ...          | ...                    | ...              |
| <i>F<sub>bry</sub></i> <sup>a</sup> , ksi:       |                                     |             |             |              |                        |                  |
| (e/D = 1.5) .....                                | ...                                 | ...         | ...         | ...          | ...                    | ...              |
| (e/D = 2.0) .....                                | 45                                  | 45          | 45          | ...          | ...                    | ...              |
| <i>e</i> , percent:                              |                                     |             |             |              |                        |                  |
| L .....                                          | 5                                   | 5           | 5           | 4            | 5                      | 5                |
| <i>E</i> , 10 <sup>3</sup> ksi .....             | 6.5                                 |             |             |              |                        |                  |
| <i>E<sub>c</sub></i> , 10 <sup>3</sup> ksi ..... | 6.5                                 |             |             |              |                        |                  |
| <i>G</i> , 10 <sup>3</sup> ksi .....             | 2.4                                 |             |             |              |                        |                  |
| <i>μ</i> .....                                   | 0.35                                |             |             |              |                        |                  |
| Physical Properties:                             |                                     |             |             |              |                        |                  |
| <i>ω</i> , lb/in. <sup>3</sup> .....             | 0.0659                              |             |             |              |                        |                  |
| <i>C</i> , <i>K</i> , and <i>α</i> .....         | See Figure 4.2.3.0                  |             |             |              |                        |                  |

a Bearing values are “dry pin” values per Section 1.4.7.1.

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 4.2.3.0(c). Design Mechanical and Physical Properties of ZK60A Magnesium Alloy Extrusion and Forging**

| Specification . . . . .                    | AMS 4352                            |             |             |             |               |               |                        |                  |                      | AMS 4362    |              |
|--------------------------------------------|-------------------------------------|-------------|-------------|-------------|---------------|---------------|------------------------|------------------|----------------------|-------------|--------------|
|                                            | Extruded rod, bar, and solid shapes |             |             |             |               |               | Extruded hollow shapes | Extruded tube    |                      | Die forging | Hand forging |
| Form . . . . .                             |                                     |             |             |             |               |               |                        |                  |                      |             |              |
| Temper . . . . .                           | T5                                  |             |             |             |               |               |                        |                  |                      |             |              |
| Cross-sectional area, in. <sup>2</sup> . . | <2.000                              | 2.000-2.999 | 3.000-4.999 | 5.000-9.999 | 10.000-24.999 | 25.000-39.999 | All                    | ≤3.000 in. O.D.  | 3.000-8.500 in. O.D. | ...         | ...          |
| Thickness, in. . . . .                     | All                                 | All         | All         | All         | All           | All           | All                    | 0.028-0.250 wall | 0.094-1.188 wall     | ≤3.000      | ≤6.000       |
| Basis . . . . .                            | S                                   | S           | S           | S           | S             | S             | S                      | S                | S                    | S           | S            |
| Mechanical Properties:                     |                                     |             |             |             |               |               |                        |                  |                      |             |              |
| $F_{tu}$ , ksi:                            |                                     |             |             |             |               |               |                        |                  |                      |             |              |
| L . . . . .                                | 45                                  | 45          | 45          | 45          | 45            | 43            | 46                     | 46               | 44                   | 42          | 38           |
| LT . . . . .                               | ...                                 | ...         | ...         | ...         | ...           | ...           | ...                    | ...              | ...                  | ...         | ...          |
| $F_{ty}$ , ksi:                            |                                     |             |             |             |               |               |                        |                  |                      |             |              |
| L . . . . .                                | 36                                  | 36          | 36          | 34          | 34            | 31            | 38                     | 38               | 33                   | 26          | 20           |
| LT . . . . .                               | ...                                 | ...         | ...         | ...         | ...           | ...           | ...                    | ...              | ...                  | ...         | ...          |
| $F_{cy}$ , ksi:                            |                                     |             |             |             |               |               |                        |                  |                      |             |              |
| L . . . . .                                | 30                                  | 28          | 25          | 23          | 22            | 20            | 26                     | 26               | 21                   | ...         | ...          |
| LT . . . . .                               | ...                                 | ...         | ...         | ...         | ...           | ...           | ...                    | ...              | ...                  | ...         | ...          |
| $F_{su}$ , ksi . . . . .                   | 22                                  | 22          | 22          | ...         | ...           | ...           | ...                    | ...              | ...                  | ...         | ...          |
| $F_{bru}^a$ , ksi:                         |                                     |             |             |             |               |               |                        |                  |                      |             |              |
| (e/D = 1.5) . . . . .                      | ...                                 | ...         | ...         | ...         | ...           | ...           | ...                    | ...              | ...                  | ...         | ...          |
| (e/D = 2.0) . . . . .                      | 71                                  | 71          | 71          | ...         | ...           | ...           | ...                    | ...              | ...                  | ...         | ...          |
| $F_{bry}^a$ , ksi:                         |                                     |             |             |             |               |               |                        |                  |                      |             |              |
| (e/D = 1.5) . . . . .                      | ...                                 | ...         | ...         | ...         | ...           | ...           | ...                    | ...              | ...                  | ...         | ...          |
| (e/D = 2.0) . . . . .                      | 47                                  | 47          | 47          | ...         | ...           | ...           | ...                    | ...              | ...                  | ...         | ...          |
| $e$ , percent:                             |                                     |             |             |             |               |               |                        |                  |                      |             |              |
| L . . . . .                                | 4                                   | 4           | 4           | 6           | 6             | 6             | 4                      | 4                | 4                    | 7           | 7            |
| $E$ , 10 <sup>3</sup> ksi . . . . .        | 6.5                                 |             |             |             |               |               |                        |                  |                      |             |              |
| $E_c$ , 10 <sup>3</sup> ksi . . . . .      | 6.5                                 |             |             |             |               |               |                        |                  |                      |             |              |
| $G$ , 10 <sup>3</sup> ksi . . . . .        | 2.4                                 |             |             |             |               |               |                        |                  |                      |             |              |
| $\mu$ . . . . .                            | 0.35                                |             |             |             |               |               |                        |                  |                      |             |              |
| Physical Properties:                       |                                     |             |             |             |               |               |                        |                  |                      |             |              |
| $\omega$ , lb/in. <sup>3</sup> . . . . .   | 0.0659                              |             |             |             |               |               |                        |                  |                      |             |              |
| $C$ , $K$ , and $\alpha$ . . . . .         | See Figure 4.2.3.0                  |             |             |             |               |               |                        |                  |                      |             |              |

a Bearing values are “dry pin” values per Section 1.4.7.1.

[VIEW INTERACTIVE GRAPH](#)

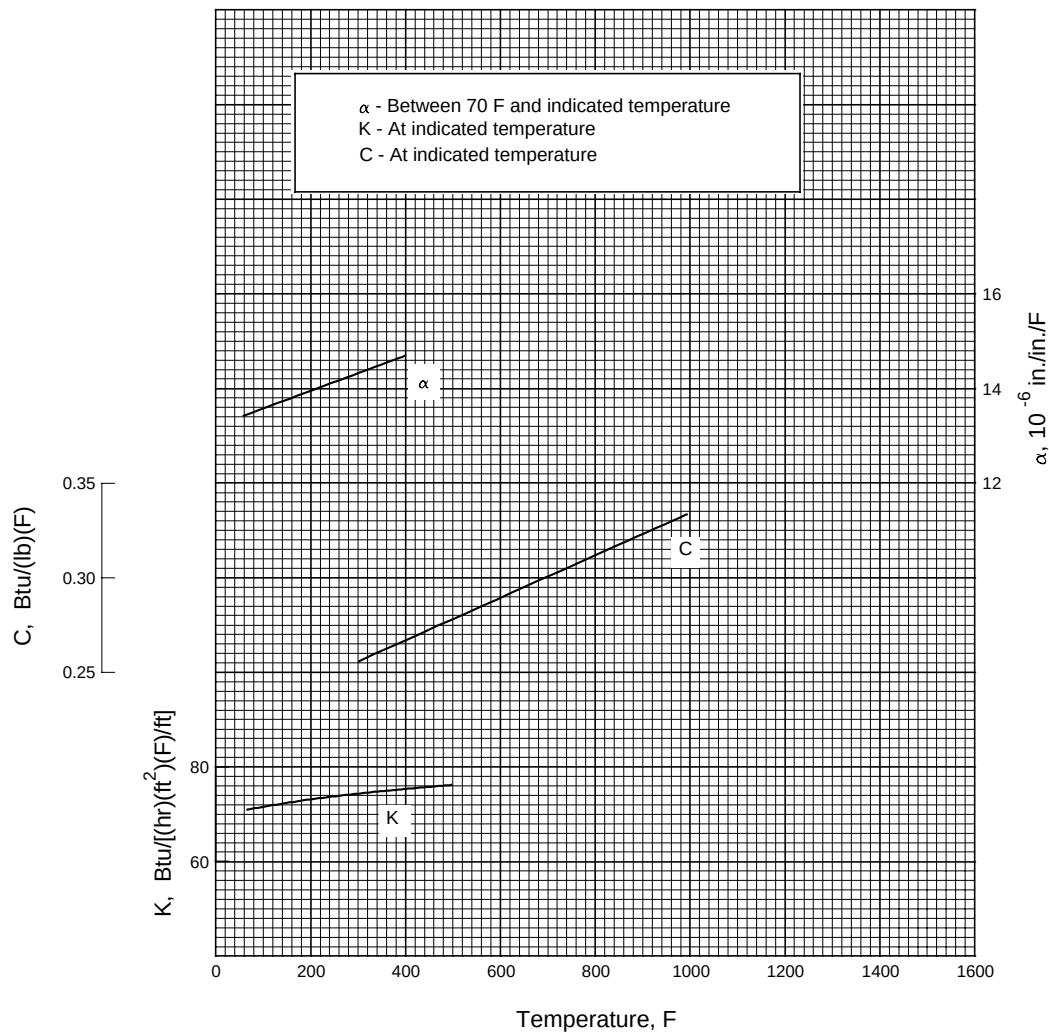


Figure 4.2.3.0. Effect of temperature on the physical properties of ZK60A magnesium alloy.

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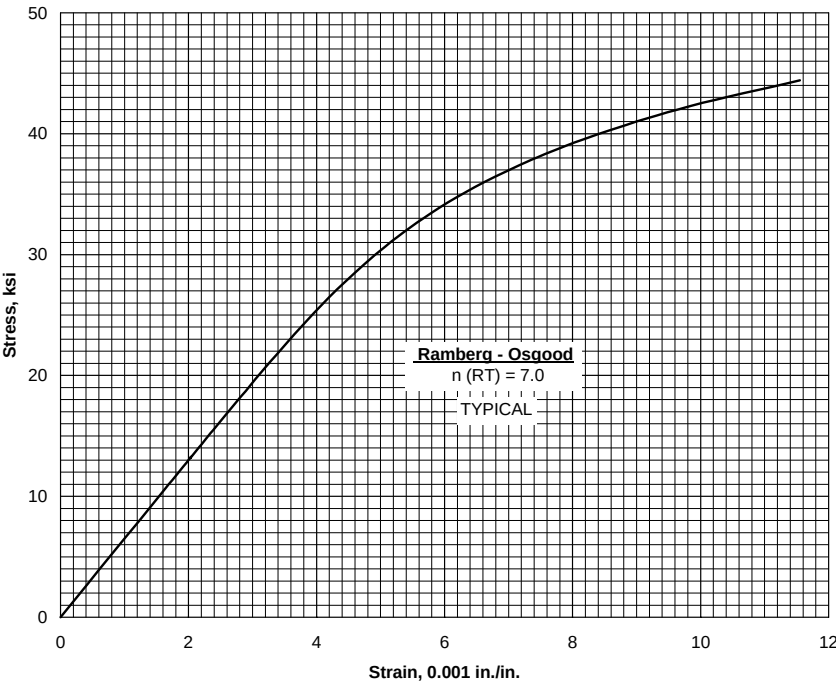


Figure 4.2.3.2.6(a). Typical tensile stress-strain curve for ZK60A-T5 extrusion at room temperature. [VIEW INTERACTIVE GRAPH](#)

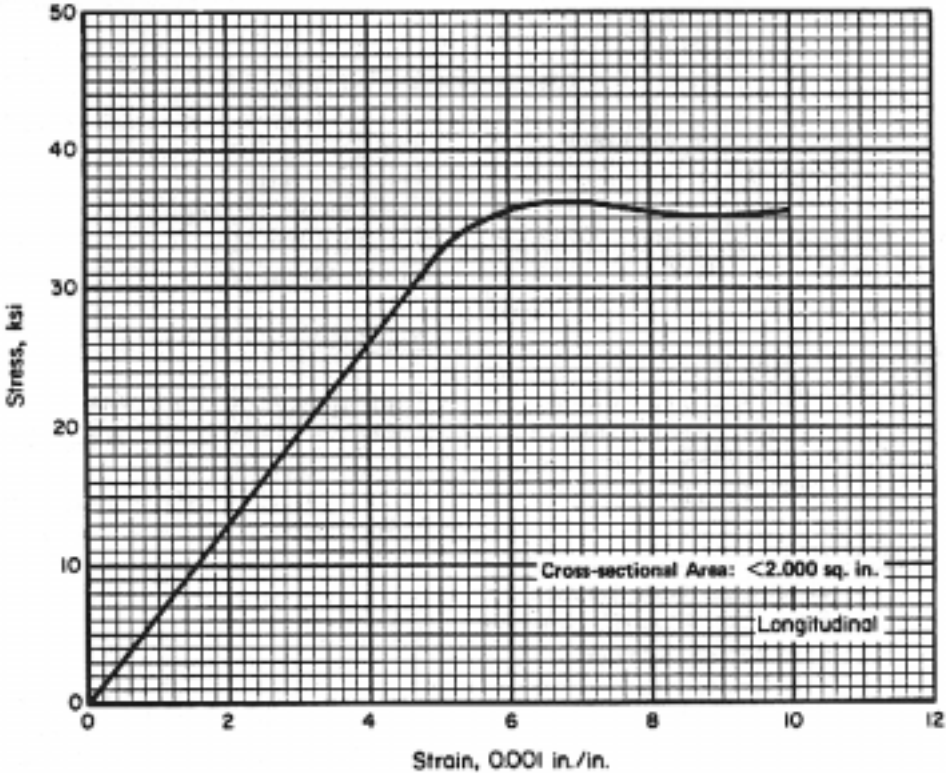


Figure 4.2.3.2.6(b). Typical compressive stress-strain curve for ZK60A-T5 extrusion at room temperature.

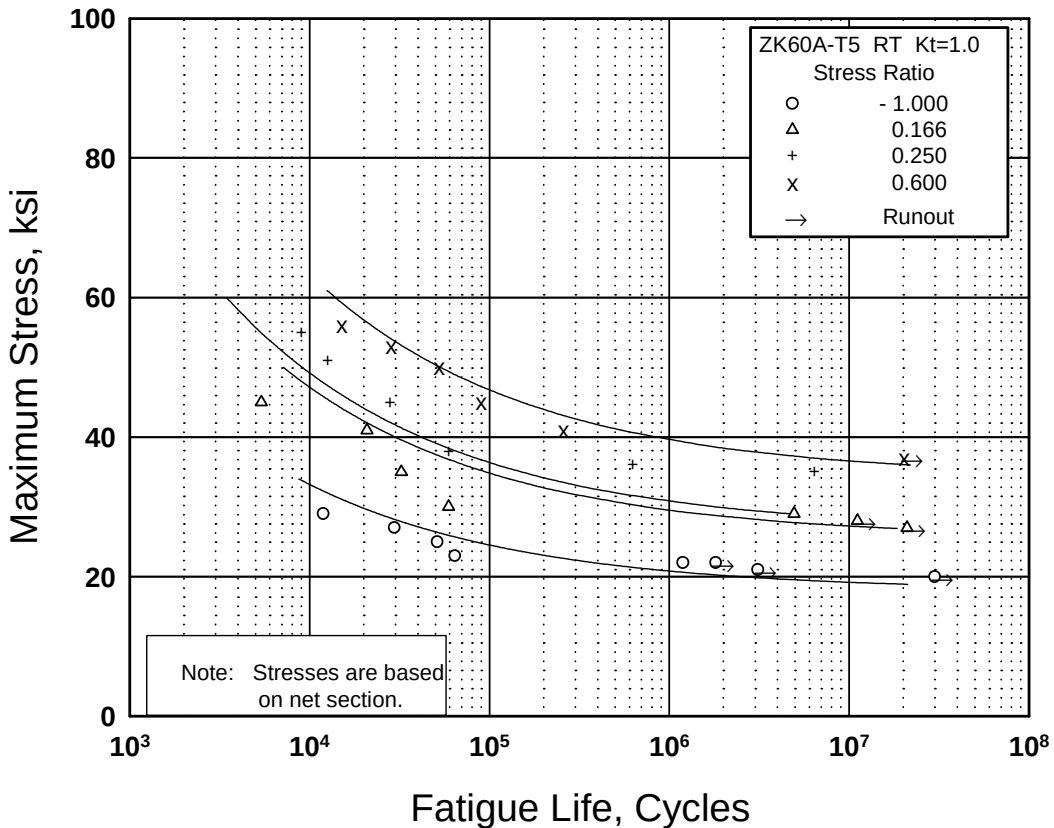


**Figure 4.2.3.2.8(a). Best-fit S/N curves for unnotched ZK60A-T5 extruded bar, longitudinal direction.**

Correlative Information for Figure 4.2.3.2.8(a)

|                      |                                  |                 |                   |
|----------------------|----------------------------------|-----------------|-------------------|
| <u>Product Form:</u> | Extruded bar, 0.50-inch diameter |                 |                   |
| <u>Properties:</u>   | <u>TUS, ksi</u>                  | <u>TYS, ksi</u> | <u>Temp., °F</u>  |
|                      | 47.5                             | 40.9            | RT<br>(unnotched) |

Test Parameters:  
Loading - Axial  
Frequency - 3600 cpm  
Temperature - RT  
Environment - Air

No. of Heats/Lots: Not specified

Specimen Details: Unnotched  
0.50-inch gross diameter  
0.40-inch net diameter  
0.750-inch root diameter  
7.50-inch long

Surface Condition: Polished with No. 240 grit  
aluminum oxide belt and  
then a No. 400 grit;  
polished with kerosene to  
better than 10 micro-inches

Equivalent Stress Equation:

$$\text{Log } N_f = 7.56 - 2.73 \log (S_{eq} - 23.7)$$

$$S_{eq} = S_{max} (1 - R)^{0.40}$$

Std. Error of Estimate,  $\text{Log (Life)} = 0.60$

Standard Deviation,  $\text{Log (Life)} = 0.85$

$R^2 = 51\%$

Sample Size = 21

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

Reference: 4.2.3.2.8

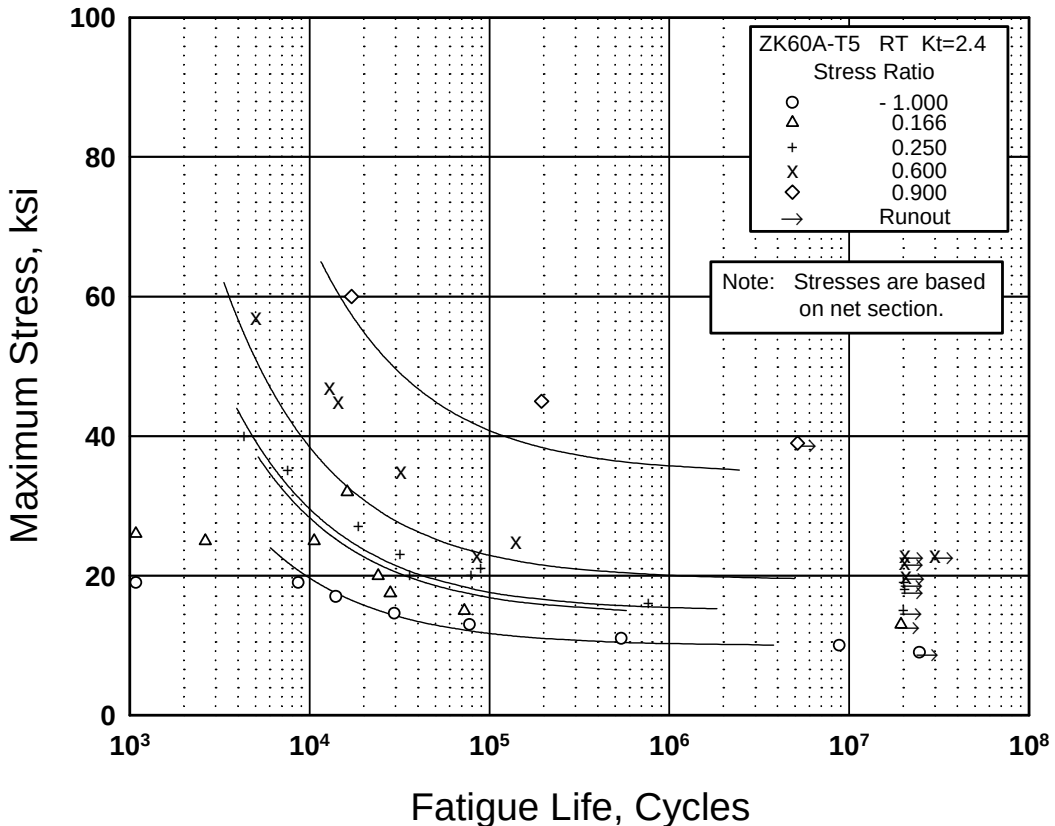


**Figure 4.2.3.2.8(b). Best-fit S/N curves for notched,  $K_t = 2.4$ , ZK60A-T5 extruded bar, longitudinal direction.**

Correlative Information for Figure 4.2.3.2.8(b)

Product Form: Extruded bar, 0.50-inch diameter

| <u>Properties:</u> | <u>TUS, ksi</u> | <u>TYS, ksi</u> | <u>Temp., °F</u> |
|--------------------|-----------------|-----------------|------------------|
|                    | 63.7            | 40.9            | RT<br>(notched)  |

Specimen Details: Circumferential notched,  
 $K_t = 2.4$   
 0.50-inch gross diameter  
 0.40-inch net diameter  
 0.032-inch notch radius  
 60° flank angle,  $\omega$

Surface Condition: Ground with aluminum oxide wheel lubricated with sulfur cutting oil; lapped with a copper rod and No. 600 grit alundum lapping compound

Reference: 4.2.3.2.8

### Test Parameters:

Loading - Axial  
 Frequency - 3600 cpm  
 Temperature - RT  
 Environment - Air

No. of Heats/Lots: Not specified

Equivalent Stress Equation:

$$\text{Log } N_f = 5.51 - 1.36 \log (S_{eq} - 13.2)$$
$$S_{eq} = S_{max}(1-R)^{0.42}$$

Std. Error of Estimate, Log (Life) = 0.46

Standard Deviation, Log (Life) = 0.82

 $R^2 = 69\%$ 

Sample Size = 30

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]



[VIEW INTERACTIVE GRAPH](#)

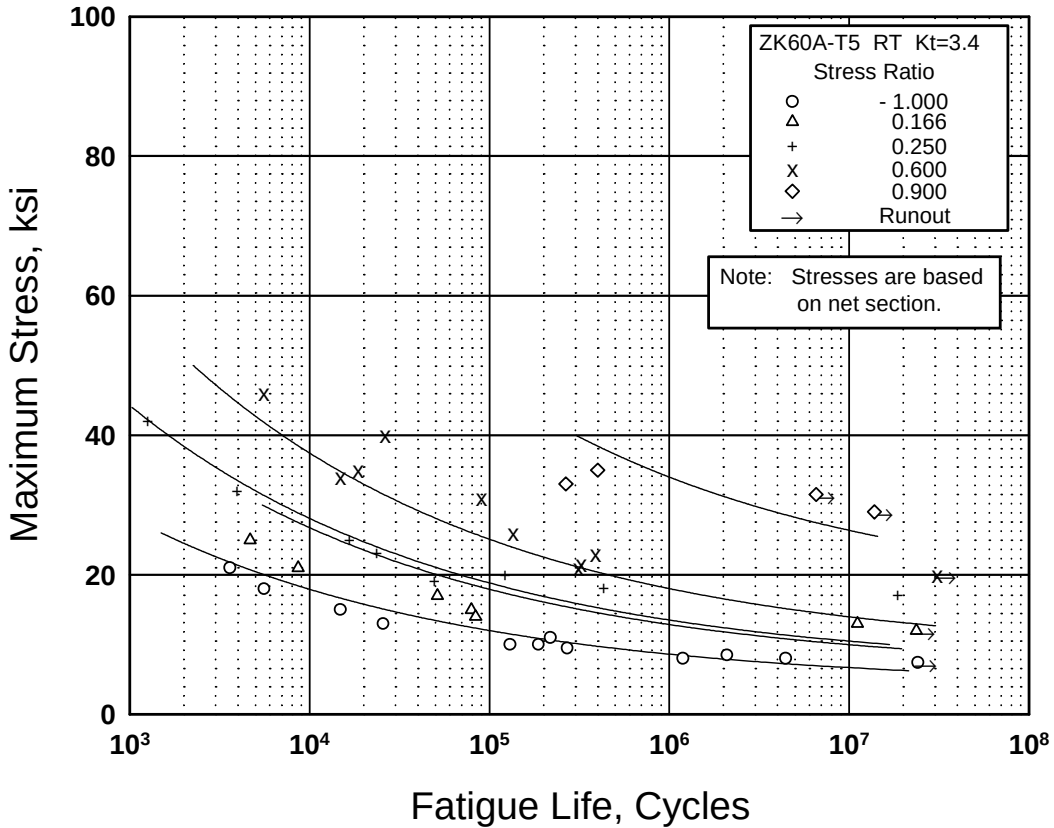


**Figure 4.2.3.2.8(c). Best-fit S/N curves for notched,  $K_t = 3.4$ , ZK60A-T5 extruded bar, longitudinal direction.**

Correlative Information for Figure 4.2.3.2.8(c)

**Product Form:** Extruded bar, 0.50-inch diameter

|                    |                 |                 |                  |
|--------------------|-----------------|-----------------|------------------|
| <u>Properties:</u> | <u>TUS, ksi</u> | <u>TYS, ksi</u> | <u>Temp., °F</u> |
|                    | 58.2            | 40.9            | RT<br>(notched)  |

Specimen Details: Circumferential notched,  
 $K_t = 4$   
 0.50-inch gross diameter  
 0.40-inch net diameter  
 0.010-inch notch radius  
 60° flank angle,  $\omega$

Surface Condition: Ground with aluminum oxide wheel lubricated with sulfur cutting oil; lapped with a copper rod and No. 600 grit alundum lapping compound

Reference: 4.2.3.2.8

Test Parameters:

Loading - Axial  
 Frequency - 3600 cpm  
 Temperature - RT  
 Environment - Air

No. of Heats/Lots: Not specified

Equivalent Stress Equation:

$$\text{Log } N_f = 9.27 - 4.13 \log (S_{eq} - 5.63)$$
$$S_{eq} = S_{max}(1-R)^{0.46}$$

Std. Error of Estimate, Log (Life) = 0.55

Standard Deviation, Log (Life) = 0.99

$$R^2 = 70\%$$

Sample Size = 36

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

4.3 MAGNESIUM CAST ALLOYS

4.3.1 AM100A

**4.3.1.0 Comments and Properties**—AM100A is a magnesium-base casting alloy containing aluminum and a small amount of manganese. It is primarily used as permanent mold castings. AM100A has about the same characteristics as AZ92A. AM100A has less tendency to microshrinkage and hot shortness than the Mg-Al-Zn alloys. It has good weldability and fair pressure tightness.

Material specifications for AM100A are given in Table 4.3.1.0(a). Room-temperature mechanical and physical properties are shown in Table 4.3.1.0(b).

**Table 4.3.1.0(a). Material Specifications for AM100A  
Magnesium Alloy**

| Specification         | Form                   |
|-----------------------|------------------------|
| AMS 4455              | Investment casting     |
| AMS 4483 <sup>a</sup> | Permanent mold casting |
| MIL-M-46062           | Casting                |

a Noncurrent specification.

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 4.3.1.0(b). Design Mechanical and Physical Properties of AM100A Magnesium Alloy Casting**

|                                       |                    |                        |                      |                      |                      |                    |
|---------------------------------------|--------------------|------------------------|----------------------|----------------------|----------------------|--------------------|
| Specification .....                   | AMS 4455           | AMS 4483 <sup>a</sup>  | MIL-M-46062          |                      |                      |                    |
| Form .....                            | Investment casting | Permanent mold casting | Casting (any method) |                      |                      |                    |
| Temper .....                          | T6                 | T6                     | T6                   |                      |                      |                    |
| Location within casting .....         | Any area           |                        | Designated area      |                      |                      | Nondesignated area |
|                                       |                    |                        | Class 1 <sup>b</sup> | Class 2 <sup>b</sup> | Class 3 <sup>b</sup> |                    |
| Basis .....                           | S                  | S                      | S                    | S                    | S                    | S                  |
| Mechanical Properties <sup>c</sup> :  |                    |                        |                      |                      |                      |                    |
| $F_{tu}$ , ksi .....                  | 17 <sup>d</sup>    | 17 <sup>d</sup>        | 38                   | 35                   | 30                   | 17                 |
| $F_{ty}$ , ksi .....                  | 9.5 <sup>d</sup>   | 10 <sup>d</sup>        | 20                   | 18                   | 16                   | 10                 |
| $F_{cy}$ , ksi .....                  | 9.5                | 10                     | 20                   | 18                   | 16                   | 10                 |
| $F_{su}$ , ksi .....                  | ...                | ...                    | ...                  | ...                  | ...                  | ...                |
| $F_{bru}$ , ksi:                      |                    |                        |                      |                      |                      |                    |
| (e/D = 1.5) .....                     | ...                | ...                    | ...                  | ...                  | ...                  | ...                |
| (e/D = 2.0) .....                     | ...                | ...                    | ...                  | ...                  | ...                  | ...                |
| $F_{bry}$ , ksi:                      |                    |                        |                      |                      |                      |                    |
| (e/D = 1.5) .....                     | ...                | ...                    | ...                  | ...                  | ...                  | ...                |
| (e/D = 2.0) .....                     | ...                | ...                    | ...                  | ...                  | ...                  | ...                |
| $e$ , percent .....                   | 1 <sup>c</sup>     | ...                    | 3                    | 1.5                  | 1                    | 0.75               |
| $E$ , 10 <sup>3</sup> ksi .....       | 6.5                |                        |                      |                      |                      |                    |
| $E_c$ , 10 <sup>3</sup> ksi .....     | 6.5                |                        |                      |                      |                      |                    |
| $G$ , 10 <sup>3</sup> ksi .....       | 2.4                |                        |                      |                      |                      |                    |
| $\mu$ .....                           | 0.35               |                        |                      |                      |                      |                    |
| Physical Properties:                  |                    |                        |                      |                      |                      |                    |
| $\omega$ , lb./in. <sup>3</sup> ..... | 0.0651             |                        |                      |                      |                      |                    |
| $C$ , $K$ , and $\alpha$ .....        | ...                |                        |                      |                      |                      |                    |

a Noncurrent specification.  
b Class of properties attainable depends on location specified and casting design and should be coordinated with the producer.  
c Reference should be made to the specific requirements of the procuring or certifying agency with regard to the use of the above values in the design of castings.  
d When specified on drawing, conformance to tensile property requirements is determined by testing specimens cut from castings.

4.3.2 AZ91C/AZ91E

**4.3.2.0 Comments and Properties** — AZ91C is a magnesium-base casting alloy containing aluminum and zinc. AZ91E is a version which contains a significantly lower level of impurities resulting in improved corrosion resistance. These alloys have good castability with a good combination of ductility and strength. AZ91C and AZ91E are the most commonly used sand castings for temperatures under 300 °F. AZ91C is available as sand and investment castings, while AZ91E is available as a sand casting. AZ91C and AZ91E have fair weldability and pressure tightness.

Some material specifications covering AZ91C/AZ91E are presented in Table 4.3.2.0(a). Room-temperature mechanical and physical properties are shown in Tables 4.3.2.0(b) and (c).

**Table 4.3.2.0(a). Material Specifications for AZ91C/AZ91E Magnesium Alloy**

| Specification | Form               |
|---------------|--------------------|
| AMS 4437      | Sand casting       |
| AMS 4452      | Investment casting |
| MIL-M-46062   | Casting            |
| AMS 4446      | Sand casting       |

The temper index for AZ91C/AZ91E is as follows:

|                |               |
|----------------|---------------|
| <u>Section</u> | <u>Temper</u> |
| 4.3.2.1        | T6            |

**4.3.2.1 T6 Temper** — Figure 4.3.2.1.4 contains an elevated temperature curve for tension and compression moduli. Typical tensile stress-strain curves at room temperature and several elevated temperatures are presented in Figure 4.3.2.1.6.

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 4.3.2.0(b). Design Mechanical and Physical Properties of AZ91C Magnesium Alloy Casting**

|                                                  |                     |                    |                      |                      |                      |                    |
|--------------------------------------------------|---------------------|--------------------|----------------------|----------------------|----------------------|--------------------|
| Specification . . . . .                          | AMS 4437            | AMS 4452           | MIL-M-46062          |                      |                      |                    |
| Form . . . . .                                   | Sand casting        | Investment casting | Casting (any method) |                      |                      |                    |
| Temper . . . . .                                 | T6                  | T6                 | T6                   |                      |                      |                    |
| Location within casting . . . . .                | Any area            |                    | Designated area      |                      |                      | Nondesignated area |
|                                                  |                     |                    | Class 1 <sup>a</sup> | Class 2 <sup>a</sup> | Class 3 <sup>a</sup> |                    |
| Basis . . . . .                                  | S                   | S                  | S                    | S                    | S                    | S                  |
| Mechanical Properties <sup>b</sup> :             |                     |                    |                      |                      |                      |                    |
| $F_{tu}$ , ksi . . . . .                         | 17 <sup>c</sup>     | 17 <sup>c</sup>    | 35                   | 29                   | 27                   | 17                 |
| $F_{ty}$ , ksi . . . . .                         | 12 <sup>c</sup>     | 12 <sup>c</sup>    | 18                   | 16                   | 14                   | 12                 |
| $F_{cy}$ , ksi . . . . .                         | 12                  | 12                 | 18                   | 16                   | 14                   | 12                 |
| $F_{su}$ , ksi . . . . .                         | ...                 | ...                | ...                  | ...                  | ...                  | ...                |
| $F_{bru}$ , ksi:                                 |                     |                    |                      |                      |                      |                    |
| (e/D = 1.5) . . . . .                            | ...                 | ...                | ...                  | ...                  | ...                  | ...                |
| (e/D = 2.0) . . . . .                            | ...                 | ...                | ...                  | ...                  | ...                  | ...                |
| $F_{bry}$ , ksi:                                 |                     |                    |                      |                      |                      |                    |
| (e/D = 1.5) . . . . .                            | ...                 | ...                | ...                  | ...                  | ...                  | ...                |
| (e/D = 2.0) . . . . .                            | ...                 | ...                | ...                  | ...                  | ...                  | ...                |
| $e$ , percent . . . . .                          | 0.75 <sup>c</sup>   | 1 <sup>c</sup>     | 4                    | 3                    | 2                    | 0.75               |
| $E$ , 10 <sup>3</sup> ksi . . . . .              | 6.5                 |                    |                      |                      |                      |                    |
| $E_c$ , 10 <sup>3</sup> ksi . . . . .            | 6.5                 |                    |                      |                      |                      |                    |
| $G$ , 10 <sup>3</sup> ksi . . . . .              | 2.4                 |                    |                      |                      |                      |                    |
| $\mu$ . . . . .                                  | 0.35                |                    |                      |                      |                      |                    |
| Physical Properties:                             |                     |                    |                      |                      |                      |                    |
| $\omega$ , lb./in. <sup>3</sup> . . . . .        | 0.0652              |                    |                      |                      |                      |                    |
| $C$ , Btu/(lb)(°F) . . . . .                     | 0.25 <sup>d</sup>   |                    |                      |                      |                      |                    |
| $K$ , Btu/[(hr)(ft <sup>2</sup> )(°F)/ft]        | 41 (212°F to 572°F) |                    |                      |                      |                      |                    |
| $\alpha$ , 10 <sup>-6</sup> in./in./°F . . . . . | 14 (65°F to 212°F)  |                    |                      |                      |                      |                    |

a Class of properties attainable depends on location specified and casting design and should be coordinated with the producer.  
b Reference should be made to the specific requirements of the procuring or certifying agency with regard to the use of the above values in the design of castings.  
c When specified on drawing, conformance to tensile property requirements is determined by testing specimens cut from castings.  
d Estimated.

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 4.3.2.0(c). Design Mechanical and Physical Properties of AZ91E Magnesium Alloy Casting**

|                                                 |                     |
|-------------------------------------------------|---------------------|
| Specification .....                             | AMS 4446            |
| Form .....                                      | Sand casting        |
| Condition .....                                 | T6                  |
| Location within casting .....                   | Any area            |
| Basis .....                                     | S                   |
| Mechanical Properties <sup>a</sup> :            |                     |
| $F_{tu}$ , ksi .....                            | 17 <sup>b</sup>     |
| $F_{ty}$ , ksi .....                            | 12 <sup>b</sup>     |
| $F_{cy}$ , ksi .....                            | 12                  |
| $F_{su}$ , ksi .....                            | ...                 |
| $F_{bru}$ , ksi:                                |                     |
| (e/D = 1.5) .....                               | ...                 |
| (e/D = 2.0) .....                               | ...                 |
| $F_{bry}$ , ksi:                                |                     |
| (e/D = 1.5) .....                               | ...                 |
| (e/D = 2.0) .....                               | ...                 |
| $e$ , percent .....                             | ...                 |
| $E$ , 10 <sup>3</sup> ksi .....                 | 6.5                 |
| $E_c$ , 10 <sup>3</sup> ksi .....               | 6.5                 |
| $G$ , 10 <sup>3</sup> ksi .....                 | 2.4                 |
| $\mu$ .....                                     | 0.35                |
| Physical Properties:                            |                     |
| $\omega$ , lb/in. <sup>3</sup> .....            | 0.0652              |
| $C$ , Btu/(lb)(°F) .....                        | 0.25 <sup>c</sup>   |
| $K$ , Btu/[(hr)(ft <sup>2</sup> )(°F)/ft] ..... | 41 (212°F to 572°F) |
| $\alpha$ , 10 <sup>-6</sup> in./in./F .....     | 14 (65°F to 212°F)  |

a Reference should be made to the specific requirements of the procuring or certifying agency with regard to the use of the above values in the design of castings.

b When specified on drawing, conformance to tensile property requirements is determined by testing specimens cut from castings.

c Estimated.

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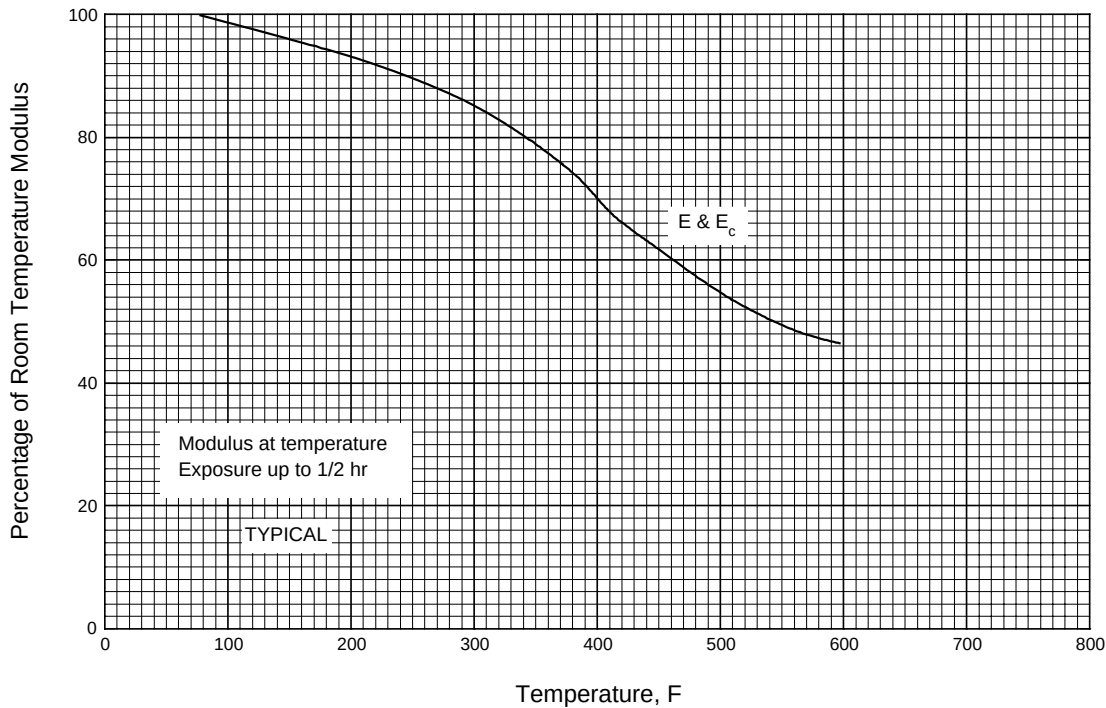


Figure 4.3.2.1.4. Effect of temperature of the tensile and compressive moduli (E and E<sub>c</sub>) of cast AZ91C-T6/AZ91E-T6.

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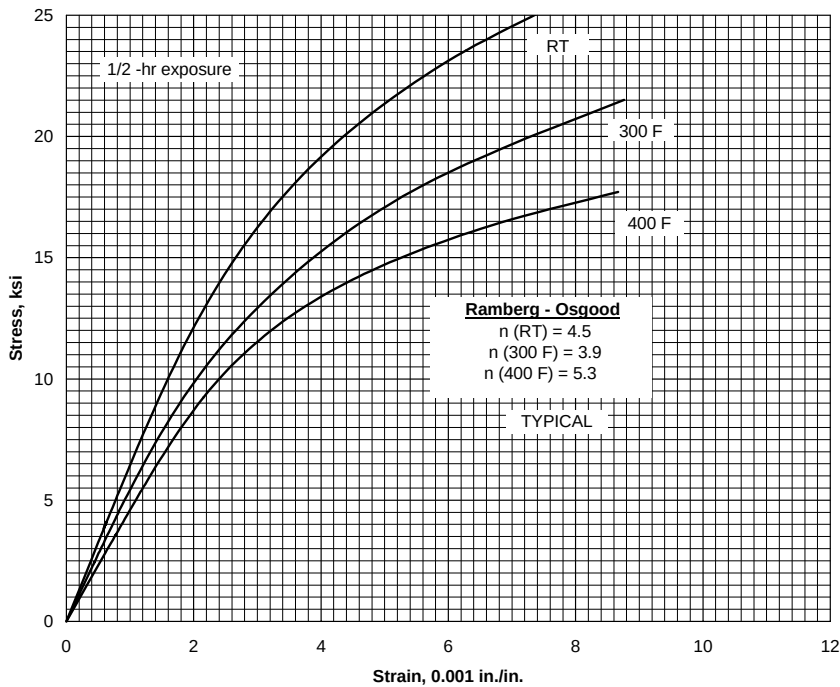


Figure 4.3.2.1.6. Typical tensile stress-stain curves for cast AZ91C-T6/AZ91E-T6 at room and elevated temperatures.

4.3.3 AZ92A

**4.3.3.0 Comments and Properties** — AZ92A is a magnesium-base casting alloy containing aluminum and zinc. It is slightly stronger and less ductile than AZ91C but is much like it in other characteristics. It is available as sand and permanent-mold casting. AZ92A has fair weldability and pressure tightness.

Material specifications for AZ92A are presented in Table 4.3.3.0(a). Room-temperature mechanical and physical properties are shown in Table 4.3.3.0(b). Elevated temperature curves for physical properties are shown in Figure 4.3.3.0.

**Table 4.3.3.0(a). Material Specifications for AZ92A Magnesium Alloy**

| Specification         | Form                   |
|-----------------------|------------------------|
| AMS 4434              | Sand casting           |
| AMS 4484 <sup>a</sup> | Permanent-mold casting |
| MIL-M-46062           | Casting                |

a Noncurrent specification.

The temper index for AZ92A is as follows:

|                |               |
|----------------|---------------|
| <u>Section</u> | <u>Temper</u> |
| 4.3.3.1        | T6            |

**4.3.3.1 AZ92A-T6 Temper** — Elevated temperature curves for various mechanical properties are presented in Figures 4.3.3.1.1(a) through (c), and 4.3.3.1.4. Typical stress-strain and tangent-modulus curves at room temperature and several elevated temperatures are shown in Figures 4.3.3.1.6(a) and (b).



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**1 October 2001**

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 4.3.3.0(b). Design Mechanical and Physical Properties of AZ92A Magnesium Alloy Casting**

|                                       |                        |                   |                      |                      |                      |                    |
|---------------------------------------|------------------------|-------------------|----------------------|----------------------|----------------------|--------------------|
| Specification .....                   | AMS 4484 <sup>a</sup>  | AMS 4434          | MIL-M-46062          |                      |                      |                    |
| Form .....                            | Permanent mold casting | Sand casting      | Casting (any method) |                      |                      |                    |
| Temper .....                          | T6                     | T6                | T6                   |                      |                      |                    |
| Location within casting .             | Any area               |                   | Designated area      |                      |                      | Nondesignated area |
|                                       |                        |                   | Class 1 <sup>b</sup> | Class 2 <sup>b</sup> | Class 3 <sup>b</sup> |                    |
| Basis .....                           | S                      | S                 | S                    | S                    | S                    | S                  |
| Mechanical Properties <sup>c</sup> :  |                        |                   |                      |                      |                      |                    |
| $F_{tu}$ , ksi .....                  | 17 <sup>d</sup>        | 17 <sup>d</sup>   | 40                   | 34                   | 30                   | 17                 |
| $F_{ty}$ , ksi .....                  | 13.5 <sup>d</sup>      | 13.5 <sup>d</sup> | 25                   | 20                   | 18                   | 13                 |
| $F_{cy}$ , ksi .....                  | 13.5                   | 13.5              | 25                   | 20                   | 18                   | 13                 |
| $F_{su}$ , ksi .....                  | ...                    | ...               | ...                  | ...                  | ...                  | ...                |
| $F_{bru}$ , ksi:                      |                        |                   |                      |                      |                      |                    |
| (e/D = 1.5) .....                     | ...                    | ...               | ...                  | ...                  | ...                  | ...                |
| (e/D = 2.0) .....                     | ...                    | ...               | ...                  | ...                  | ...                  | ...                |
| $F_{bry}$ , ksi:                      |                        |                   |                      |                      |                      |                    |
| (e/D = 1.5) .....                     | ...                    | ...               | ...                  | ...                  | ...                  | ...                |
| (e/D = 2.0) .....                     | ...                    | ...               | ...                  | ...                  | ...                  | ...                |
| $e$ , percent .....                   | ...                    | ...               | 3                    | 1                    | 0.75                 | 0.50               |
| $E$ , 10 <sup>3</sup> ksi .....       | 6.5                    |                   |                      |                      |                      |                    |
| $E_c$ , 10 <sup>3</sup> ksi .....     | 6.5                    |                   |                      |                      |                      |                    |
| $G$ , 10 <sup>3</sup> ksi .....       | 2.4                    |                   |                      |                      |                      |                    |
| $\mu$ .....                           | 0.35                   |                   |                      |                      |                      |                    |
| Physical Properties:                  |                        |                   |                      |                      |                      |                    |
| $\omega$ , lb./in. <sup>3</sup> ..... | 0.0659                 |                   |                      |                      |                      |                    |
| $C$ , Btu/(lb)(°F) .....              | 0.25 <sup>e</sup>      |                   |                      |                      |                      |                    |
| $K$ and $\alpha$ .....                | See Figure 4.3.3.0     |                   |                      |                      |                      |                    |

- a Noncurrent specification.  
b Class of properties attainable depends on location specified and casting design and should be coordinated with the producer.  
c Reference should be made to the specific requirements of the procuring or certifying agency with regard to the use of the above values in the design of castings.  
d When specified on drawing, conformance to tensile property requirements is determined by testing specimens cut from castings.  
e Estimated.

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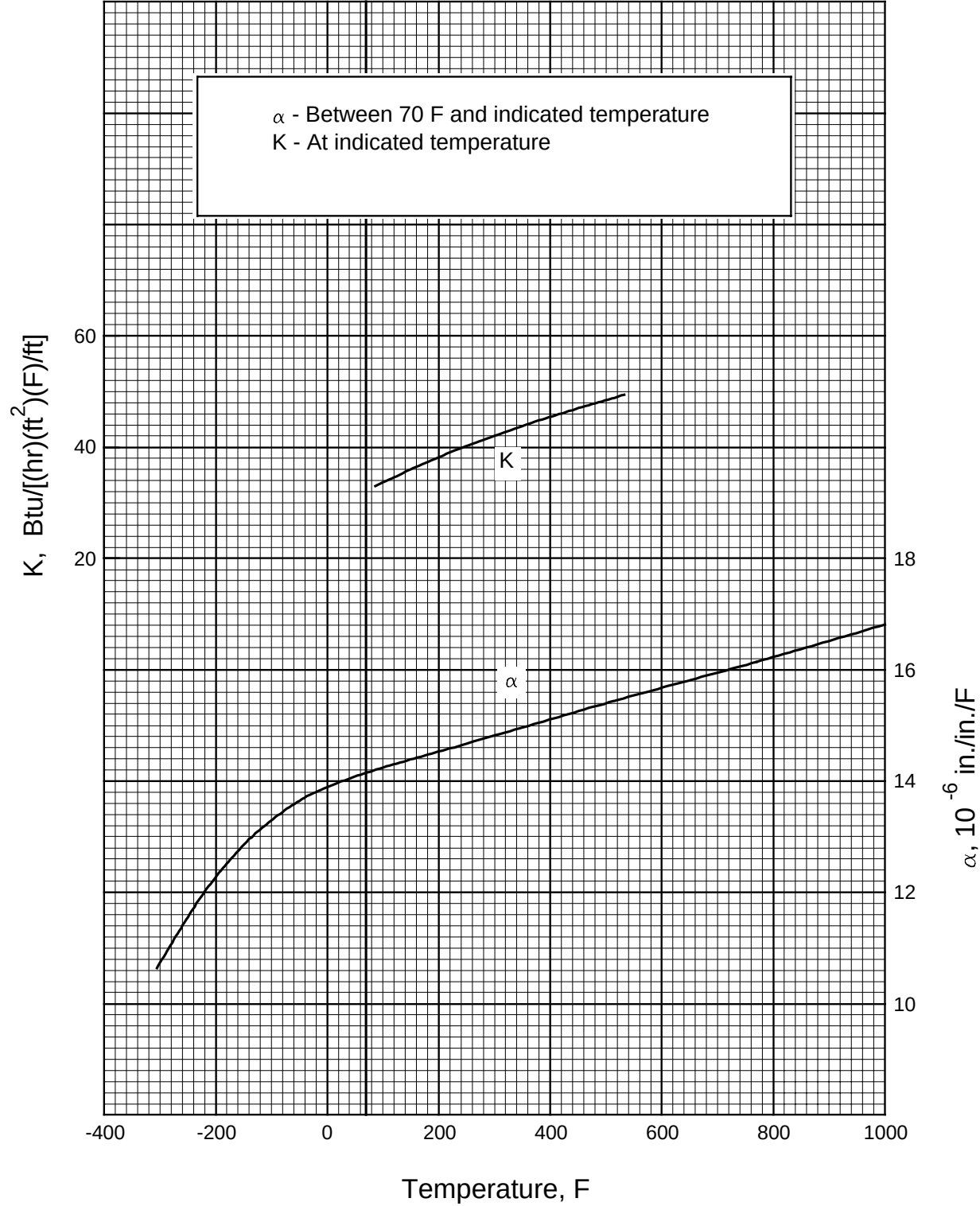


Figure 4.3.3.0. Effect of temperature on the physical properties of cast AZ92A-T6.

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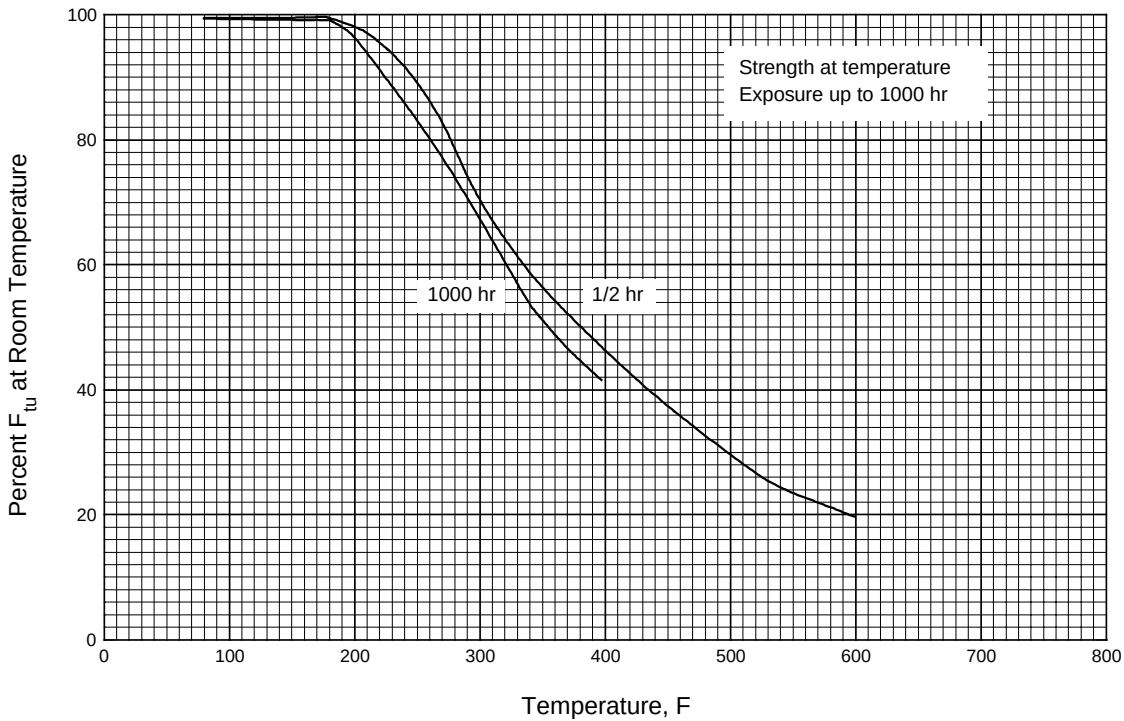


Figure 4.3.3.1.1(a). Effect of temperature on the tensile ultimate strength ( $F_{tu}$ ) of cast AZ92A-T6.

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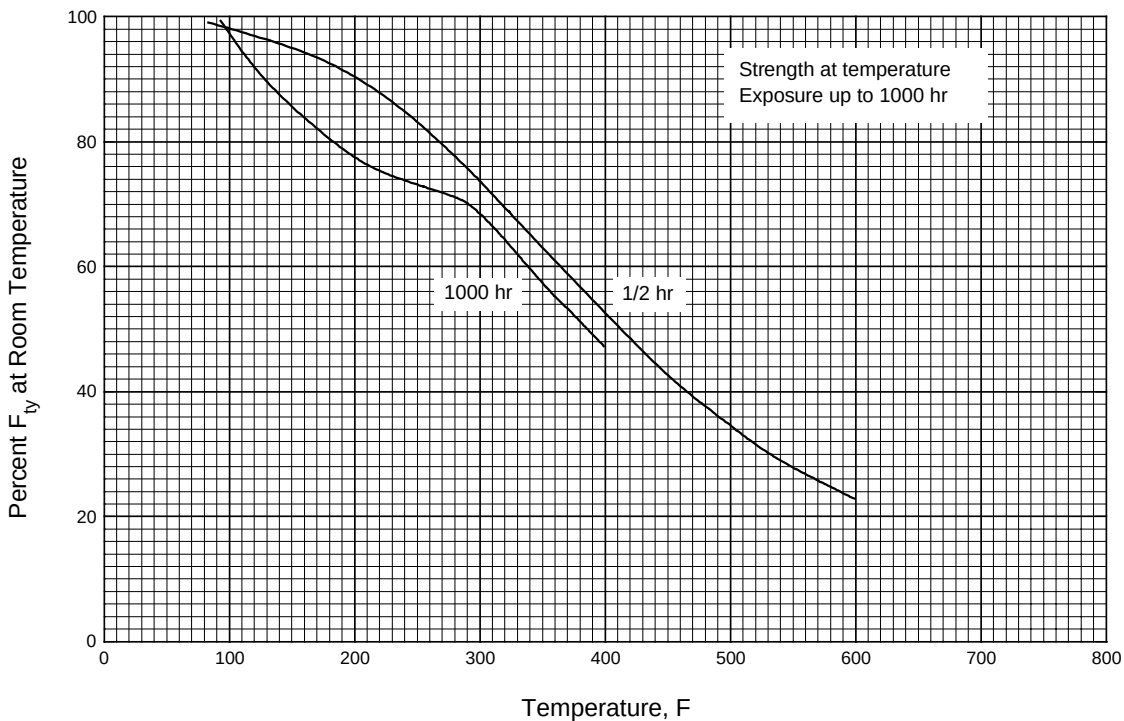


Figure 4.3.3.1.1(b). Effect of temperature on the tensile yield strength ( $F_{ty}$ ) of cast AZ92A-T6.

[VIEW INTERACTIVE GRAPH](#)

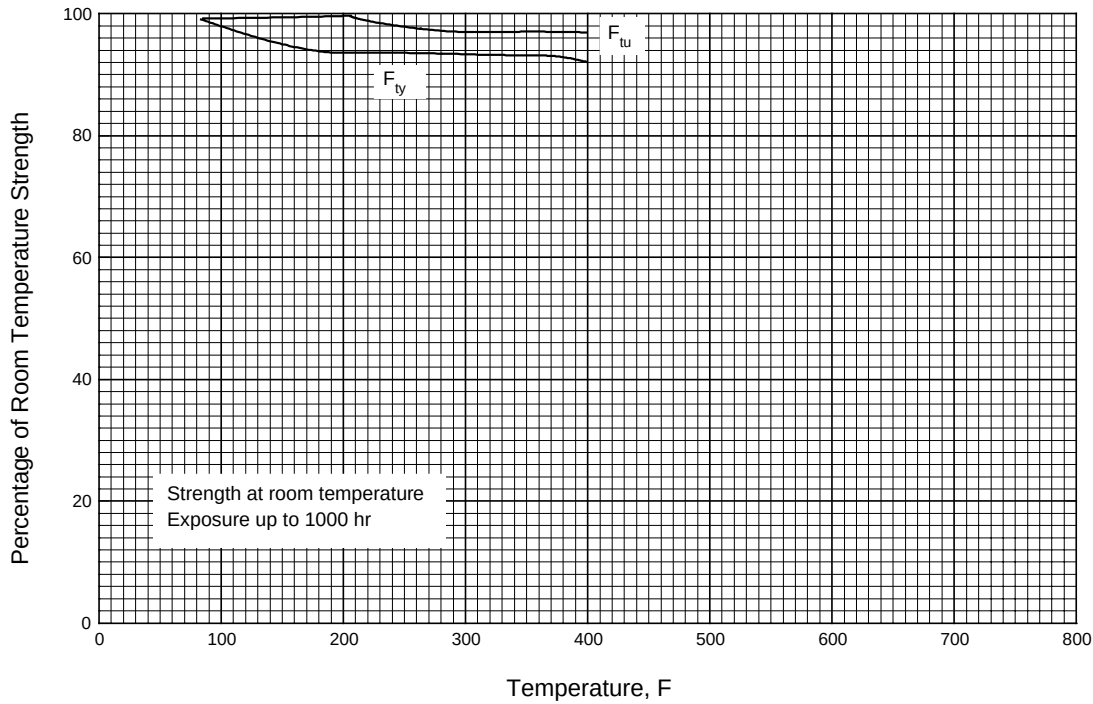


Figure 4.3.3.1.1(c). Effect of exposure at elevated temperature on the room-temperature tensile ultimate strength ( $F_{tu}$ ) and the tensile yield strength ( $F_{ty}$ ) of cast AZ92A-T6.

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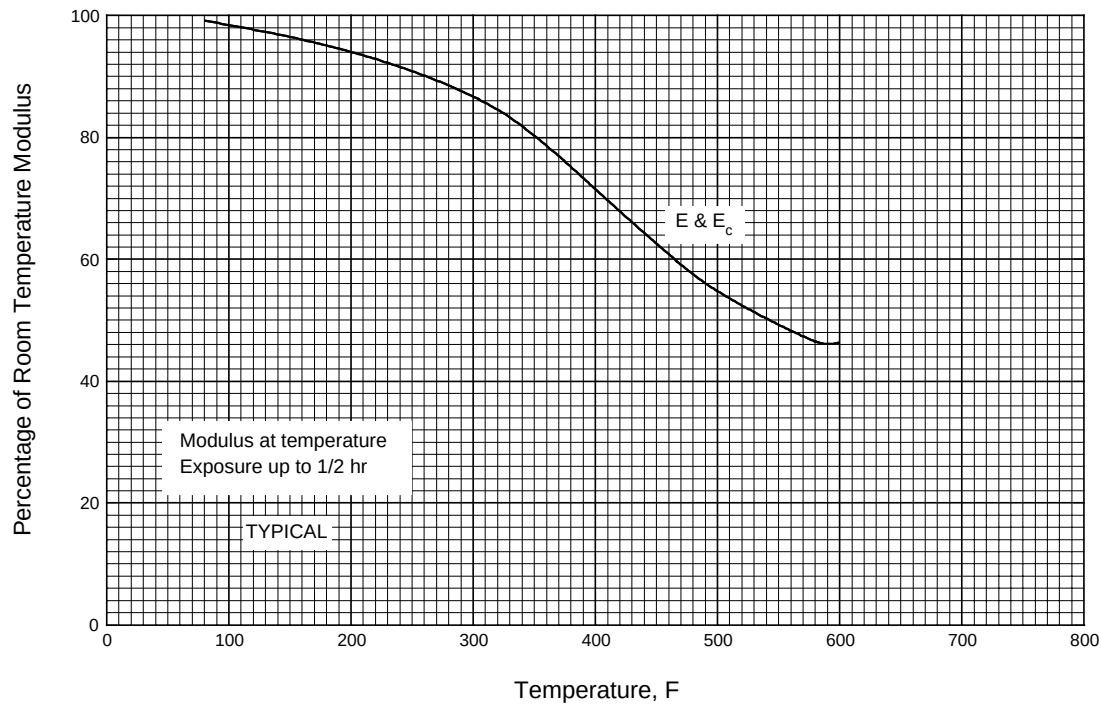


Figure 4.3.3.1.4. Effect of temperature on the tensile and compressive moduli ( $E$  and  $E_c$ ) of cast AZ92A-T6.

[VIEW INTERACTIVE GRAPH](#)

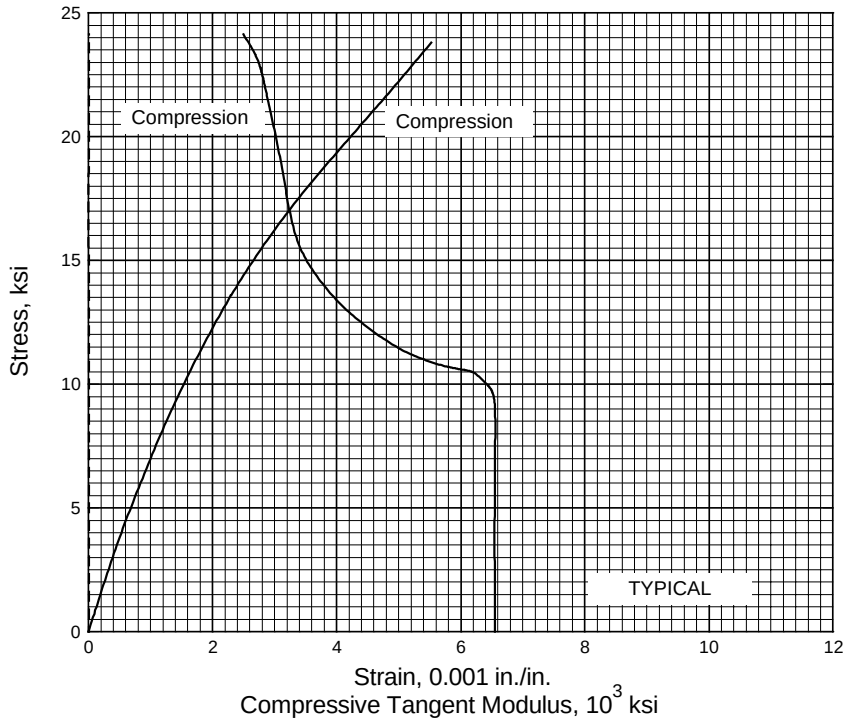


Figure 4.3.3.1.6(a). Typical compressive stress-strain and compressive tangent-modulus curves for cast AZ92A-T6 at room temperature.

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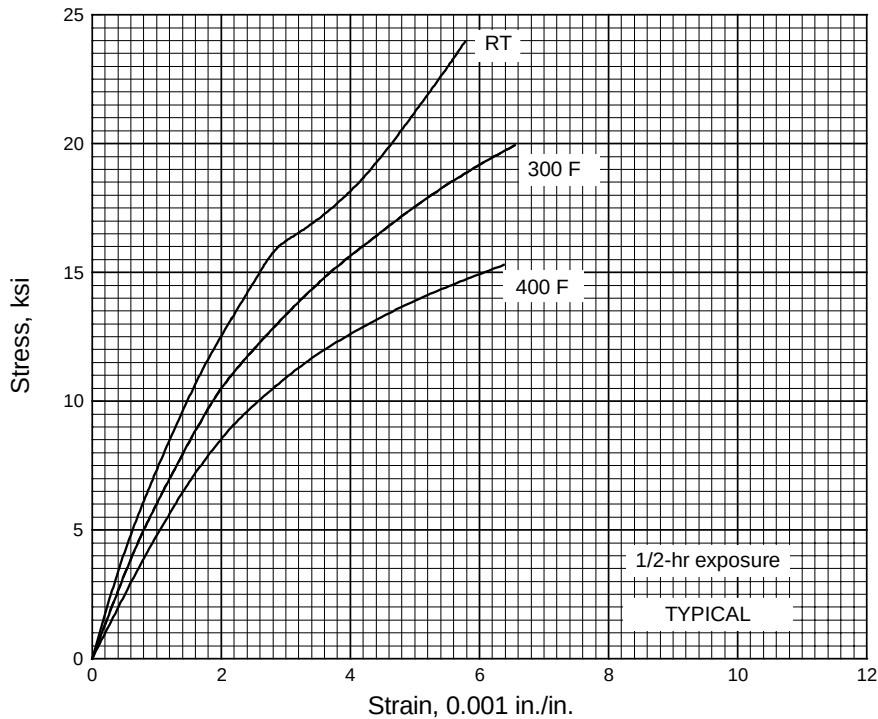


Figure 4.3.3.1.6(b). Typical tensile stress-strain curves for cast AZ92A-T6 at room and elevated temperatures.

4.3.4 EZ33A

**4.3.4.0 Comments and Properties** — EZ33A is a magnesium-base casting alloy containing rare earths, zinc, and zirconium. It is available as sand castings in the artificially aged (T5) temper. EZ33A has lower strength than the Mg-Al-Zn alloys at room temperature but is less affected by increasing temperature. It is generally used for applications at temperatures of 300 to 500°F. EZ33A castings are very sound and are sometimes used for pressure tightness. It has good stability in the T5 temper and excellent weldability. It is sometimes used for applications requiring good damping ability.

A material specification for EZ33A is presented in Table 4.3.4.0(a). Room-temperature mechanical and physical properties are shown in Table 4.3.4.0(b). The effect of temperature on physical properties is shown in Figure 4.3.4.0.

**Table 4.3.4.0(a). Material Specifications for EZ33A Magnesium Alloy**

| Specification | Form         |
|---------------|--------------|
| AMS 4442      | Sand casting |

The temper index for EZ33A is as follows:

|                |               |
|----------------|---------------|
| <u>Section</u> | <u>Temper</u> |
| 4.3.4.1        | T5            |

**4.3.4.1 EZ33A-T5 Temper** — Elevated temperature curves for tensile properties are presented in Figures 4.3.4.1.1(a) through (c). A typical tensile stress-strain curve at room temperature is presented in Figure 4.3.4.1.6.

**Table 4.3.4.0(b). Design Mechanical and Physical Properties  
of EZ33A Magnesium Alloy Casting**

|                                      |                    |
|--------------------------------------|--------------------|
| Specification .....                  | AMS 4442           |
| Form .....                           | Sand casting       |
| Temper .....                         | T5                 |
| Location within<br>casting .....     | Any area           |
| Basis .....                          | S                  |
| Mechanical Properties <sup>a</sup> : |                    |
| $F_{tu}$ , ksi .....                 | 13 <sup>b</sup>    |
| $F_{ty}$ , ksi .....                 | 11 <sup>b</sup>    |
| $F_{cy}$ , ksi .....                 | 11                 |
| $F_{su}$ , ksi .....                 | ...                |
| $F_{bru}$ , ksi:                     |                    |
| (e/D = 1.5) .....                    | ...                |
| (e/D = 2.0) .....                    | ...                |
| $F_{bry}$ , ksi:                     |                    |
| (e/D = 1.5) .....                    | ...                |
| (e/D = 2.0) .....                    | ...                |
| e, percent .....                     | 1.5                |
| $E$ , 10 <sup>3</sup> ksi .....      | 6.5                |
| $E_c$ , 10 <sup>3</sup> ksi .....    | 6.5                |
| $G$ , 10 <sup>3</sup> ksi .....      | 2.4                |
| $\mu$ .....                          | 0.35               |
| Physical Properties:                 |                    |
| $\omega$ , lb/in. <sup>3</sup> ..... | 0.0659             |
| C, Btu/(lb)(°F) .....                | 0.25               |
| K and $\alpha$ .....                 | See Figure 4.3.4.0 |

a Reference should be made to the specific requirements of the procuring or certifying agency with regard to the use of the above values in the design of castings.

b When specified on drawing, conformance to tensile property requirements is determined by testing specimens cut from castings.

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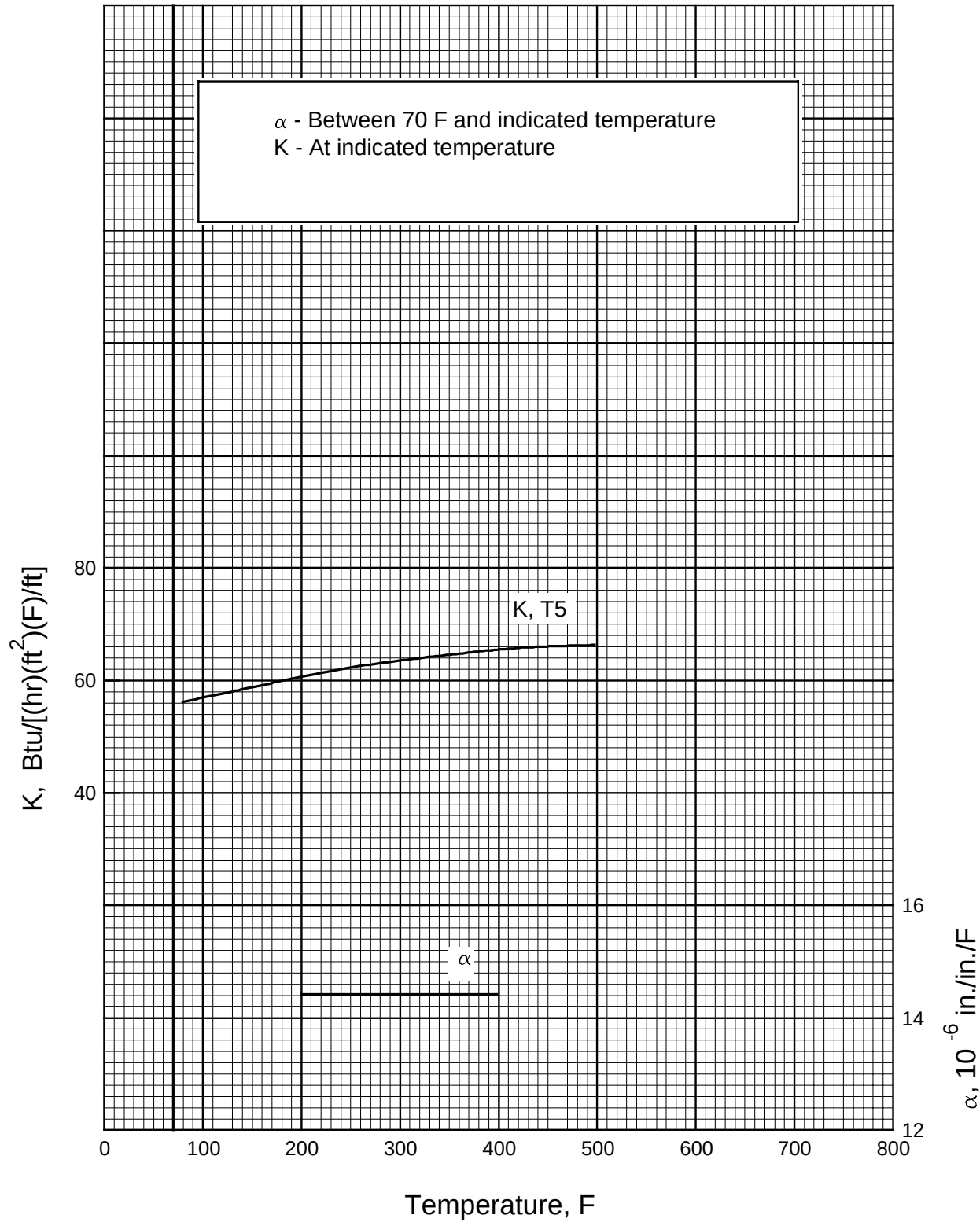


Figure 4.3.4.0. Effect of temperature on the physical properties of cast EZ33A.



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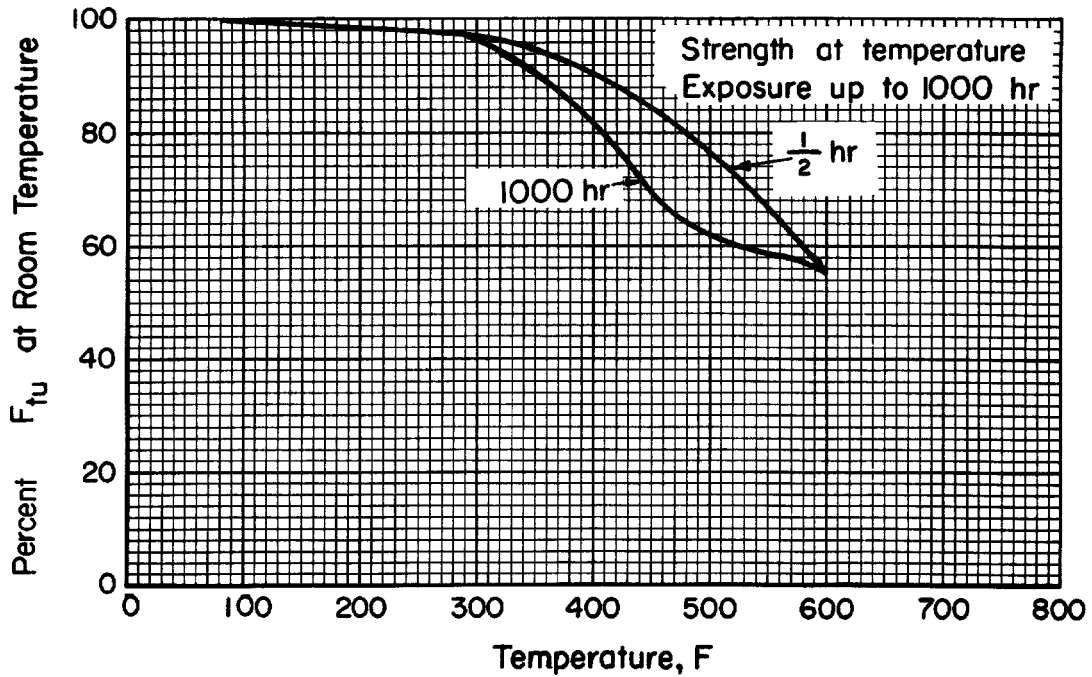


Figure 4.3.4.1.1(a). Effect of temperature on the tensile ultimate strength ( $F_{tu}$ ) of cast EZ33A-T5.

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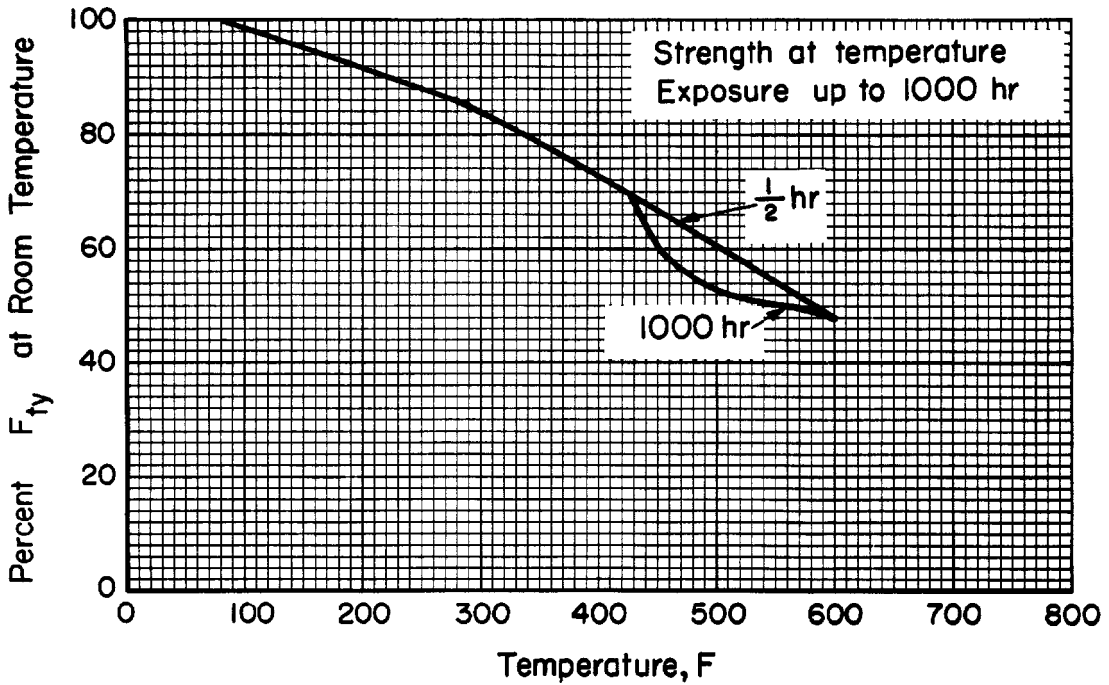


Figure 4.3.4.1.1(b). Effect of temperature on the tensile yield strength ( $F_{ty}$ ) of cast EZ33A-T5.

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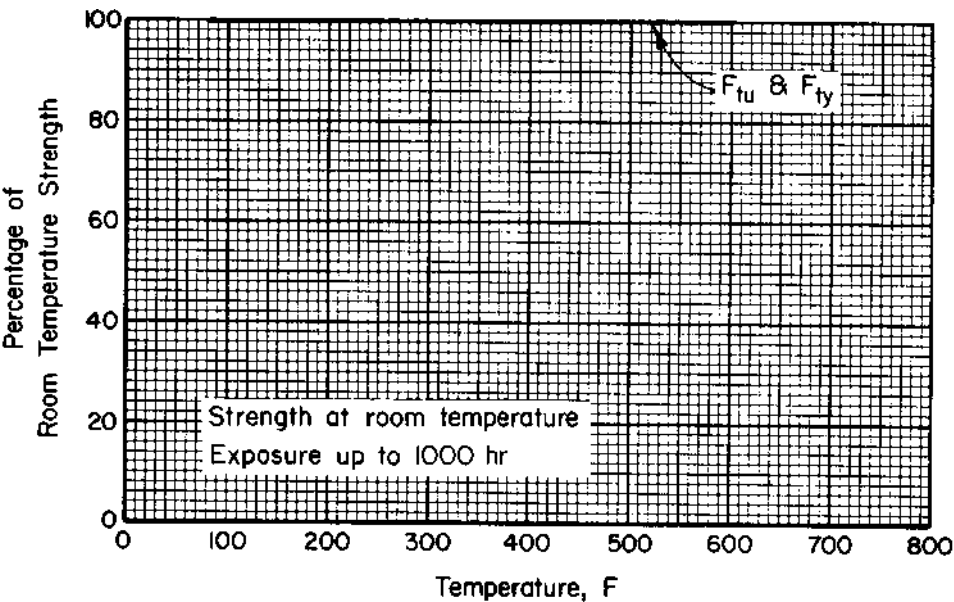


Figure 4.3.4.1.1(c). Effect of exposure at elevated temperatures on the room temperature tensile ultimate strength ( $F_{tu}$ ) and the tensile yield strength ( $F_{ty}$ ) of cast EZ33A-T5.

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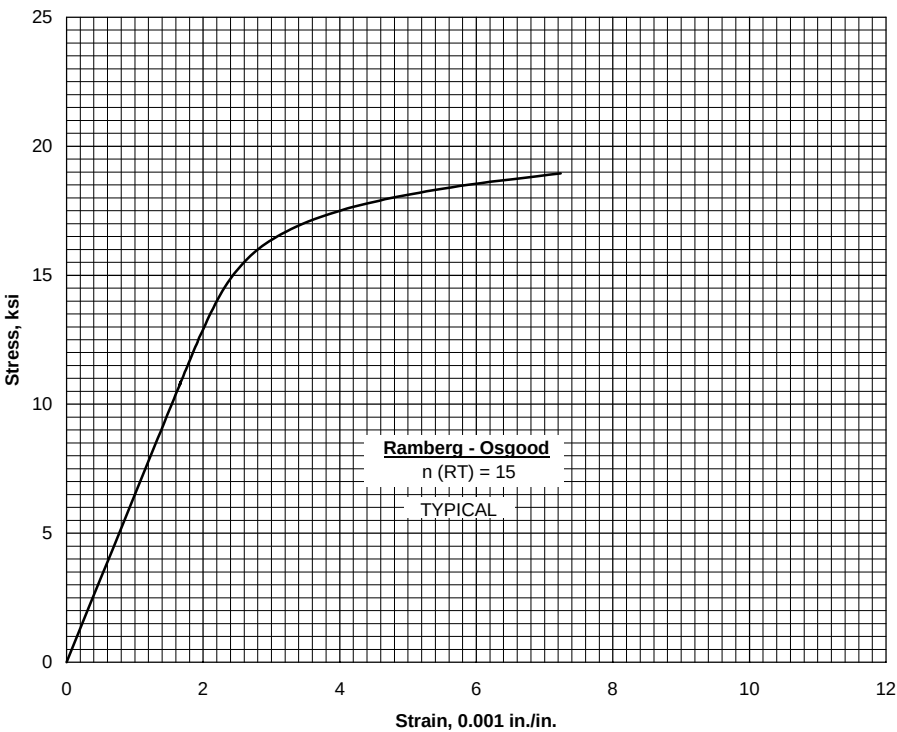


Figure 4.3.4.1.6. Typical tensile stress-strain curve for cast EZ33A-T5 at room temperature.

4.3.5 QE22A

**4.3.2.0 Comments and Properties** — QE22A is a magnesium-base alloy containing silver, rare earths in the form of didymium, and zirconium. It is available as sand and permanent-mold castings. It is used in the solution heat-treated and artificially aged (T6) condition where a high yield strength is needed at temperatures up to 600°F. QE22A has good weldability and fair pressure tightness.

Material specifications for QE22A are presented in Table 4.3.5.0(a). Room-temperature mechanical and physical properties are shown in Table 4.3.5.0(b).

**Table 4.3.5.0(a). Material Specifications for QE22A Magnesium Alloy**

| Specification | Form         |
|---------------|--------------|
| AMS 4418      | Sand casting |
| MIL-M-46062   | Casting      |

The temper index for QE22A is as follows:

|                |               |
|----------------|---------------|
| <u>Section</u> | <u>Temper</u> |
| 4.3.5.1        | T6            |

**4.3.5.1 QE22A-T6 Temper** — Elevated temperature curves for various tensile properties and modulus of elasticity are presented in Figures 4.3.5.1.1 and 4.3.5.1.4. Typical tensile stress-strain curves at various temperatures from room temperature through 700°F are shown in Figure 4.3.5.1.6.

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 4.3.5.0(b). Design Mechanical and Physical Properties of QE22A Magnesium Alloy Casting**

|                                                  |                    |                      |                      |                      |                    |
|--------------------------------------------------|--------------------|----------------------|----------------------|----------------------|--------------------|
| Specification . . . . .                          | AMS 4418           | MIL-M-46062          |                      |                      |                    |
| Form . . . . .                                   | Sand casting       | Casting (any method) |                      |                      |                    |
| Temper . . . . .                                 | T6                 |                      |                      |                      |                    |
| Location within casting .                        | Any area           | Designated area      |                      |                      | Nondesignated area |
|                                                  |                    | Class 1 <sup>a</sup> | Class 2 <sup>a</sup> | Class 3 <sup>a</sup> |                    |
| Basis . . . . .                                  | S                  | S                    | S                    | S                    | S                  |
| Mechanical Properties <sup>b</sup> :             |                    |                      |                      |                      |                    |
| $F_{tu}$ , ksi . . . . .                         | 32 <sup>c</sup>    | 40                   | 37                   | 33                   | 28                 |
| $F_{ty}$ , ksi . . . . .                         | 23 <sup>c</sup>    | 28                   | 26                   | 23                   | 20                 |
| $F_{cy}$ , ksi . . . . .                         | 23                 | 28                   | 26                   | 23                   | 20                 |
| $F_{su}$ , ksi . . . . .                         | ...                | ...                  | ...                  | ...                  | ...                |
| $F_{bru}$ , ksi:                                 |                    |                      |                      |                      |                    |
| (e/D = 1.5) . . . . .                            | ...                | ...                  | ...                  | ...                  | ...                |
| (e/D = 2.0) . . . . .                            | ...                | ...                  | ...                  | ...                  | ...                |
| $F_{bry}$ , ksi:                                 |                    |                      |                      |                      |                    |
| (e/D = 1.5) . . . . .                            | ...                | ...                  | ...                  | ...                  | ...                |
| (e/D = 2.0) . . . . .                            | ...                | ...                  | ...                  | ...                  | ...                |
| $e$ , percent . . . . .                          | 2 <sup>c</sup>     | 4                    | 2                    | 2                    | 1                  |
| $E$ , 10 <sup>3</sup> ksi . . . . .              | 6.5                |                      |                      |                      |                    |
| $E_c$ , 10 <sup>3</sup> ksi . . . . .            | 6.5                |                      |                      |                      |                    |
| $G$ , 10 <sup>3</sup> ksi . . . . .              | 2.4                |                      |                      |                      |                    |
| $\mu$ . . . . .                                  | 0.35               |                      |                      |                      |                    |
| Physical Properties:                             |                    |                      |                      |                      |                    |
| $\omega$ , lb/in. <sup>3</sup> . . . . .         | 0.0653             |                      |                      |                      |                    |
| $C$ , Btu/(lb)(°F) . . . . .                     | 0.25 <sup>d</sup>  |                      |                      |                      |                    |
| $K$ , Btu/[(hr)(ft <sup>2</sup> )(°F)/ft] .      | 59                 |                      |                      |                      |                    |
| $\alpha$ , 10 <sup>-6</sup> in./in./°F . . . . . | 14 (68°F to 392°F) |                      |                      |                      |                    |

a Class of properties attainable depends on location specified and casting design and should be coordinated with the producer.

b Reference should be made to the specific requirements of the procuring or certifying agency with regard to the use of the above values in the design of castings.

c When specified on drawing, conformance to tensile property requirements is determined by testing specimens cut from castings.

d Estimated.

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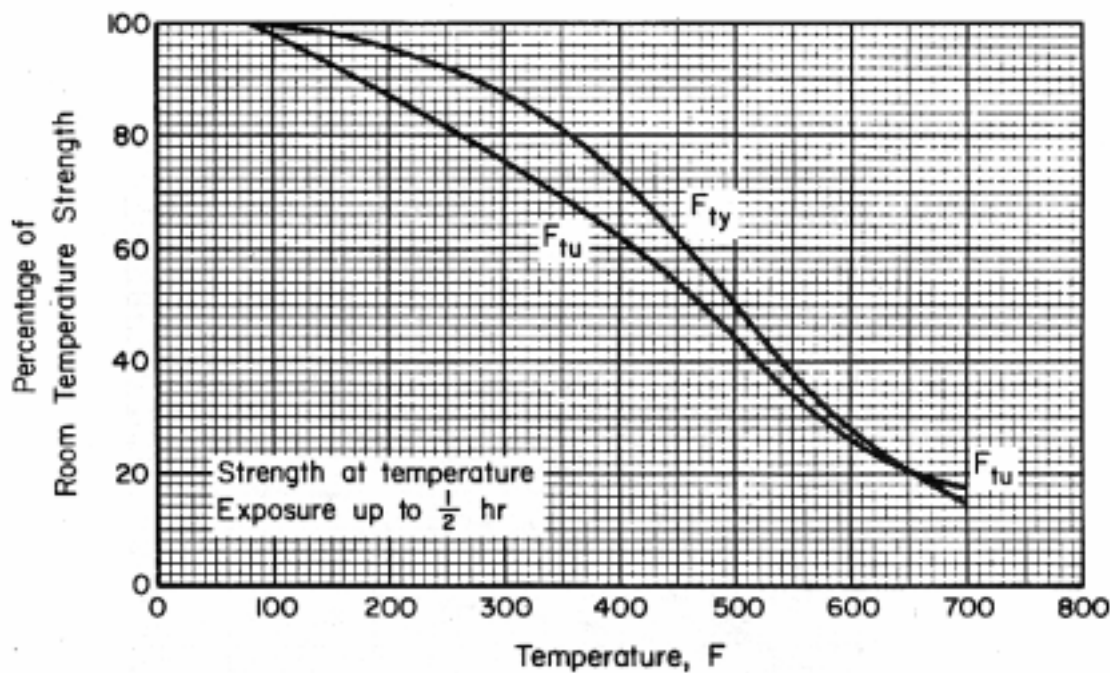


Figure 4.3.5.1.1. Effect of temperature on the tensile ultimate strength ( $F_{tu}$ ) and the tensile yield strength ( $F_{ty}$ ) of cast QE22A-T6.

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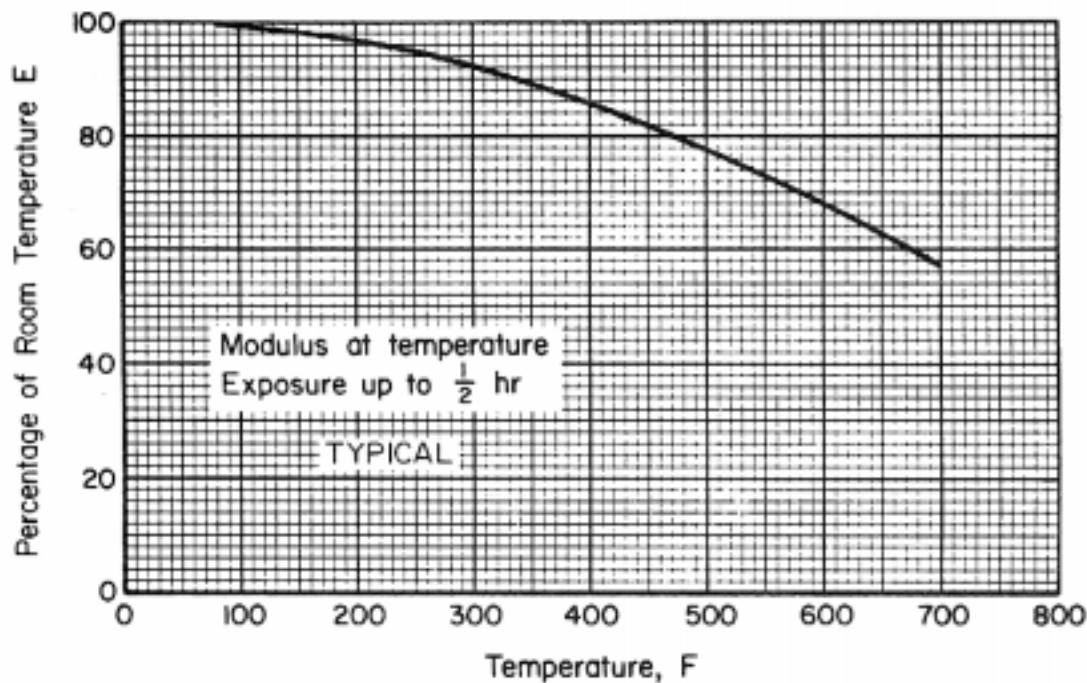


Figure 4.3.5.1.4. Effect of temperature on the tensile modulus (E) of cast QE22A-T6.

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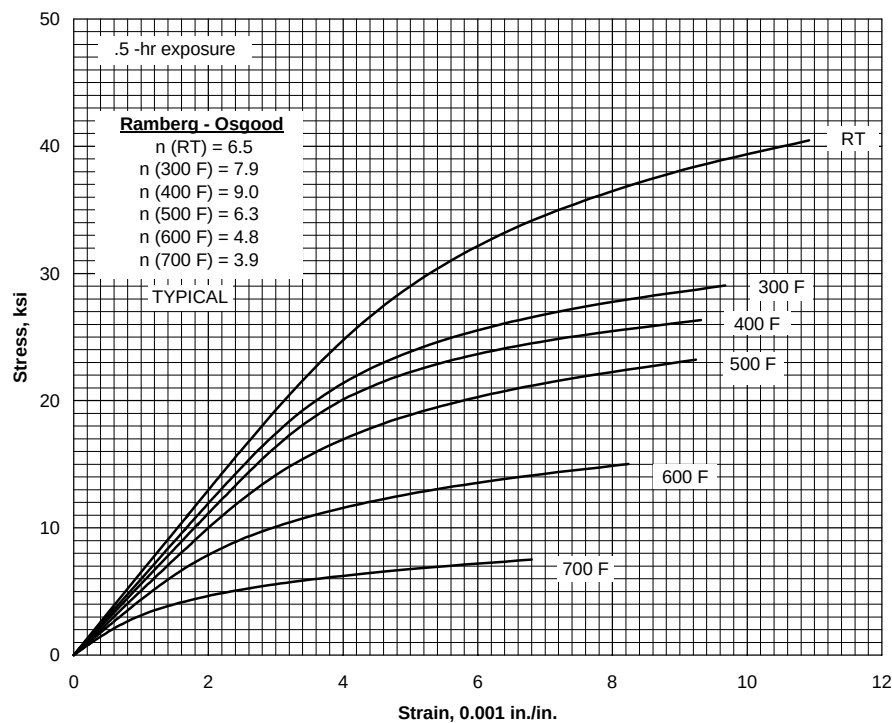


Figure 4.3.5.16. Typical tensile stress-strain curves for cast QE22A-T6 at room and elevated temperatures.

4.3.6 ZE41A

**4.3.3.0 Comments and Properties** — ZE41A is a magnesium-base casting alloy containing zinc, zirconium, and rare earth elements. It is available as sand or permanent-mold castings in the artificially aged temper (T5). ZE41A has a higher yield strength than the Mg-Al-Zn alloys at room temperature and is more stable at elevated temperatures. It is useful for applications at temperatures up to 320 °F. ZE41A castings possess good weldability and are pressure tight.

A material specification for ZE41A is presented in Table 4.3.6.0(a). Room temperature mechanical and physical properties are shown in Table 4.3.6.0(b). The effect of temperature on thermal conductivity is shown in Figure 4.3.6.0.

**Table 4.3.6.0(a). Material Specifications for ZE41A  
Magnesium Alloy**

| Specification | Form         |
|---------------|--------------|
| AMS 4439      | Sand casting |

The temper index for ZE41A is as follows:

|                |               |
|----------------|---------------|
| <u>Section</u> | <u>Temper</u> |
| 4.3.6.1        | T5            |

**4.3.6.1 T5 Temper** — Elevated temperature curves for tensile yield and ultimate strengths are presented in Figure 4.3.6.1.1. The effect of temperature on the tensile modulus of elasticity is shown in Figure 4.3.6.1.4. Figures 4.3.6.1.6(a) and (b) contain tensile and compressive stress-strain curves as well as a compressive tangent-modulus curve.

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 4.3.6.0(b). Design Mechanical and Physical Properties of ZE41A Magnesium Alloy Casting**

|                                                 |                     |
|-------------------------------------------------|---------------------|
| Specification .....                             | AMS 4439            |
| Form .....                                      | Sand casting        |
| Temper .....                                    | T5                  |
| Thickness, in. ....                             | Any area            |
| Basis .....                                     | S                   |
| Mechanical Properties <sup>a</sup> :            |                     |
| $F_{tu}$ , ksi .....                            | 26 <sup>b</sup>     |
| $F_{ty}$ , ksi .....                            | 17.5 <sup>b</sup>   |
| $F_{cy}$ , ksi .....                            | 15                  |
| $F_{su}$ , ksi .....                            | 17                  |
| $F_{bru}$ , ksi:                                |                     |
| (e/D = 1.5) .....                               | 38                  |
| (e/D = 2.0) .....                               | 49                  |
| $F_{bry}^c$ , ksi:                              |                     |
| (e/D = 1.5) .....                               | 31                  |
| (e/D = 2.0) .....                               | 35                  |
| $e$ , percent .....                             | 2 <sup>b</sup>      |
| $E$ , 10 <sup>3</sup> ksi .....                 | 6.5                 |
| $E_c$ , 10 <sup>3</sup> ksi .....               | 6.5                 |
| $G$ , 10 <sup>3</sup> ksi .....                 | 2.4                 |
| $\mu$ .....                                     | 0.35                |
| Physical Properties:                            |                     |
| $\omega$ , lb/in. <sup>3</sup> .....            | 0.0656              |
| $C$ , Btu/(lb)(°F) .....                        | 0.234 (at 68 °F)    |
| $K$ , Btu/[(hr)(ft <sup>2</sup> )(°F)/ft] ..... | See Figure 4.3.6.0  |
| $\alpha$ , 10 <sup>-6</sup> in./in./°F .....    | 15.5 (68 to 212 °F) |

a The mechanical properties shown are reliably obtainable when castings are produced under the quality assurance provisions of AMS 4439. These provisions require preproduction approval, documentation of foundry procedures, and specific testing procedures for the acceptance of each production lot of castings. Strict adherence to these requirements is mandatory if these properties are to be reliably assured in each casting.

b Conformance to tensile property requirements is determined by testing specimens cut from casting only when specified on drawing.

c Bearing values are “dry pin” values per Section 1.4.7.1.



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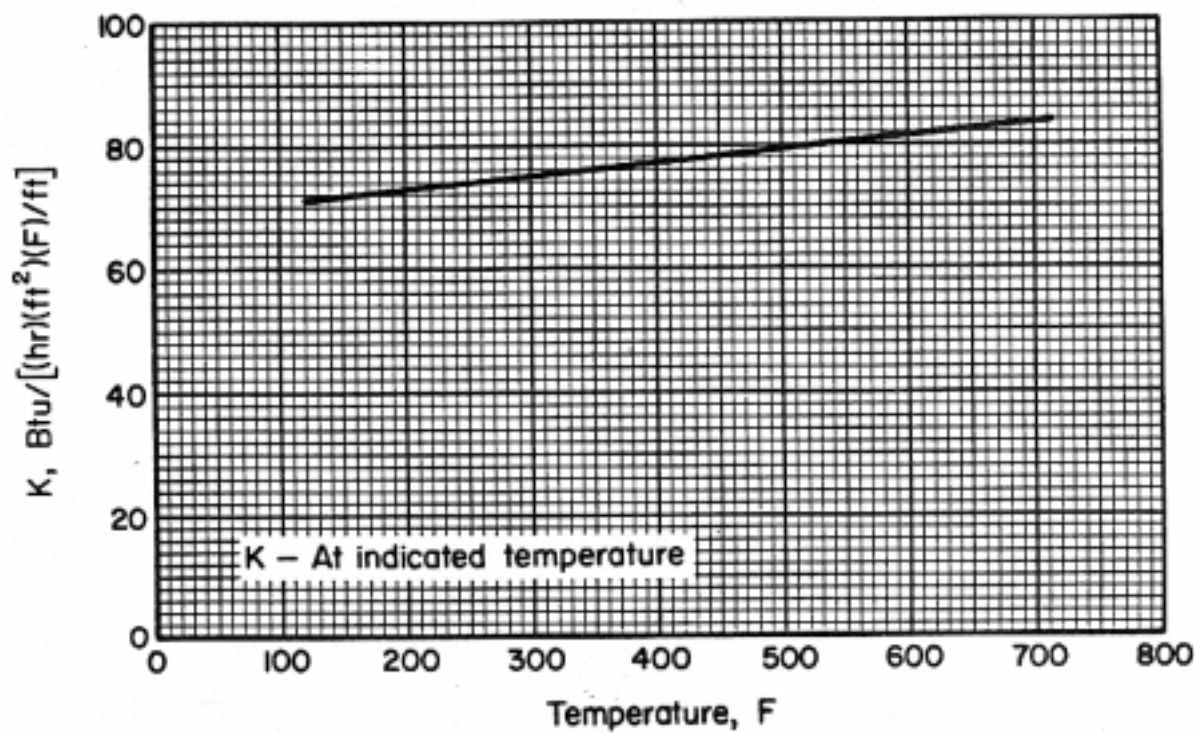


Figure 4.3.6.0. Effect of temperature on the thermal conductivity (K) of ZE41A-T5 sand casting.

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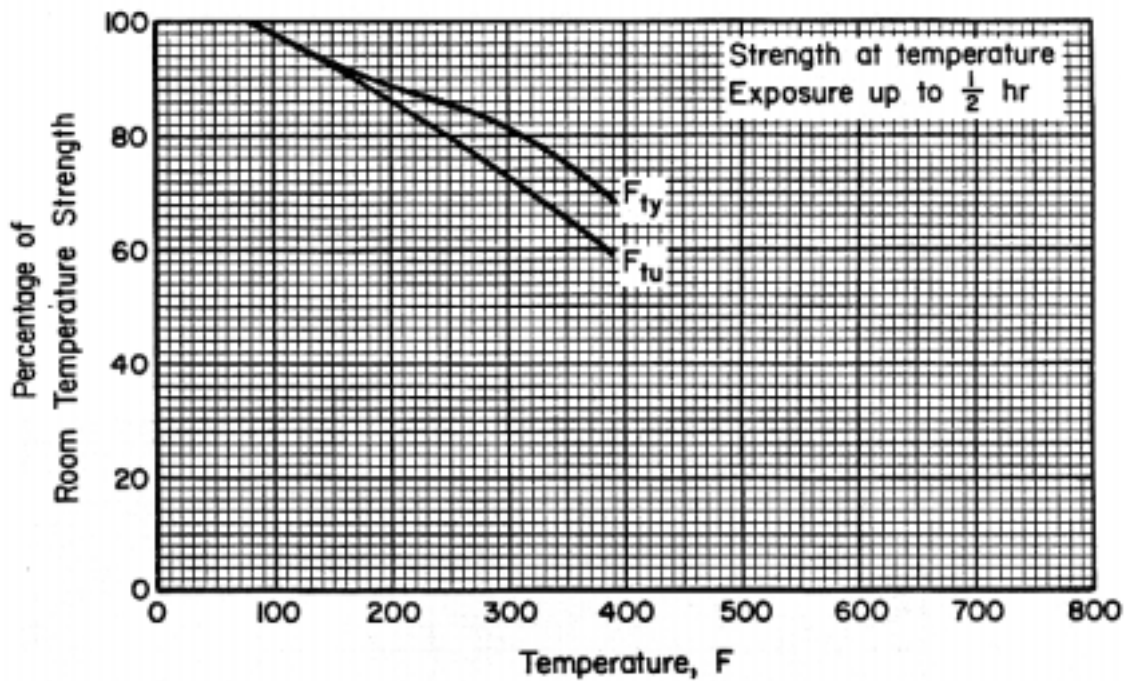


Figure 4.3.6.1.1. Effect of temperature on the tensile ultimate strength ( $F_{tu}$ ) and tensile yield strength ( $F_{ty}$ ) of ZE41A-T5 sand casting.

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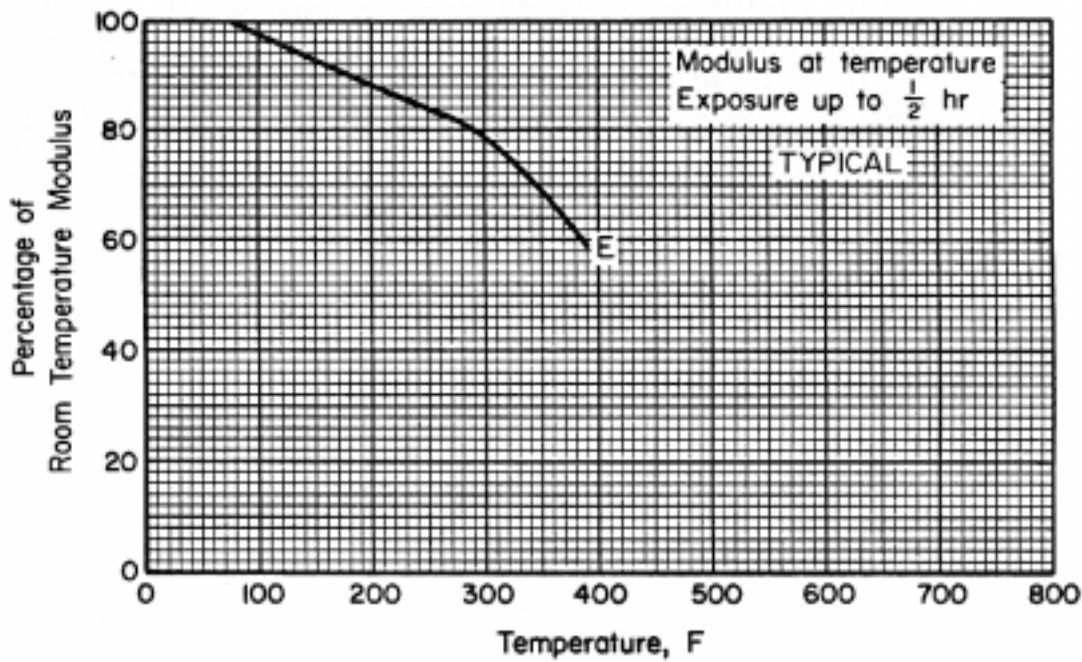


Figure 4.3.6.1.4. Effect of temperature on the tensile modulus (E) of ZE41A-T5 sand casting.

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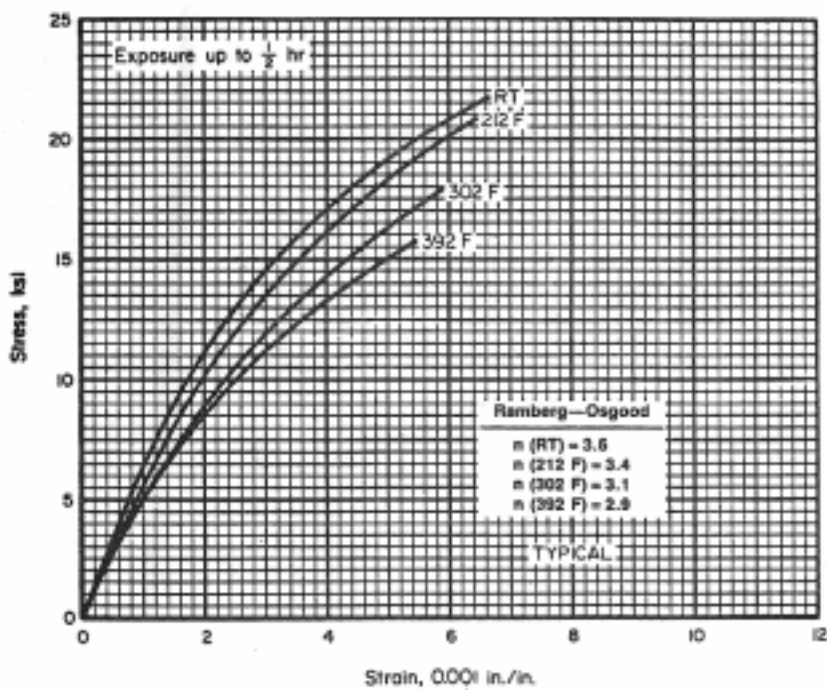


Figure 4.3.6.1.6(a). Typical tensile stress-strain curves for ZE41A-T5 sand casting at room and elevated temperatures.

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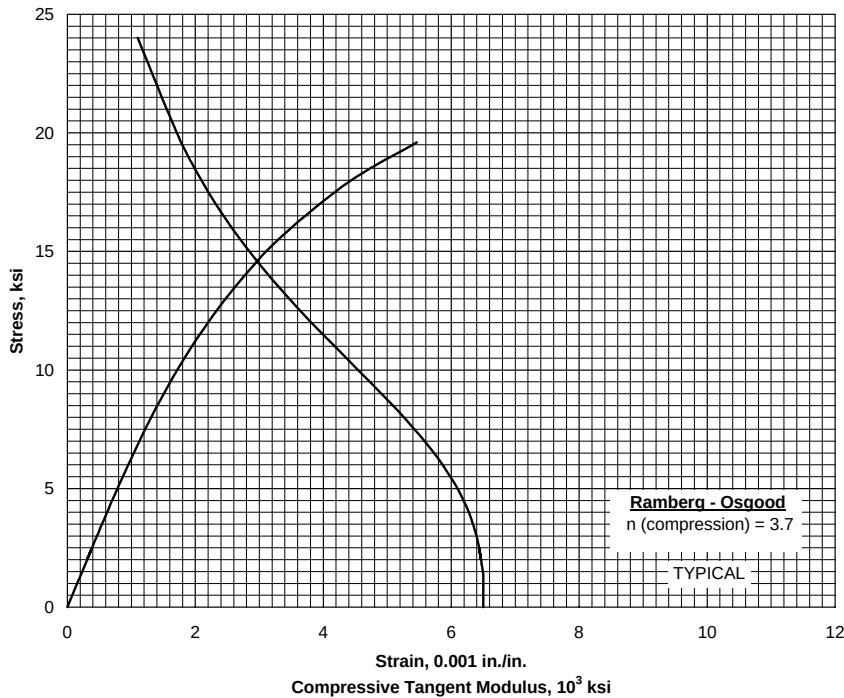


Figure 4.3.6.1.6(b). Typical compressive stress-strain and tangent-modulus curves for ZE41A-T5 sand casting at room temperature.

4.4 ELEMENT PROPERTIES

**4.4.1 BEAMS** — Refer to Chapter 1 and References 1.7.1(a) and (b) for general information on stress analysis of beam s.

**4.4.1.1 Simple Beams** — Beams of solid tubular, or similar cross sections can be assumed to fail through exceeding an allowable modulus of rupture in bending ( $F_b$ ). In the absence of specific data, the ratio  $F_b/F_w$  can be assumed to be 1.25 for solid sections.

**4.4.1.1.1 Round Tubes** — For round tubes, the value of  $F_b$  will depend on the  $D/t$  ratio as well as the compressive yield stress.

**4.4.1.1.2 Unconventional Cross Sections** — Sections other than solid or tubular should be tested to determine allowable bending stress.

**4.4.1.2 Built-Up Beams** — Built-up beams will usually fail because of local failure of compo-

**4.4.1.3 Thin-Web Beams** — The allowable stress for thin-web beams will depend on the nature of the failure and are determined from the allowable stress of the web in tension and of the flanges or stiffeners in compression.

4.4.2 COLUMNS

**4.4.2.1 Primary Failure** — The general formula for primary instability is given in Section 1.3.8. Formulas applicable to magnesium-alloy columns are given in Tables 4.4.2.1(a) and (b). See References 4.4.2(a) and (b).

**Table 4.4.2.1(a). Column Formula for Magnesium-Alloy  
Extruded Open Shapes**

General Formula<sup>a</sup>

$$\frac{P}{A} = \frac{K(F_{cy})^n}{(L'/\rho)^m}$$

(Stress values are in ksi)

| Alloy        | K     | n | m   | Max. P/A      |
|--------------|-------|---|-----|---------------|
| AZ31B, AZ61A | 2,900 | ¼ | 1.5 | $F_{cy}$      |
| ZK60A-T5     | 3,300 | ¼ | 1.5 | $0.96 F_{cy}$ |

<sup>a</sup> Formula is for members that do not fail by local buckling.  
See Figure 4.4.2.3(a).

**Table 4.4.2.1(b). Column Formula for AZ31B-H24  
Magnesium-Alloy Sheet**

---

$$\frac{P}{A} = 1.05 F_{cy} - \frac{(1.05 F_{cy})^2 (L'/\rho)^2}{4 \pi^2 E}$$

$$\text{MAX } \frac{P}{A} = F_{cy}$$

See Figure 4.4.2.3(b).

---

#### **4.4.2.2 Local Failure**

**4.4.2.3 Column Properties** — Curves of the allowable column stresses for various magnesium alloy columns are given in Figures 4.4.2.3(a) and (b). The allowable stress is plotted against the effective slenderness ratio defined by Equation 3.11.2.3.

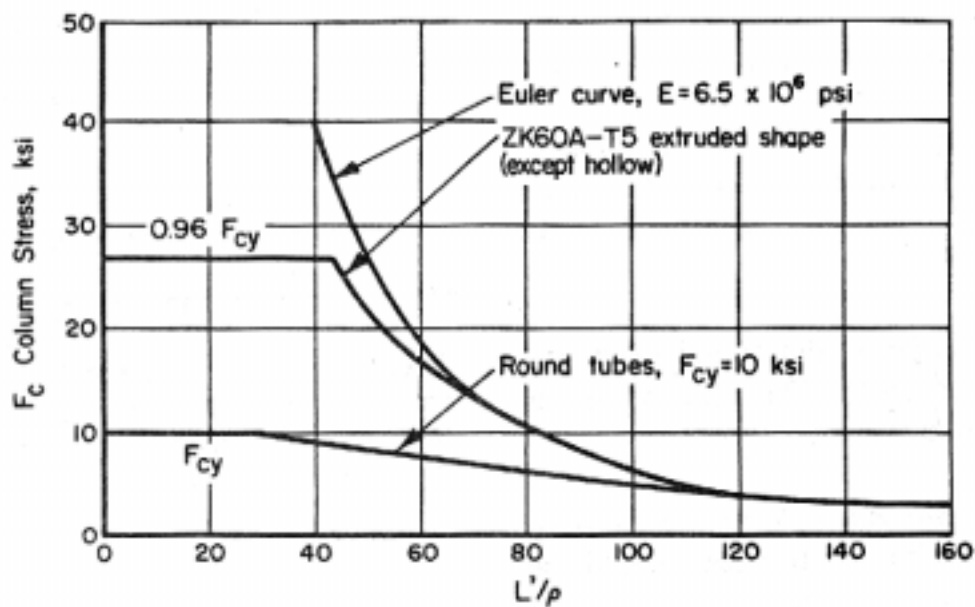


Figure 4.4.2.3(a). Allowable column stresses for magnesium-alloy columns.

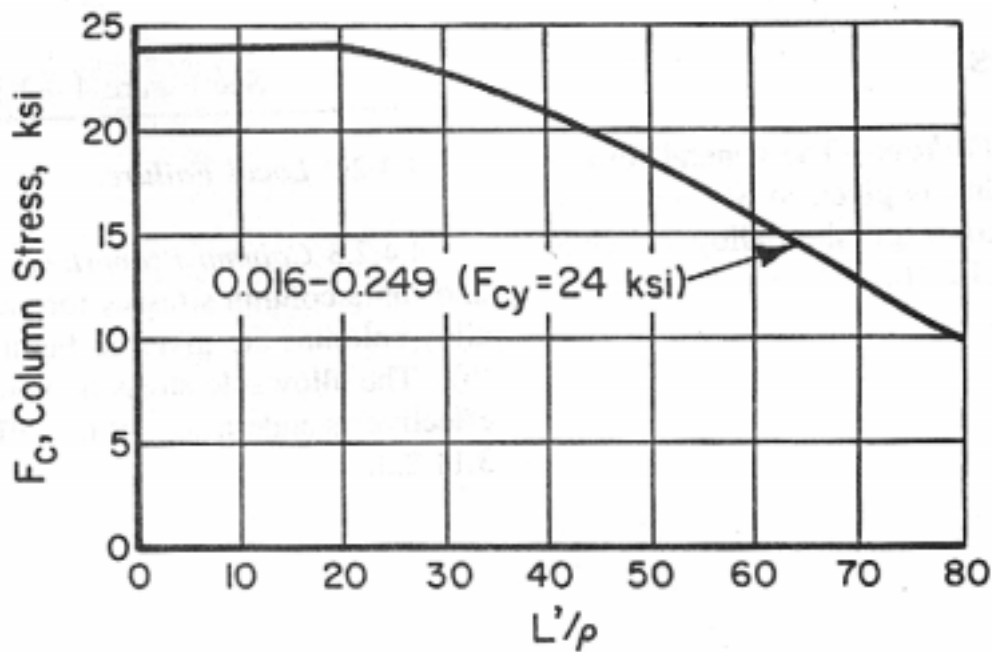


Figure 4.4.2.3(b). Allowable column stresses for AZ31B-H24 magnesium-alloy sheet.

4.4.3 TORSION

**4.4.3.1 General** — The general statements relating to aluminum-alloy tubing in 3.11.3 are applicable to magnesium tubing.

**4.4.3.2 Torsion Properties** — An empirical curve of the allowable torsional modulus of rupture for AZ62A-F magnesium-alloy round tubing (specification WW-T-825) is given in Figure 4.4.3.2.

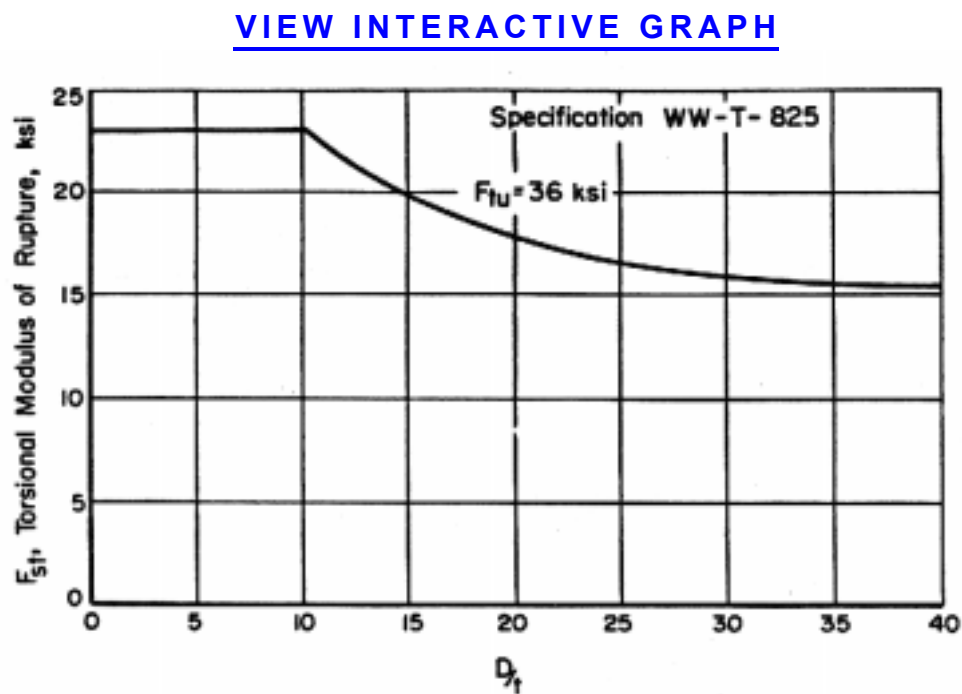


Figure 4.4.3.2. Torsional modulus of rupture for AZ61A-F magnesium-alloy round tubing.

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- 4.4.2(a) Schuette, E. H., “Hyperbolic Column Formulas for Magnesium Alloy Extrusions”, Journal of the Aeronautical Sciences, 15, pp 523-529 (1948).
- 4.4.2(b) Schuette, E. H., “Column Curves for Magnesium Alloy Sheet”, Journal of the Aeronautical Sciences, 16, pp 301-305 (1949).

## CHAPTER 5

### TITANIUM

#### 5.1 GENERAL

This chapter contains the engineering properties and related characteristics of titanium and titanium alloys used in aircraft and missile structural applications.

General comments on engineering properties and the considerations relating to alloy selection are presented in Section 5.1. Mechanical- and physical-property data and characteristics pertinent to specific alloy groups or individual alloys are reported in Sections 5.2 through 5.5.

Titanium is a relatively lightweight, corrosion-resistant structural material that can be strengthened greatly through alloying and, in some of its alloys, by heat treatment. Among its advantages for specific applications are: good strength-to-weight ratio, low density, low coefficient of thermal expansion, good corrosion resistance, good oxidation resistance at intermediate temperatures, good toughness, and low heat-treating temperature during hardening, and others.

**5.1.1 TITANIUM INDEX** — The coverage of titanium and its alloys in this chapter has been divided into four sections for systematic presentation. The system takes into account unalloyed titanium and three groups of alloys based on metallurgical differences which in turn result in differences in fabrication and property characteristics. The sections and the individual alloys covered under each are shown in Table 5.1.

**Table 5.1. Titanium Alloys Index**

| Section    | Alloy Designation                                      |
|------------|--------------------------------------------------------|
| <b>5.2</b> | <b>Unalloyed Titanium</b>                              |
| 5.2.1      | Commercially Pure Titanium                             |
| <b>5.3</b> | <b>Alpha and Near-Alpha Titanium Alloys</b>            |
| 5.3.1      | Ti-5Al-2.5Sn (Alpha)                                   |
| 5.3.2      | Ti-8Al-1Mo-1V (Near-Alpha)                             |
| 5.3.3      | Ti-6Al-2Sn-4Zr-2Mo (Near-Alpha)                        |
| <b>5.4</b> | <b>Alpha-Beta Titanium Alloys</b>                      |
| 5.4.1      | Ti-6Al-4V                                              |
| 5.4.2      | Ti-6Al-6V-2Sn                                          |
| 5.4.3      | Ti - 4.5Al-3V-2Fe-2Mo                                  |
| <b>5.5</b> | <b>Beta, Near-Beta, and Metastable Titanium Alloys</b> |
| 5.5.1      | Ti-13V-11Cr-3Al                                        |
| 5.5.2      | Ti-15V-3Cr-3Sn-3Al                                     |
| 5.5.3      | Ti-10V-2Fe-3Al                                         |

**5.1.2 MATERIAL PROPERTIES** — The material properties of titanium and its alloys are determined mainly by their alloy content and heat treatment, both of which are influential in determining the allotropic forms in which this material will be bound. Under equilibrium conditions, pure titanium has an “alpha” structure up to 1620°F, above which it transforms to a “beta” structure. The inherent properties of these two structures are quite different. Through alloying and heat treatment, one or the other or a combination of these two structures can be made to exist at service temperatures, and the properties of the material vary

accordingly. References 5.1.2(a) and (b) provide general discussion of titanium microstructures and associated metallography.

Titanium and titanium alloys of the alpha and alpha-beta type exhibit crystallographic textures in sheet form in which certain crystallographic planes or directions are closely aligned with the direction of prior working. The presence of textures in these materials lead to anisotropy with respect to many mechanical and physical properties. Poisson's ratio and Young's modulus are among those properties strongly affected by texture. Wide variations experienced in these properties both within and between sheets of titanium alloys have been qualitatively related to variations of texture. In general, the degree of texturing, and hence the variation of Young's modulus and Poisson's ratio, that is developed for alpha-beta alloys tends to be less than that developed in all alpha titanium alloys. Rolling temperature has a pronounced effect on the texturing of titanium alloys which may not in general be affected by subsequent thermal treatments. The degree of applicability of the effect of textural variations discussed above on the mechanical properties of products other than sheet is unknown at present. The values of Young's modulus and Poisson's ratio listed in this document represent the usual values obtained on products resulting from standard mill practices. References 5.1.2(c) and (d) provide further information on texturing in titanium alloys.

#### **5.1.2.1 Mechanical Properties —**

**5.1.2.1.1 Fracture Toughness** — The fracture toughness of titanium alloys is greatly influenced by such factors as chemistry variations, heat treatment, microstructure, and product thickness, as well as yield strength. For fracture critical applications, these factors should be closely controlled. Typical values of plane-strain fracture toughness for titanium alloys are presented in Table 5.1.2.1.1. Minimum, average, and maximum values, as well as coefficient of variation, are presented for various products for which valid data are available, but these values do not have the statistical reliability of the room-temperature mechanical properties.

**5.1.3 MANUFACTURING CONSIDERATIONS** — Comments relating to formability, weldability, and final heat treatment are presented under individual alloys. These comments are necessarily brief and are intended only to aid the designer in the selection of an alloy for a specific application. In practice, departures from recommended practices are very common and are based largely on in-plant experience. Springback is nearly always a factor in hot or cold forming.

Final heat treatments that are indicated as "specified" heat treatments do not necessarily coincide with the producers' recommended heat treatments. Rather, these treatments, along with the specified room-temperature minimum tensile properties, are contained in the heat treating-capability requirements of applicable specifications, for example, MIL-H-81200. Departures from the specified aging cycles are often necessary to account for aging that may take place during hot working or hot sizing or to obtain more desirable mechanical properties, for example, improved fracture toughness. More detailed recommendations for specific applications are generally available from the material producers.

**5.1.4 ENVIRONMENTAL CONSIDERATIONS** — Comments relating to temperature limitations in the application of titanium and titanium alloys are presented under the individual alloys.

Below about 300°F, as well as above about 700°F, creep deformation of titanium alloys can be expected at stresses below the yield strength. Available data indicate that room-temperature creep of unalloyed titanium may be significant (exceed 0.2 percent creep-strain in 1,000 hours) at stresses that exceed approximately 50 percent  $F_{ty}$ , room-temperature creep of Ti-5Al-1.5Sn ELI may be significant at stresses above approximately 60 percent  $F_{ty}$ , and room-temperature creep of the standard grades of titanium alloys may be significant at stresses above approximately 75 percent  $F_{ty}$ . References 5.1.4(a) through (c) provide some limited data regarding room-temperature creep of titanium alloys.

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The use of titanium and its alloys in contact with either liquid oxygen or gaseous oxygen at cryogenic temperatures should be avoided, since either the presentation of a fresh surface (such as produced by tensile rupture) or impact may initiate a violent reaction [Reference 5.1.4(d)]. Impact of the surface in contact with liquid oxygen will result in a reaction at energy levels as low as 10 ft-lb. In gaseous oxygen, a partial pressure of about 50 psi is sufficient to ignite a fresh titanium surface over the temperature range from -250°F to room temperature or higher.

Titanium is susceptible to stress-corrosion cracking in certain anhydrous chemicals including methyl alcohol and nitrogen tetroxide. Traces of water tend to inhibit the reaction in either environment. However, in  $N_2O_4$ , NO is preferred and inhibited  $N_2O_4$  contains 0.4 to 0.8 percent NO. Red fuming nitric acid with less than 1.5 percent water and 10 to 20 percent  $NO_2$  can crack the metal and result in a pyrophoric reaction.

Titanium alloys are also susceptible to stress corrosion by dry sodium chloride at elevated temperatures. This problem has been observed largely in laboratory tests at 450 to 500°F and higher and occasionally in fabrication shops. However, there have been no reported failures of titanium components in service by hot salt stress corrosion. Cleaning with a nonchlorinated solvent (to remove salt deposits, including fingerprints) of parts used above 450°F is recommended.

In laboratory tests, with a fatigue crack present in the specimen, certain titanium alloys show an increased crack propagation rate in the presence of water or salt water as compared with the rate in air. These alloys also may show reduced sustained load-carrying ability in aqueous environments in the presence of fatigue cracks. Crack growth rates in salt water are a function of sheet or section thickness. These alloys are not susceptible in the form of thin-gauge sheet, but become susceptible as thickness increases. The thickness at which susceptibility occurs varies over a visual range with the alloy and processing. Alloys of titanium found susceptible to this effect include some from alpha, alpha-beta, and beta-type microstructures. In some cases, special processing techniques and heat treatments have been developed that minimize this effect. References 5.1.4(e) through (g) present detailed summaries of corrosion and stress corrosion of titanium alloys.

Under certain conditions, titanium, when in contact with cadmium, silver, mercury, or certain of their compounds, may become embrittled. Refer to MIL-HDBK-1568 for restrictions concerning applications with titanium in contact with these metals or their compounds.

**Table 5.1.2.1.1. Values of Room Temperature Plain-Strain Fracture of Titanium Alloys<sup>a</sup>**

|           |                      |              |                          |                           |                                 |                   |             |                                  | $K_{IC}$ , ksi $\sqrt{\text{in.}}$ |      |      |                          |
|-----------|----------------------|--------------|--------------------------|---------------------------|---------------------------------|-------------------|-------------|----------------------------------|------------------------------------|------|------|--------------------------|
| Alloy     | Heat Treat Condition | Product Form | Orientation <sup>b</sup> | Yield Strength Range, ksi | Product Thickness Range, inches | Number of Sources | Sample Size | Specimen Thickness Range, inches | Max.                               | Avg. | Min. | Coefficient of Variation |
| Ti-6Al-4V | Mill Annealed        | Forged Bar   | L-T                      | 121-143                   | <3.5                            | 2                 | 43          | 0.6-1.1                          | 77                                 | 60   | 38   | 10.5                     |
| Ti-6Al-4V | Mill Annealed        | Forged Bar   | T-L                      | 124-145                   | <3.5                            | 2                 | 64          | 0.5-1.3                          | 81                                 | 57   | 33   | 11.7                     |

<sup>a</sup> These values are for information only.

<sup>b</sup> Refer to Figure 1.4.12.3 for definition of symbols.

## 5.2 UNALLOYED TITANIUM

Several grades of unalloyed titanium are offered and are classified on the basis of manufacturing method, degree of purity, or strength, there being a close relationship among these. The unalloyed titanium grades most commonly used are produced by the Kroll process, are intermediate in purity, and are commonly referred to as being of commercial purity.

### 5.2.1 COMMERCIAL PURE TITANIUM

**5.2.1.0 Comments and Properties** — Unalloyed titanium is available in all familiar product forms and is noted for its excellent formability. Unalloyed titanium is readily welded or brazed. It has been used primarily where strength is not the main requirement.

*Manufacturing Considerations* — Unalloyed titanium is supplied in the annealed condition permitting extensive forming at room temperature. Severe forming operations also can be accomplished at elevated temperatures (300 to 900°F). Property degradation can be experienced after severe forming if as-received material properties are not restored by re-annealing.

Commercially pure titanium can be welded readily by the several methods employed for titanium joining. Atmospheric shielding is preferable although spot or seam welding may be accomplished without shielding. Brazing requires protection from the atmosphere which may be obtained by fluxing as well as by inert gas or vacuum shielding.

*Environmental Considerations* — Titanium has an unusually high affinity for oxygen, nitrogen, and hydrogen at temperatures above 1050°F. This results in embrittlement of the material, thus usage should be limited to temperatures below that indicated. Additional chemical reactivity between titanium and selected environments such as methyl alcohol, chloride salt solutions, hydrogen, and liquid metal, can take place at lower temperatures, as discussed in Section 5.1.4 and its references.

Under certain conditions, titanium, when in contact with cadmium, silver, mercury, or certain of their compounds, may become embrittled. Refer to MIL-S-5002 and MIL-STD-1568 for restrictions concerning applications with titanium in contact with these metals or their compounds.

*Heat Treatment* — Commercially pure titanium is fully annealed by heating to 1000 to 1300°F for 10 to 30 minutes. It is stress relieved by heating to 900 to 1000°F for 30 minutes. Commercially pure titanium cannot be hardened by heat treatment.

*Specifications and Properties* — Some material specifications for commercially pure titanium are presented in Table 5.2.1.0(a). Room-temperature mechanical properties for commercially pure titanium are shown in Tables 5.1.2.0(b) and (c). The effect of temperature on physical properties is shown in Figure 5.2.1.0.

**5.2.1.1 Annealed Condition** — Elevated-temperature data for annealed commercially pure titanium are presented in Figures 5.2.1.1.1(a) through 5.2.1.1.3(b). Typical full-range stress-strain curves for the 40 and 70 ksi yield strength commercially pure titanium are shown in Figures 5.2.1.1.6(a) and (b).

**Table 5.2.1.0(a). Material Specifications for  
Commercially Pure Titanium**

| Specification           | Form                     |
|-------------------------|--------------------------|
| AMS 4900                | Sheet, strip, and plate  |
| AMS 4901                | Sheet, strip, and plate  |
| AMS 4902                | Sheet, strip, and plate  |
| AMS-T-9046              | Sheet, strip, and plate  |
| MIL-T-9047 <sup>a</sup> | Bar                      |
| AMS 4921                | Bar                      |
| AMS-T-81556             | Extruded bars and shapes |

a Inactive for new design

**Table 5.2.1.0(b). Design Mechanical and Physical Properties of Commercially Pure Titanium**

|                                                  |                         |                                |                                |                                |                                |                              |
|--------------------------------------------------|-------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|------------------------------|
| Specification .....                              | MIL-T-9046              | AMS 4902<br>and MIL-T-<br>9046 | AMS 4900<br>and MIL-T-<br>9046 | AMS 4901<br>and MIL-T-<br>9046 | AMS 4921<br>and MIL-T-<br>9047 | MIL-T-<br>9047               |
| Designation .....                                | CP-4                    | CP-3                           | CP-2                           | CP-1                           | CP-70                          |                              |
| Form .....                                       | Sheet, strip, and plate |                                |                                |                                | Bar                            |                              |
| Condition .....                                  | Annealed                |                                |                                |                                | Annealed                       |                              |
| Thickness or diameter, in. ....                  | ≤1.000                  |                                |                                |                                | ≤2.999 <sup>a</sup>            | 3.000-<br>4.000 <sup>a</sup> |
| Basis .....                                      | S                       | S                              | S                              | S                              | S                              | S                            |
| Mechanical Properties:                           |                         |                                |                                |                                |                                |                              |
| <i>F<sub>u</sub></i> , ksi:                      |                         |                                |                                |                                |                                |                              |
| L .....                                          | 35                      | 50                             | 65                             | 80                             | 80                             | 80                           |
| LT .....                                         | 35                      | 50                             | 65                             | 80                             | 80 <sup>b</sup>                | 80                           |
| ST .....                                         | ...                     | ...                            | ...                            | ...                            | ...                            | 80                           |
| <i>F<sub>ty</sub></i> , ksi:                     |                         |                                |                                |                                |                                |                              |
| L .....                                          | 25                      | 40                             | 55                             | 70                             | 70                             | 70                           |
| LT .....                                         | 25                      | 40                             | 55                             | 70                             | 70 <sup>b</sup>                | 70                           |
| ST .....                                         | ...                     | ...                            | ...                            | ...                            | ...                            | 70                           |
| <i>F<sub>cy</sub></i> , ksi:                     |                         |                                |                                |                                |                                |                              |
| L .....                                          | ...                     | ...                            | ...                            | 70                             | ...                            | ...                          |
| LT .....                                         | ...                     | ...                            | ...                            | 70                             | ...                            | ...                          |
| <i>F<sub>su</sub></i> , ksi .....                | ...                     | ...                            | ...                            | 42                             | ...                            | ...                          |
| <i>F<sub>bru</sub></i> , ksi:                    |                         |                                |                                |                                |                                |                              |
| (e/D = 1.5) .....                                | ...                     | ...                            | ...                            | 120                            | ...                            | ...                          |
| (e/D = 2.0) .....                                | ...                     | ...                            | ...                            | ...                            | ...                            | ...                          |
| <i>F<sub>bry</sub></i> , ksi:                    |                         |                                |                                |                                |                                |                              |
| (e/D = 1.5) .....                                | ...                     | ...                            | ...                            | 101                            | ...                            | ...                          |
| (e/D = 2.0) .....                                | ...                     | ...                            | ...                            | ...                            | ...                            | ...                          |
| <i>e</i> , percent:                              |                         |                                |                                |                                |                                |                              |
| L .....                                          | 24 <sup>c</sup>         | 20 <sup>c</sup>                | 18 <sup>c</sup>                | 15 <sup>c</sup>                | 15                             | 15                           |
| LT .....                                         | 24 <sup>c</sup>         | 20 <sup>c</sup>                | 18 <sup>c</sup>                | 15 <sup>c</sup>                | 15 <sup>b</sup>                | 15                           |
| ST .....                                         | ...                     | ...                            | ...                            | ...                            | ...                            | 15                           |
| <i>RA</i> , percent:                             |                         |                                |                                |                                |                                |                              |
| L .....                                          | ...                     | ...                            | ...                            | ...                            | 30                             | 30                           |
| LT .....                                         | ...                     | ...                            | ...                            | ...                            | 30 <sup>b</sup>                | 30                           |
| ST .....                                         | ...                     | ...                            | ...                            | ...                            | ...                            | 30                           |
| <i>E</i> , 10 <sup>3</sup> ksi .....             | 15.5                    |                                |                                |                                |                                |                              |
| <i>E<sub>c</sub></i> , 10 <sup>3</sup> ksi ..... | 16.0                    |                                |                                |                                |                                |                              |
| <i>G</i> , 10 <sup>3</sup> ksi .....             | 6.5                     |                                |                                |                                |                                |                              |
| <i>μ</i> .....                                   | ...                     |                                |                                |                                |                                |                              |
| Physical Properties:                             |                         |                                |                                |                                |                                |                              |
| <i>ω</i> , lb/in. <sup>3</sup> .....             | 0.163                   |                                |                                |                                |                                |                              |
| <i>C</i> , <i>K</i> , and <i>α</i> .....         | See Figure 5.2.1.0      |                                |                                |                                |                                |                              |

a Maximum of 16-square-inch cross-sectional area.  
b Long transverse properties apply to rectangular bar only for thickness >0.500 inches and widths >3.000 inches.  
For AMS 4921, (e) (LT) = 12% and RA (LT) = 25%.  
c Thickness of 0.025 inch and above.



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[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 5.2.1.0(c). Design Mechanical and Physical Properties of Commercially Pure Titanium Extruded Bars and Shapes**

| Specification .....                  | AMS-T-81556              |            |            |            |
|--------------------------------------|--------------------------|------------|------------|------------|
|                                      | Comp. CP-4               | Comp. CP-3 | Comp. CP-2 | Comp. CP-1 |
| Form .....                           | Extruded bars and shapes |            |            |            |
| Condition .....                      | Annealed                 |            |            |            |
| Thickness or diameter, in. . .       | 0.188-3.000              |            |            |            |
| Basis .....                          | S                        | S          | S          | S          |
| Mechanical Properties:               |                          |            |            |            |
| $F_{tu}$ , ksi:                      |                          |            |            |            |
| L .....                              | 40                       | 50         | 65         | 80         |
| LT .....                             | ...                      | ...        | ...        | ...        |
| $F_{ty}$ , ksi:                      |                          |            |            |            |
| L .....                              | 30                       | 40         | 55         | 70         |
| LT .....                             | ...                      | ...        | ...        | ...        |
| $F_{cy}$ , ksi:                      |                          |            |            |            |
| L .....                              | ...                      | ...        | ...        | ...        |
| LT .....                             | ...                      | ...        | ...        | ...        |
| $F_{su}$ , ksi .....                 | ...                      | ...        | ...        | ...        |
| $F_{bru}$ , ksi:                     |                          |            |            |            |
| (e/D = 1.5) .....                    | ...                      | ...        | ...        | ...        |
| (e/D = 2.0) .....                    | ...                      | ...        | ...        | ...        |
| $F_{bry}$ , ksi:                     |                          |            |            |            |
| (e/D = 1.5) .....                    | ...                      | ...        | ...        | ...        |
| (e/D = 2.0) .....                    | ...                      | ...        | ...        | ...        |
| $e$ , percent:                       |                          |            |            |            |
| L .....                              | a                        | a          | a          | a          |
| $E$ , $10^3$ ksi .....               | 15.5                     |            |            |            |
| $E_c$ , $10^3$ ksi .....             | 16.0                     |            |            |            |
| $G$ , $10^3$ ksi .....               | 6.5                      |            |            |            |
| $\mu$ .....                          | ...                      |            |            |            |
| Physical Properties:                 |                          |            |            |            |
| $\omega$ , lb/in. <sup>3</sup> ..... | 0.163                    |            |            |            |
| $C$ , $K$ , and $\alpha$ .....       | See Figure 5.2.1.0       |            |            |            |

a Elongation in percent as follows:

| <u>Thickness, inches</u> | <u>Comp. CP-4</u> | <u>Comp. CP-3</u> | <u>Comp. CP-2</u> | <u>Comp. CP-1</u> |
|--------------------------|-------------------|-------------------|-------------------|-------------------|
| 0.188-1.000              | 25                | 20                | 18                | 15                |
| 1.001-2.000              | 20                | 18                | 15                | 12                |
| 2.001-3.000              | 18                | 15                | 12                | 10                |

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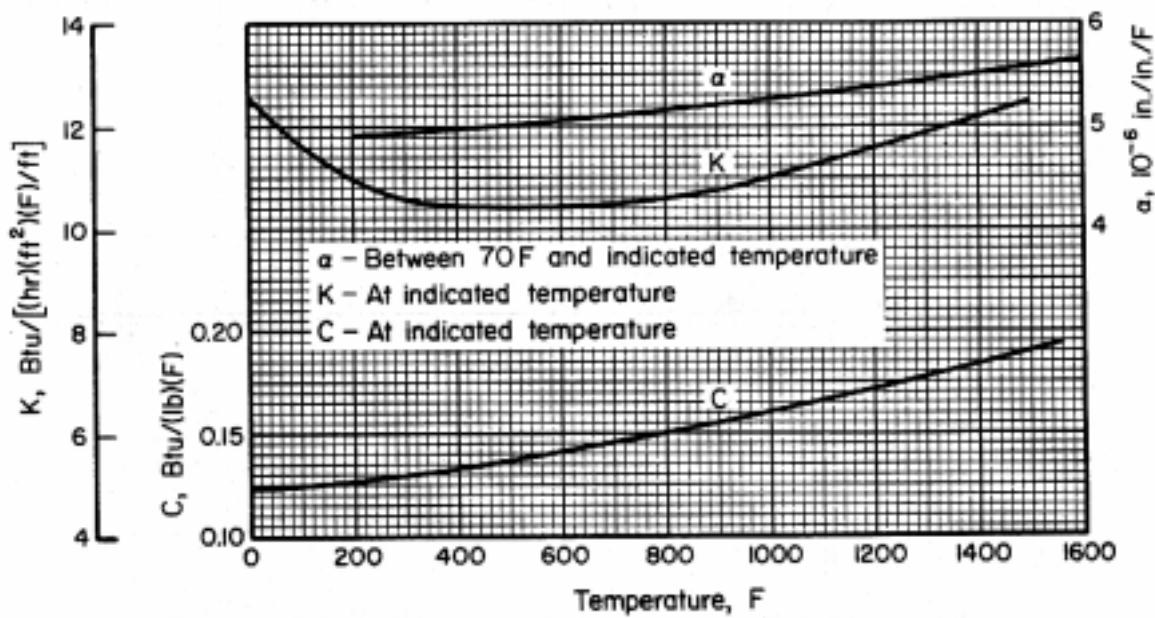


Figure 5.2.1.0. Effect of temperature on the physical properties of commercially pure titanium.

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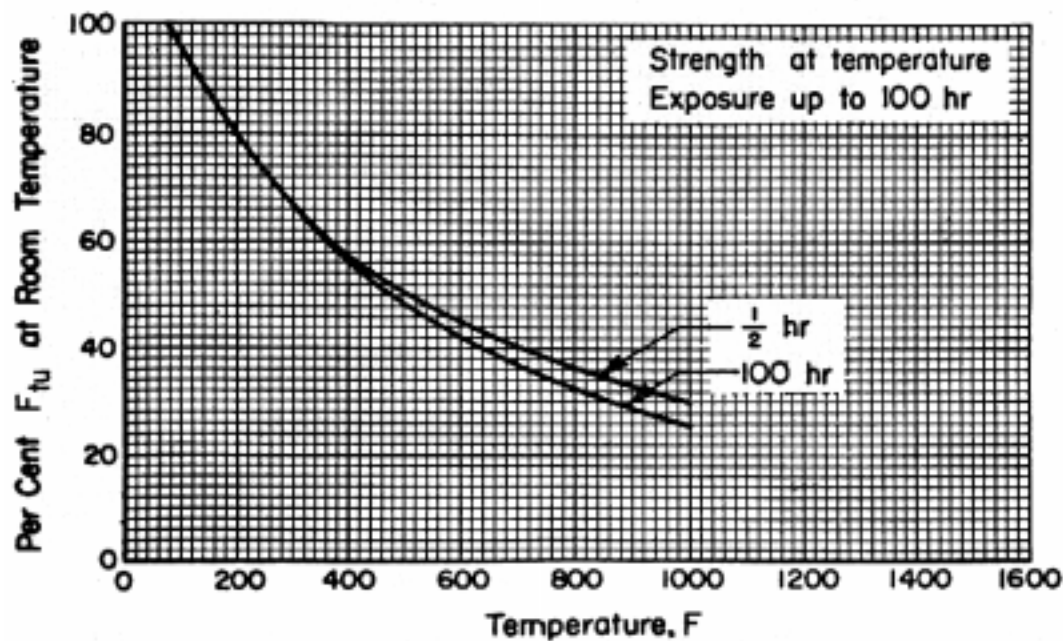


Figure 5.2.1.1.1(a). Effect of temperature on the tensile ultimate strength ( $F_{tu}$ ) of annealed commercially pure titanium.

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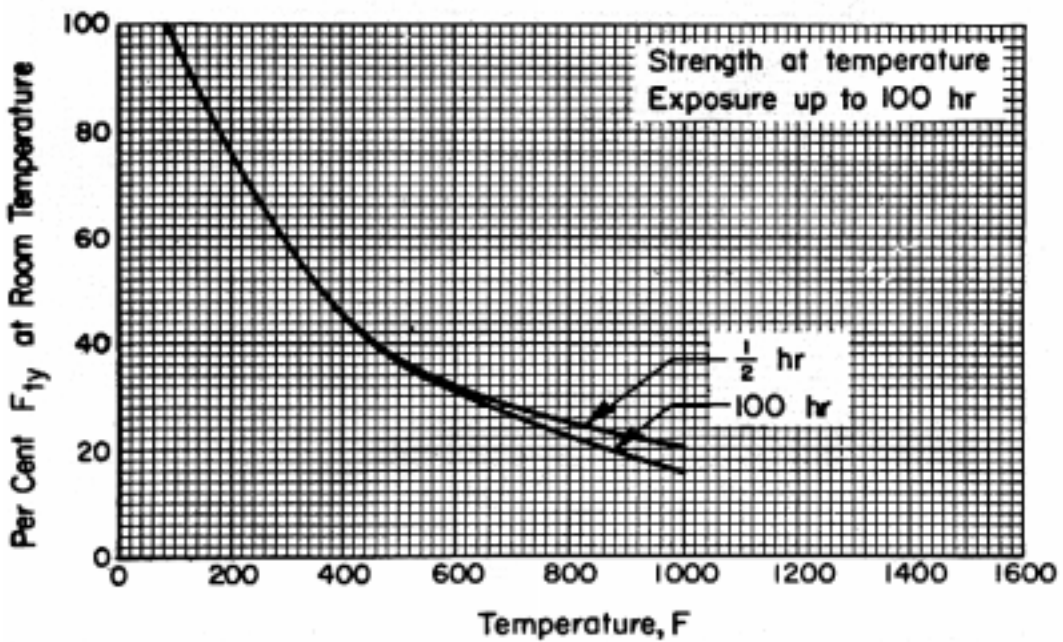


Figure 5.2.1.1.1(b). Effect of temperature on the tensile yield strength ( $F_{ty}$ ) of annealed commercially pure titanium.

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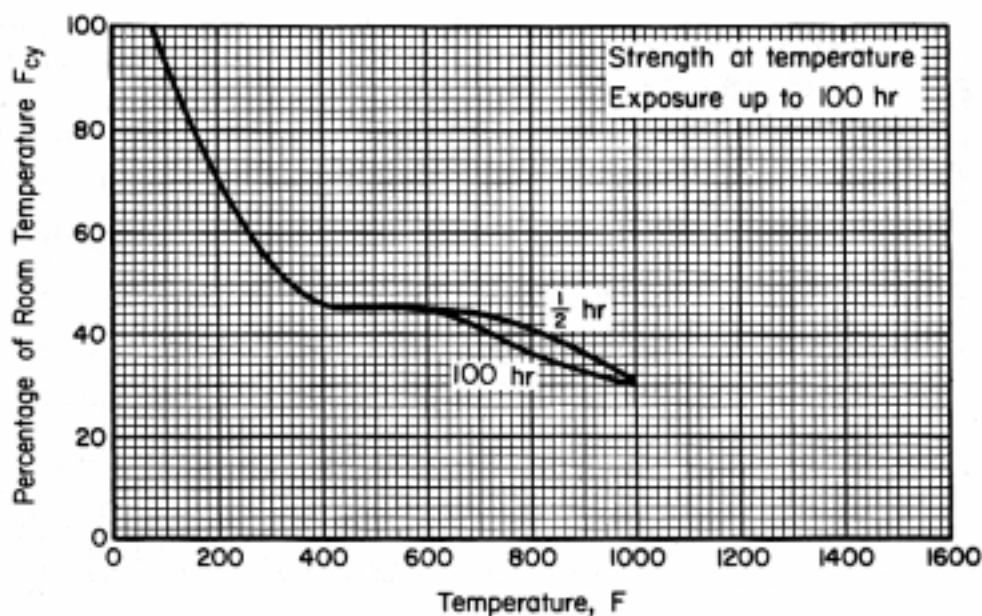


Figure 5.2.1.1.2(a). Effect of temperature on the compressive yield strength ( $F_{cy}$ ) of annealed commercially pure titanium.

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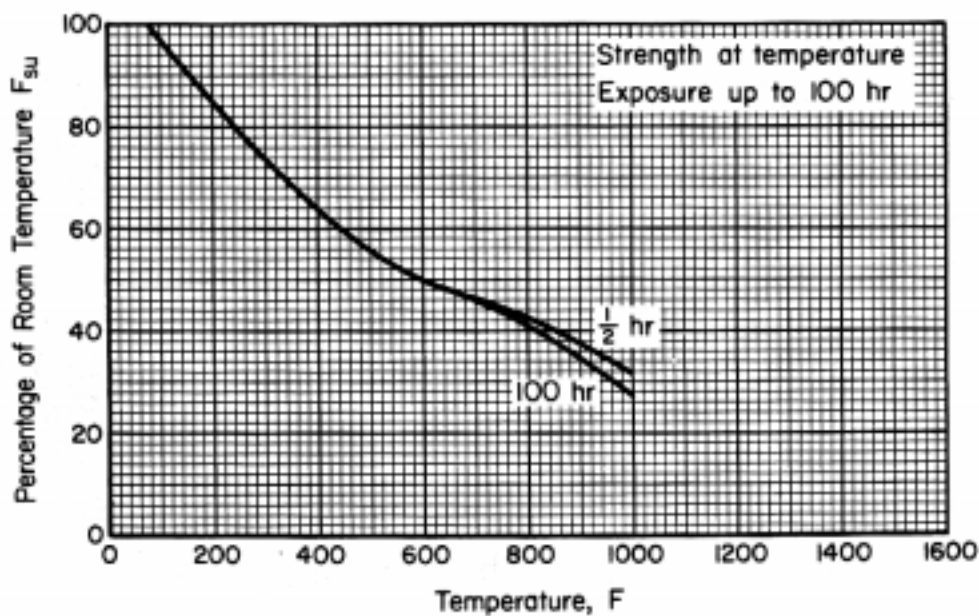


Figure 5.2.1.1.2(b). Effect of temperature on the shear ultimate strength ( $F_{su}$ ) of annealed commercially pure titanium.



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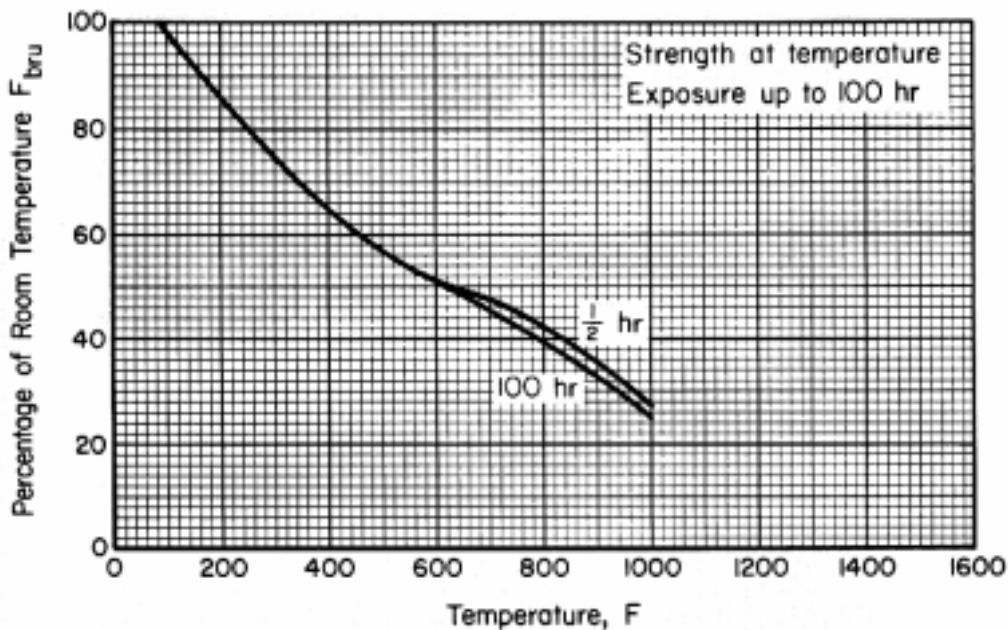


Figure 5.2.1.1.3(a). Effect of temperature on the bearing ultimate strength ( $F_{bru}$ ) of annealed commercially pure titanium.

[VIEW INTERACTIVE GRAPH](#)

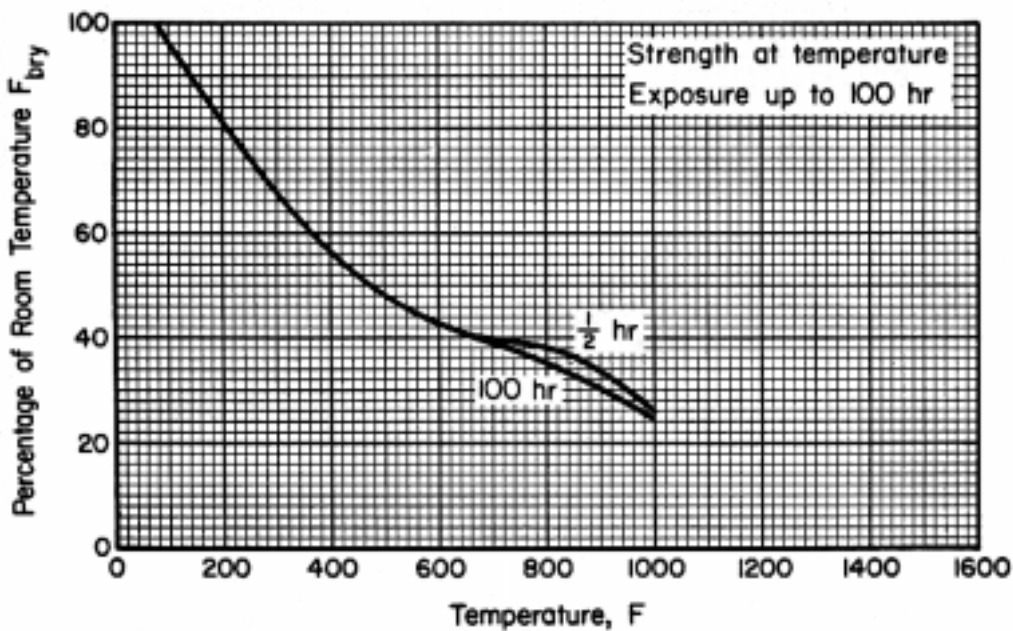


Figure 5.2.1.1.3(b). Effect of temperature on the bearing yield strength ( $F_{bry}$ ) of annealed commercially pure titanium.

[VIEW INTERACTIVE GRAPH](#)

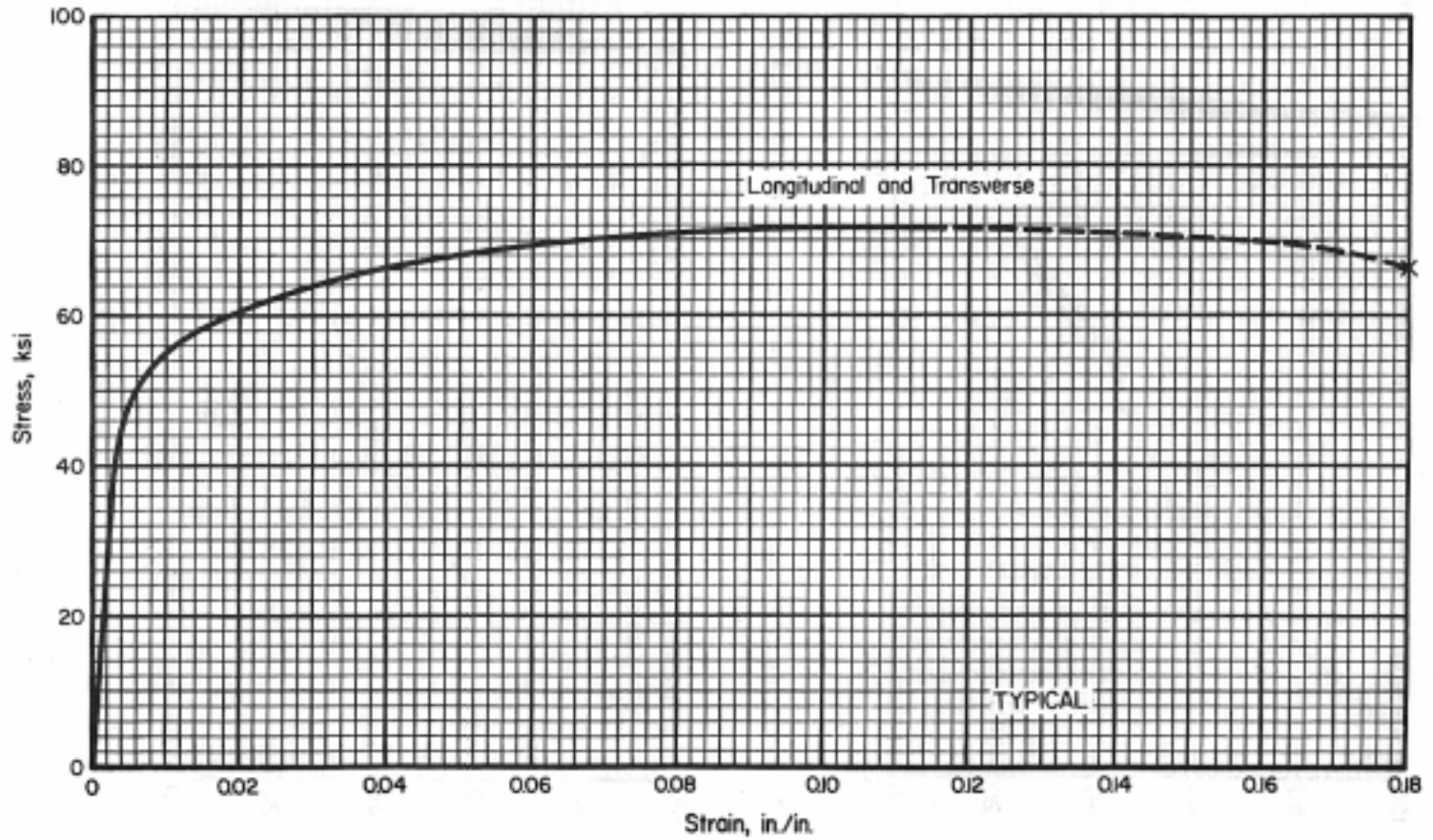


Figure 5.2.1.1.6(a). Typical full-range tensile stress-strain curve for commercially pure titanium sheet (40 ksi yield at room temperature).

## [VIEW INTERACTIVE GRAPH](#)

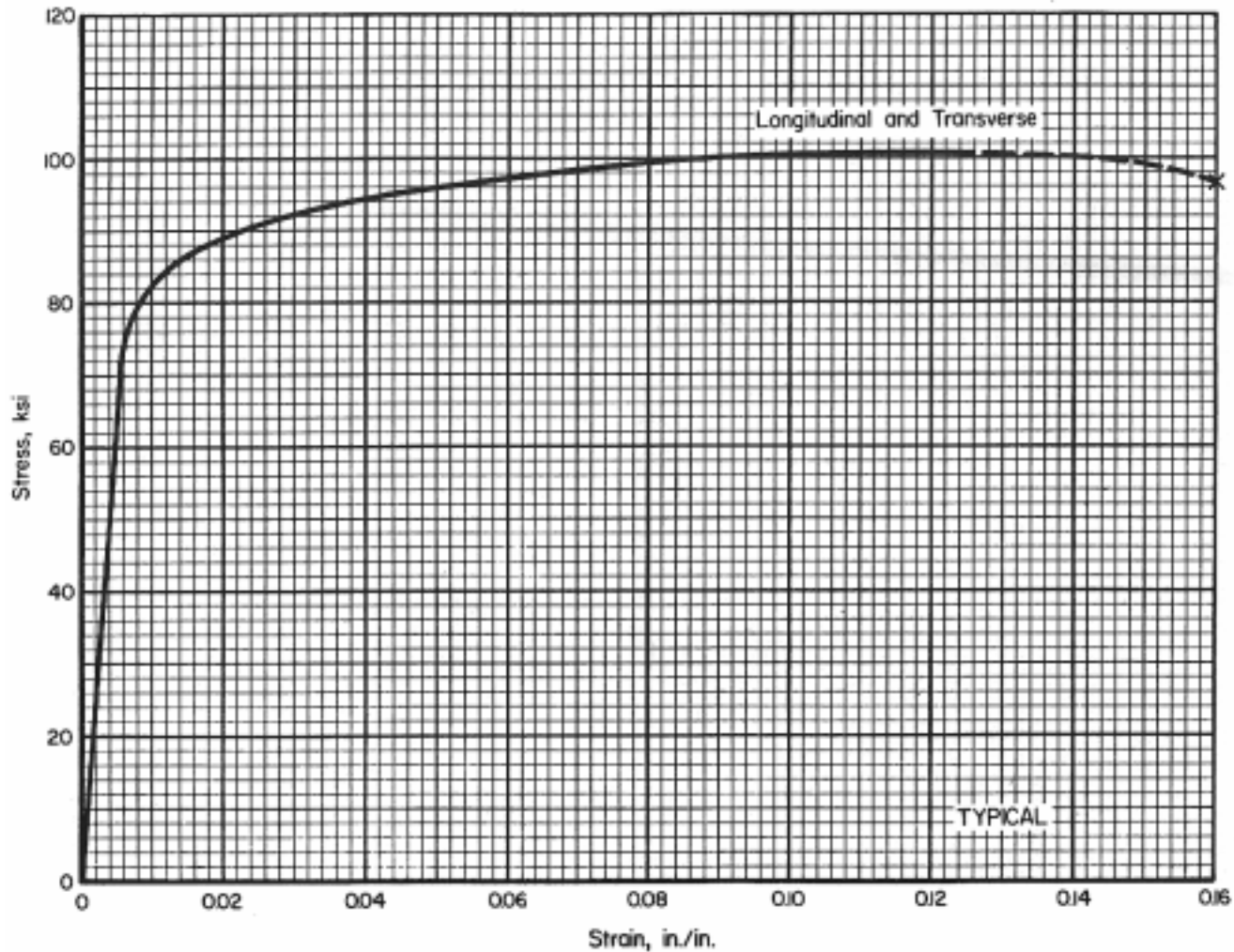


Figure 5.2.1.1.6(b). Typical full-range tensile stress-strain curve for commercially pure titanium sheet (70 ksi yield at room temperature).

**CHAPTER 6****HEAT-RESISTANT ALLOYS****6.1 GENERAL**

Heat-resistant alloys are arbitrarily defined as iron alloys richer in alloy content than the 18 percent chromium, 8 percent nickel types, or as alloys with a base element other than iron and which are intended for elevated-temperature service. These alloys have adequate oxidation resistance for service at elevated temperatures and are normally used without special surface protection. So-called “refractory” alloys that require special surface protection for elevated-temperature service are not included in this chapter.

This chapter contains strength properties and related characteristics of wrought heat-resistant alloy products used in aerospace vehicles. The strength properties are those commonly used in structural design, such as tension, compression, bearing, and shear. The effects of elevated temperature are presented. Factors such as metallurgical considerations influencing the selection of metals are included in comments preceding the specific properties of each alloy or alloy group. Data on creep, stress-rupture, and fatigue strength, as well as crack-growth characteristics, are presented in the applicable alloy section.

There is no standardized numbering system for the alloys in this chapter. For this reason, each alloy is identified by its most widely accepted trade designation.

For convenience in presenting these alloys and their properties, the heat-resistant alloys have been divided into three groups, based on alloy composition. These groups and the alloys for which specifications and properties are included are shown in Table 6.1.

The heat treatments applied to the alloys in this chapter vary considerably from one alloy to another. For uniformity of presentation, the heat-treating terms are defined as follows:

*Stress-Relieving* — Heating to a suitable temperature, holding long enough to reduce residual stresses, and cooling in air or as prescribed.

*Annealing* — Heating to a suitable temperature, holding, and cooling at a suitable rate for the purpose of obtaining minimum hardness or strength.

*Solution-Treating* — Heating to a suitable temperature, holding long enough to allow one or more constituents to enter into solid solution, and cooling rapidly enough to hold the constituents in solution.

*Aging, Precipitation-Hardening* — Heating to a suitable temperature and holding long enough to obtain hardening by the precipitation of a constituent from the solution-treated condition.

The actual temperatures, holding times, and heating and cooling rates used in these treatments vary from alloy to alloy and are described in the applicable specifications.



**Table 6.1. Heat-Resistant Alloys Index**

| Section    | Designation                             |
|------------|-----------------------------------------|
| <b>6.2</b> | <b>Iron-Chromium-Nickel-Base Alloys</b> |
|            | A-286                                   |
| 6.2.1      | N-155                                   |
| 6.2.2      |                                         |
| <b>6.3</b> | <b>Nickel-Base Alloys</b>               |
| 6.3.1      | Hastelloy X                             |
| 6.3.2      | Inconel 600 (Inconel)                   |
| 6.3.3      | Inconel 625                             |
| 6.3.4      | Inconel 706                             |
| 6.3.5      | Inconel 718                             |
| 6.3.6      | Inconel X-750 (Inconel X)               |
| 6.3.7      | René 41                                 |
| 6.3.8      | Waspaloy                                |
| <b>6.4</b> | <b>Cobalt-Base Alloys</b>               |
| 6.4.1      | L-605 (Haynes Alloy 25)                 |
| 6.4.2      | HS 188                                  |

### 6.1.1 MATERIAL PROPERTIES

**6.1.1.1 Mechanical Properties** — The mechanical properties of the heat-resistant alloys are affected by relatively minor variations in chemistry, processing, and heat treatment. Consequently, the mechanical properties shown for the various alloys in this chapter are intended to apply only to the alloy, form (shape), size (thickness), and heat treatment indicated. When statistical values are shown, these are intended to represent a fair cross section of all mill production within the indicated scope.

*Strength Properties* — Room-temperature strength properties for alloys in this chapter are based primarily on minimum tensile property requirements of material specifications. Values for nonspecification strength properties are derived. The variation of properties with temperature and other data of interest are presented in figures or tables, as appropriate.

The strength properties of the heat-resistant alloys generally decrease with increasing temperatures or increasing time at temperature. There are exceptions to this statement, particularly in the case of age-hardening alloys; these alloys may actually show an increase in strength with temperature or time, within a limited range, as a result of further aging. In most cases, however, this increase in strength is temporary and, furthermore, cannot usually be taken advantage of in service. For this reason, this increase in strength has been ignored in the preparation of elevated temperature curves as described in Chapter 9.

At cryogenic temperatures, the strength properties of the heat-resistant alloys are generally higher than at room temperature, provided some ductility is retained at the low temperatures. For additional information on mechanical properties at cryogenic temperatures, other references, such as the Cryogenic Materials Data Handbook (Reference 6.1.1.1), should be consulted.

*Ductility* — Specified minimum ductility requirements are presented for these alloys in the room-temperature property tables. The variation in ductility with temperature is somewhat erratic for the heat-resistant alloys. Generally, ductility decreases with increasing temperature from room temperature up to about 1200 to 1400°F, where it reaches a minimum value, then it increases with higher temperatures. Prior creep exposure may also affect ductility adversely. Below room temperature, ductility decreases with decreasing temperature for some of these alloys.

*Stress-Strain Relationships* — The stress-strain relationships presented are typical curves prepared as described in Section 9.3.2.

*Creep* — Data covering the temperatures and times of exposure and the creep deformations of interest are included as typical information in individual material sections. These presentations may be in the form of creep stress-lifetime curves for various deformation criteria as specified in Chapter 9 or as creep nomographs.

*Fatigue* — Fatigue S/N curves for unnotched and notched specimens at room temperature and elevated temperatures are shown in each alloy section. Fatigue crack propagation data are also presented.

**6.1.1.2 Physical Properties** — Selected physical-property data are presented for these alloys. Processing variables and heat treatment have only a slight effect on these values; thus, the properties listed are applicable to all forms and heat treatments.

## 6.2 IRON-CHROMIUM-NICKEL-BASE ALLOYS

**6.2.0 General Comments** — The alloys in this group, in terms of cost and in maximum service temperature, generally fall between the austenitic stainless steels and the nickel- and cobalt-base alloys. They are used in airframes, principally, in the temperature range 1000 to 1200 °F, in those applications in which the stainless steels are inadequate and service requirements do not justify the use of the more costly nickel or cobalt alloys.

### 6.2.0.2 Metallurgical Considerations

*Composition* — The complex-base alloys comprising this group range from those in which iron is considered the base element to those which border on the nickel-base alloys. All of them contain sufficient alloying elements to place them in the “Superalloy” category, yet contain enough iron to reduce their cost considerably.

Chromium, in amounts ranging from 10 to 20 percent or higher, primarily increases oxidation resistance and contributes to strengthening of these alloys. Nickel and cobalt strengthen and toughen these materials. Molybdenum, tungsten, and columbium contribute to hardness and strength, particularly at elevated temperatures. Titanium and aluminum are added to provide age-hardening.

*Heat Treatment* — The complex-base alloys are heat treated with conventional equipment and fixtures such as would be used for austenitic stainless steels. Since these alloys are susceptible to carburization during heat treatment, it is good practice to remove all grease, oil, cutting, lubricant, etc., from the surface before heating. A low-sulfur and neutral or slightly oxidizing furnace atmosphere is recommended for heating.

**6.2.0.2 Manufacturing Considerations** — The iron-chromium-nickel-base alloys closely resemble the austenitic stainless steels insofar as forging, cold forming, machining, welding, and brazing are concerned. Their higher strength may require the use of heavier forging or forming equipment, and machining is somewhat more difficult than for the stainless steels. Pertinent comments are included under the individual alloys.

### 6.2.1 A-286

**6.2.1.1 Comments and Properties** — A-286 is a precipitation-hardening iron-base alloy designed for parts requiring high strength up to 1300 °F and oxidation resistance up to 1500 °F. It is used in jet engines and gas turbines for parts such as turbine buckets, bolts, and discs, and sheet metal assemblies. A-286 is available in the usual mill forms.

A-286 is somewhat harder to hot or cold work than the austenitic stainless steels. Its forging range is 2150 to 1800 °F; when finishing below 1800 °F, light reductions (under 15 percent) must be avoided to prevent grain coarsening during subsequent heat treatment. A-286 is readily machined in the partially or fully aged condition but is soft and “gummy” in the solution-treated condition. A-286 should be welded in the solution-treated condition. Fusion welding is difficult for large section sizes and moderately difficult for small cross sections and sheet. Cracking may be encountered in the welding of heavy sections or parts under high restraint. A dimensional contraction of 0.0008 inch per inch is experienced during aging. Oxidation resistance of A-286 is equivalent to that of Type 310 stainless steel up to 1800 °F.

Some material specifications for A-286 alloy are presented in Table 6.2.1.0(a). Room-temperature mechanical and physical properties are shown in Table 6.2.1.0(b). The effect of temperature on physical properties is shown in Figure 6.2.1.0.

**6.2.1.1 Solution-Treated and Aged Condition** — Elevated-temperature data are presented in Figures 6.2.1.1.1, 6.2.1.1.3, and 6.2.1.1.4(a) through (c). Stress rupture properties are specified at 1200 °F; the appropriate specifications should be consulted for detailed requirements. Figures 6.2.1.1.8(a) through (e) are fatigue S/N curves for several elevated temperatures.

**Table 6.2.1.0(a). Material Specifications for A-286 Alloy**

| Specification | Form                           | Condition                           |
|---------------|--------------------------------|-------------------------------------|
| AMS 5525      | Sheet, strip, and plate        | Solution treated (1800 °F)          |
| AMS 5731      | Bar, forging, tubing, and ring | Solution treated (1800 °F)          |
| AMS 5732      | Bar, forging, tubing, and ring | Solution treated (1800 °F) and aged |
| AMS 5734      | Bar, forging, and tubing       | Solution treated (1650 °F)          |
| AMS 5737      | Bar, forging, and tubing       | Solution treated (1650 °F) and aged |

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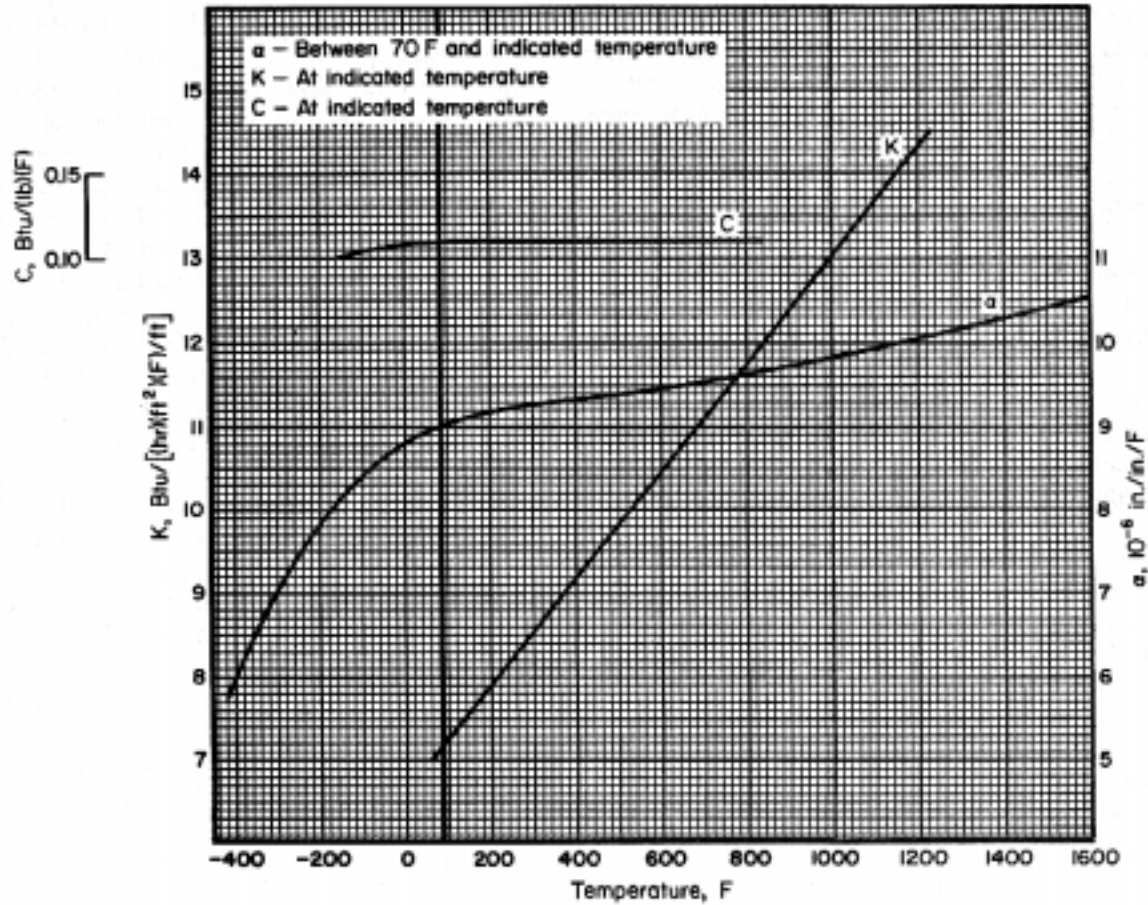


**Figure 6.2.1.0. Effect of temperature on the physical properties of A-286.**

**MIL-HDBK-5H, Change Notice 1**  
**1 October 2001**

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 6.2.1.0(b). Design Mechanical and Physical Properties of A-286 Alloy**

| Specification .....                  | AMS 5525                   | AMS 5731<br>AMS 5732 |             | AMS 5734<br>AMS 5737 |             |
|--------------------------------------|----------------------------|----------------------|-------------|----------------------|-------------|
| Form .....                           | Sheet, strip,<br>and plate | Bar                  |             |                      |             |
| Condition .....                      | Solution treated and aged  |                      |             |                      |             |
| Thickness or diameter, in.           | >0.004                     | ≤2.499               | 2.500-5.000 | ≤2.499               | 2.500-5.000 |
| Basis .....                          | S <sup>a</sup>             | S                    | S           | S                    | S           |
| Mechanical Properties:               |                            |                      |             |                      |             |
| $F_{tu}$ , ksi:                      |                            |                      |             |                      |             |
| L .....                              | ...                        | 130                  | 130         | 140                  | 140         |
| LT .....                             | 140                        | 130 <sup>b</sup>     | 130         | 140 <sup>b</sup>     | 140         |
| ST .....                             | ...                        | ...                  | 130         | ...                  | 140         |
| $F_{ty}$ , ksi:                      |                            |                      |             |                      |             |
| L .....                              | ...                        | 85                   | 85          | 95                   | 95          |
| LT .....                             | 95                         | 85 <sup>b</sup>      | 85          | 95 <sup>b</sup>      | 95          |
| ST .....                             | ...                        | ...                  | 85          | ...                  | 95          |
| $F_{cy}$ , ksi:                      |                            |                      |             |                      |             |
| L .....                              | ...                        | 85                   | 85          | 95                   | 95          |
| LT .....                             | 95                         | ...                  | ...         | ...                  | ...         |
| $F_{su}$ , ksi .....                 | 91                         | 85                   | 85          | 91                   | 91          |
| $F_{bru}$ , ksi:                     |                            |                      |             |                      |             |
| (e/D = 1.5) .....                    | 210                        | 195                  | 195         | 210                  | 210         |
| (e/D = 2.0) .....                    | 266                        | 247                  | 247         | 266                  | 266         |
| $F_{bry}$ , ksi:                     |                            |                      |             |                      |             |
| (e/D = 1.5) .....                    | 142                        | 127                  | 127         | 142                  | 142         |
| (e/D = 2.0) .....                    | 171                        | 153                  | 153         | 171                  | 171         |
| $e$ , percent:                       |                            |                      |             |                      |             |
| L .....                              | ...                        | 15                   | 15          | 12                   | 12          |
| LT .....                             | 15                         | 15 <sup>b</sup>      | 15          | 12 <sup>b</sup>      | 12          |
| ST .....                             | ...                        | ...                  | 15          | ...                  | 12          |
| $RA$ , percent:                      |                            |                      |             |                      |             |
| L .....                              | ...                        | 20                   | 20          | 15                   | 15          |
| LT .....                             | ...                        | 20 <sup>b</sup>      | 20          | 15 <sup>b</sup>      | 15          |
| ST .....                             | ...                        | ...                  | 20          | ...                  | 15          |
| $E$ , 10 <sup>3</sup> ksi .....      | 29.1                       |                      |             |                      |             |
| $E_c$ , 10 <sup>3</sup> ksi .....    | 29.1                       |                      |             |                      |             |
| $G$ , 10 <sup>3</sup> ksi .....      | 11.1                       |                      |             |                      |             |
| $\mu$ .....                          | 0.31                       |                      |             |                      |             |
| Physical Properties:                 |                            |                      |             |                      |             |
| $\omega$ , lb/in. <sup>3</sup> ..... | 0.287                      |                      |             |                      |             |
| $C$ , $K$ , and $\alpha$ .....       | See Figure 6.2.1.0         |                      |             |                      |             |

a Test direction longitudinal for widths less than 9 inches; transverse for widths 9 inches and over.

b Applicable to widths ≥ 2.500 inches only.

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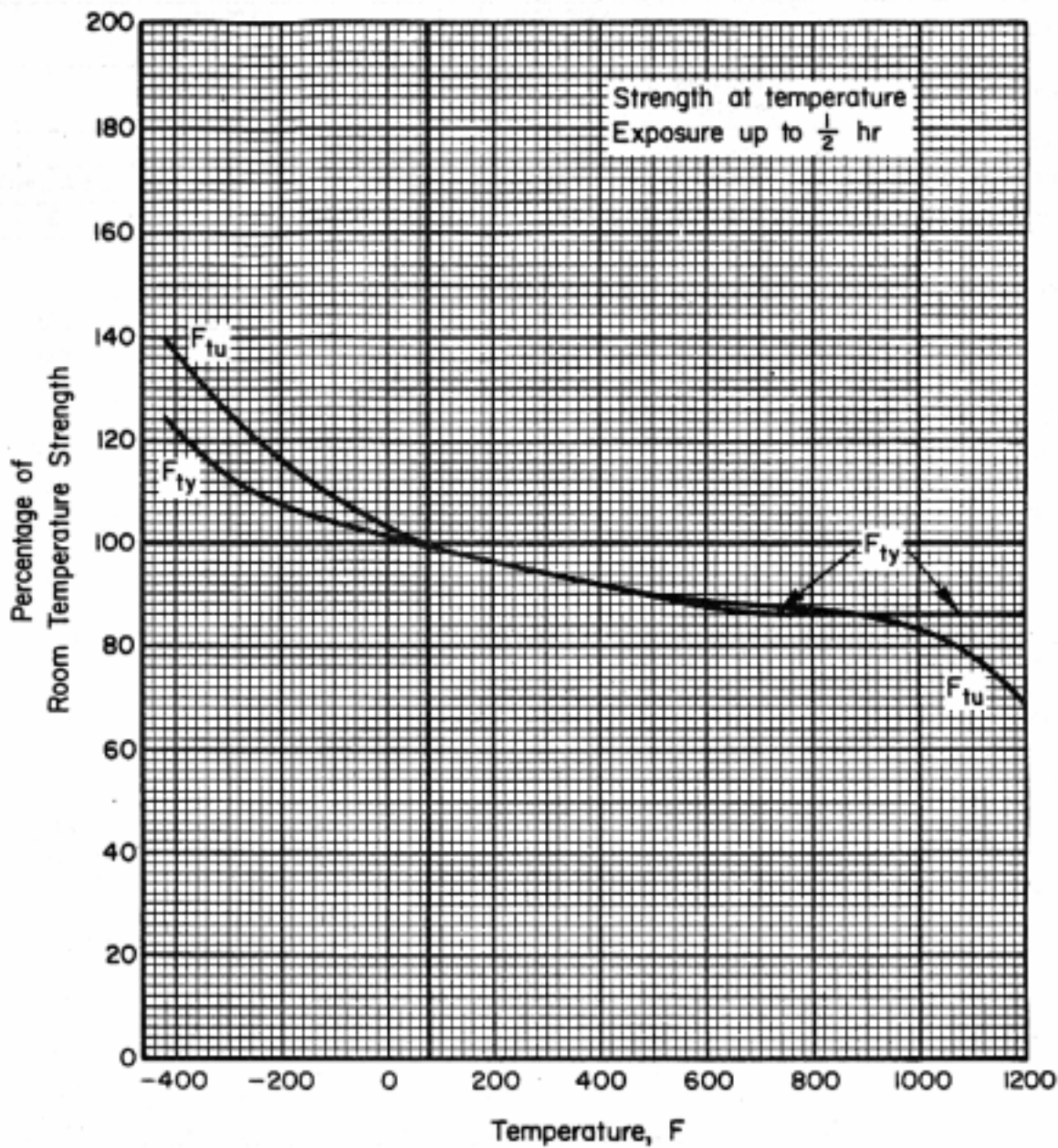


Figure 6.2.1.1.1. Effect of temperature on the tensile yield strength ( $F_{ty}$ ) and tensile ultimate strength ( $F_{tu}$ ) of A-286 alloy (1800°F solution treatment temperature).



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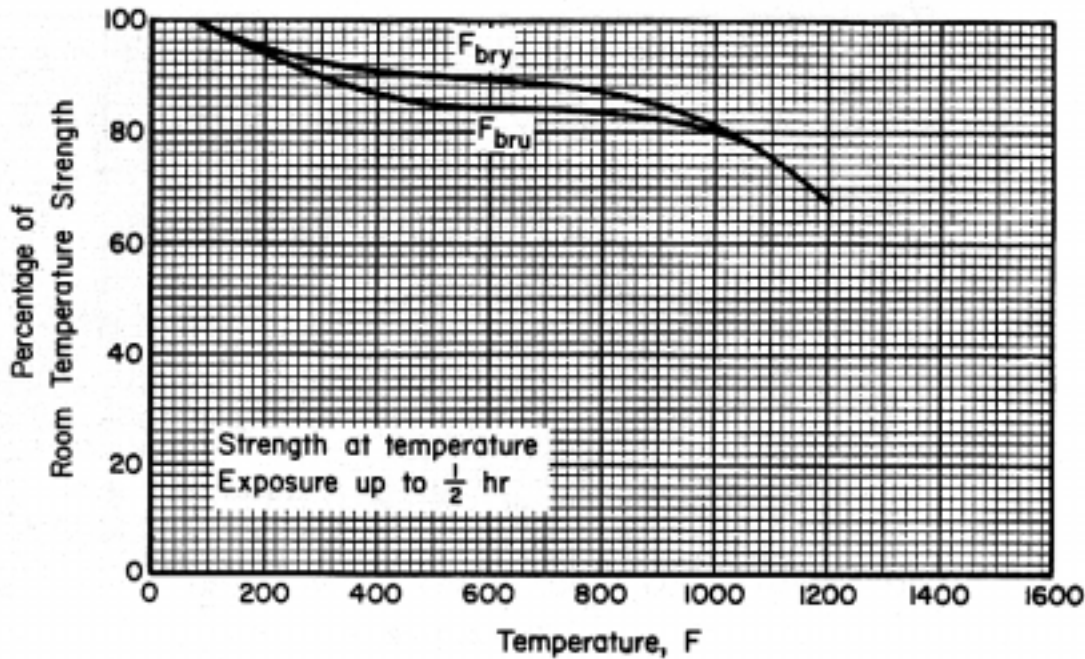


Figure 6.2.1.1.3. Effect of temperature on the bearing ultimate strength ( $F_{bru}$ ) and the bearing yield strength ( $F_{bry}$ ) of A-286 alloy (1800°F solution treatment temperature).

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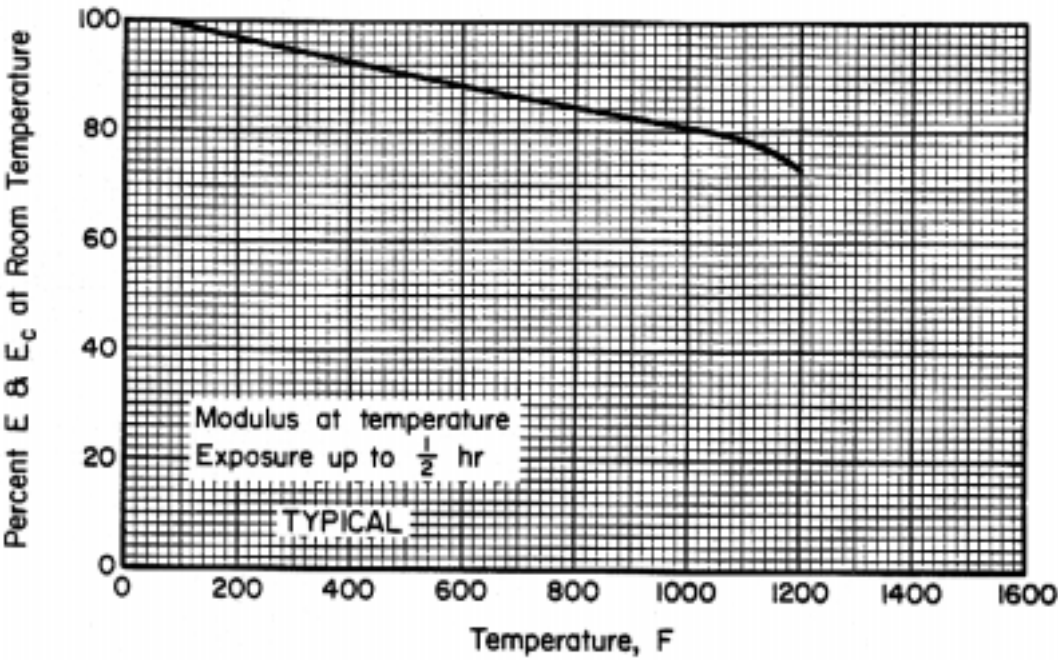


Figure 6.2.1.1.4(a). Effect of temperature on the tensile and compressive moduli ( $E$  and  $E_c$ ) of A-286 alloy (1800°F solution treatment temperature).

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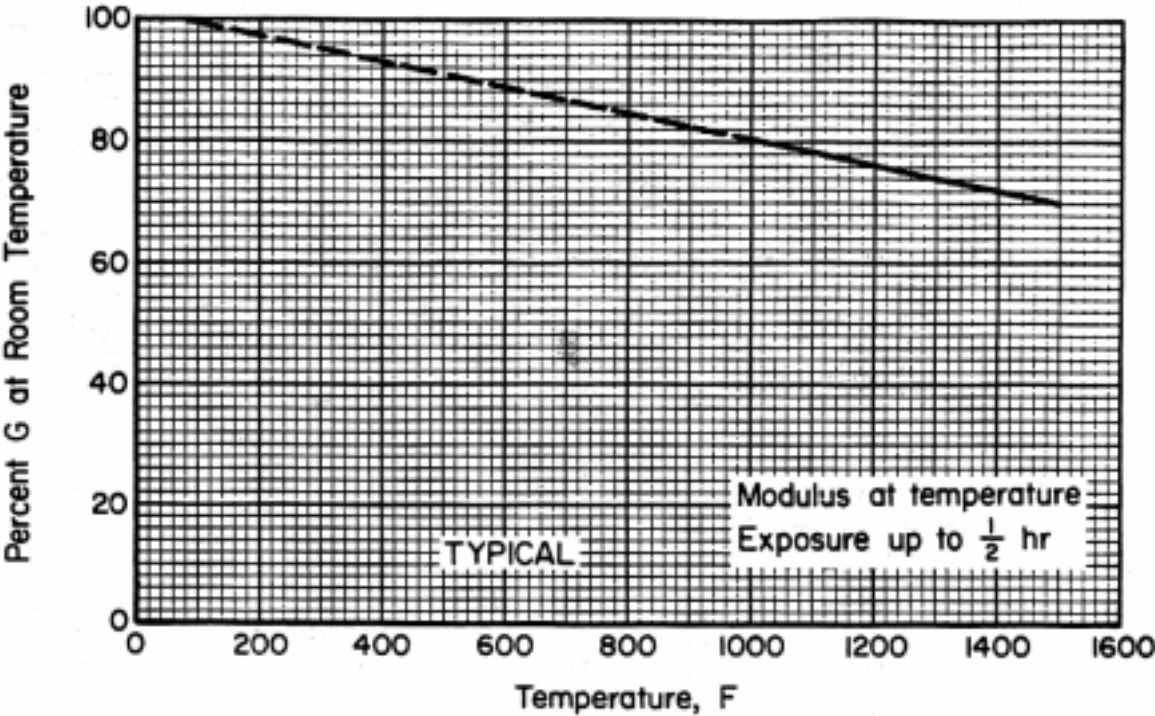


Figure 6.2.1.1.4(b). Effect of temperature on the shear modulus (G) of A-286 alloy.

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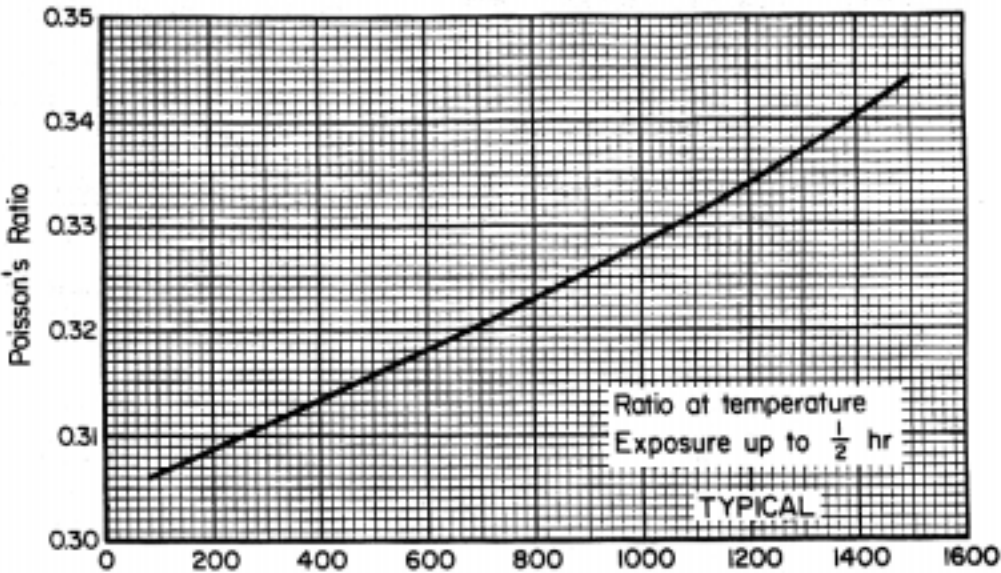


Figure 6.2.1.1.4(c). Effect of temperature on Poisson's ratio ( $\mu$ ) for A-286 alloy.



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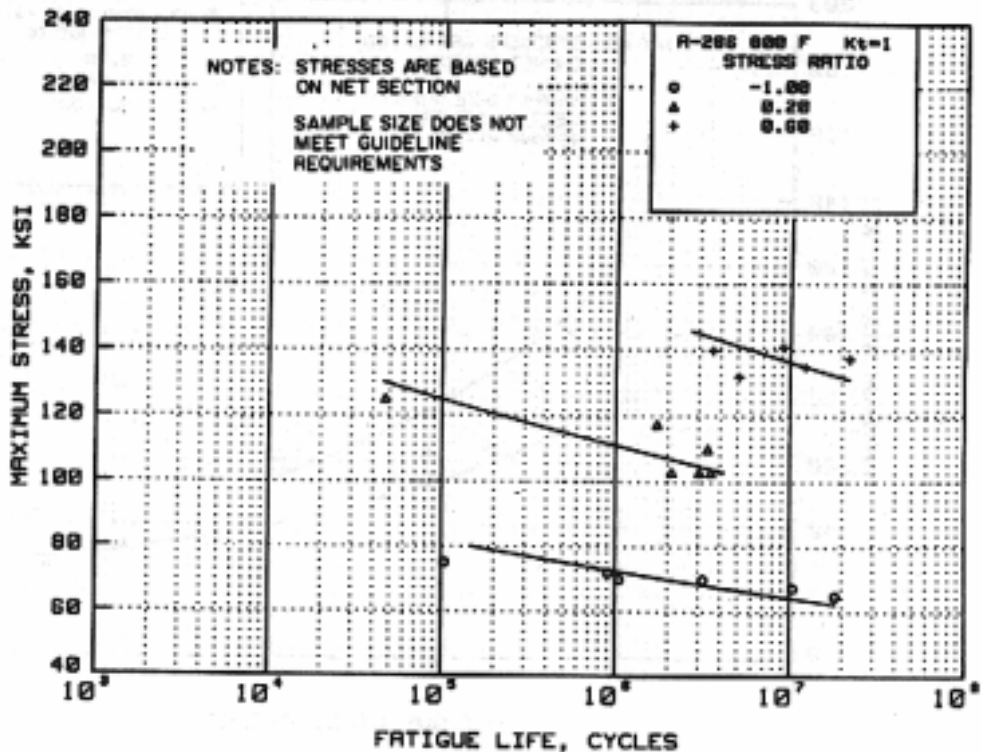


Figure 6.2.1.1.8(a). Best-fit S/N curves for unnotched A-286 bar at 800°F, longitudinal direction.

Correlative Information for Figure 6.2.1.1.8(a)

Product Form: Bar, air melted

Properties:     TUS, ksi    TYS, ksi    Temp., °F  
                    141.4       95.3       800

Specimen Details: Unnotched  
                             0.250-inch diameter

Heat Treatment:    1650°F for 2 hours, oil  
                             quenched and 1300°F for  
                             16 hours, air cooled.

Surface Condition: Not given

Reference:         6.2.1.1.8

Test Parameters:

Loading - Axial  
Frequency - 3600 cpm  
Temperature - 800°F  
Environment - Air

No. of Heats/Lots: 1

Equivalent Stress Equation:

$\log N_f = 45.1 - 19.5 \log (S_{eq})$   
 $S_{eq} = S_{max} (1-R)^{0.47}$   
Standard Error of Estimate = 0.418  
Standard Deviation in Life = 0.717  
 $R^2 = 65.9\%$

Sample Size = 17

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

1 December 1998

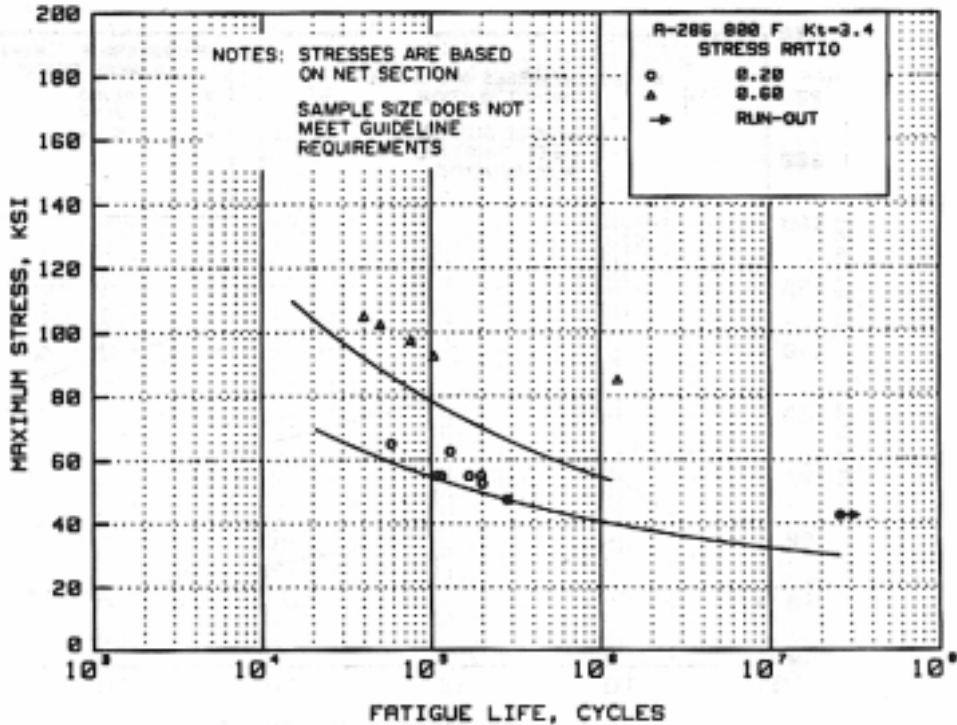
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**Figure 6.2.1.1.8(b). Best-fit S/N curves for notched,  $K_t = 3.4$ , A-286 alloy bar at 800°F, longitudinal direction.**

Correlative Information for Figure 6.2.1.1.8(b)

Product Form: Bar, air melted

Test Parameters:

Loading - Axial

Frequency - 3600 cpm

Temperature - 800°F

Environment - Air

Properties: TUS, ksi TYS, ksi Temp., °F

141.4 95.3 800  
Unnotched

No. of Heats/Lots: 1

Specimen Details: Notched, V-Groove,  
 $K_t = 3.4$   
0.375-inch gross diameter  
0.250-inch net diameter  
0.010-inch root radius,  $r$   
60° flank angle,  $\omega$

Equivalent Stress Equation:

$$\log N_f = 11.4 - 4.4 \log (S_{eq} - 20)$$

$$S_{eq} = S_{max} (1 - R)^{0.75}$$

Standard Error of Estimate = 0.271

Standard Deviation in Life = 0.387

$$R^2 = 50.9\%$$

Heat Treatment: 1650°F for 2 hours, oil  
quenched and 1300°F for  
16 hours, air cooled.

Sample Size = 13

Surface Condition: As machined

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

Reference: 6.2.1.1.8

1 December 1998

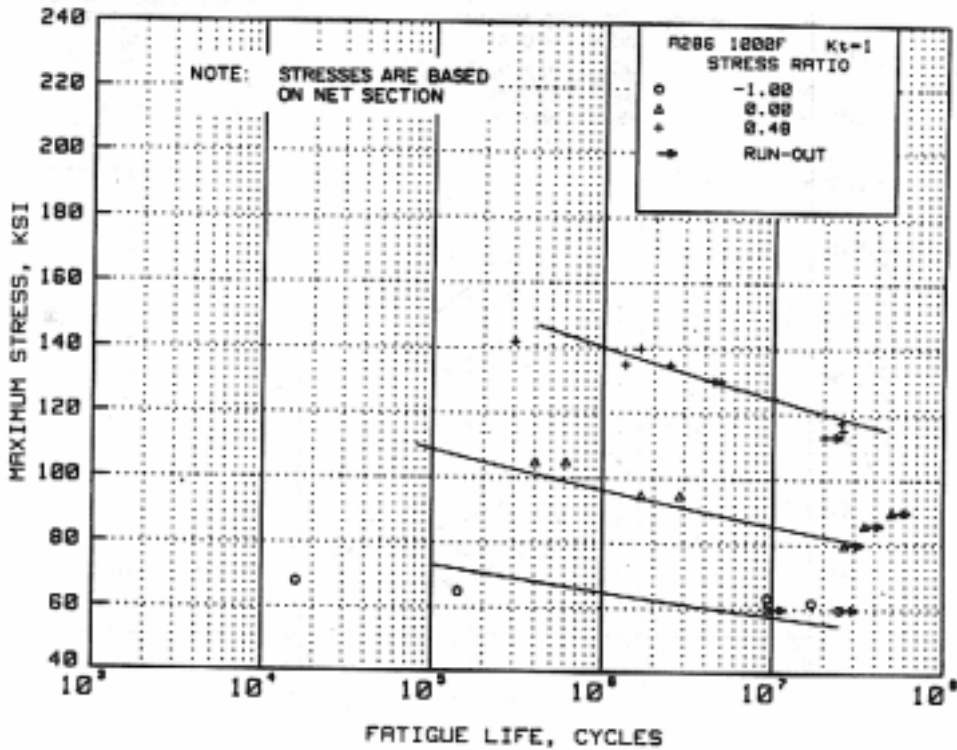
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**Figure 6.2.1.1.8(c). Best-fit S/N curves for unnotched A-286 bar at 1000°F, longitudinal direction.**

Correlative Information for Figure 6.2.1.1.8(c)

Product Form: Bar, air melted

Test Parameters:

Properties:      TUS, ksi    TYS, ksi    Temp., °F

Loading - Axial  
Frequency - 3600 cpm  
Temperature - 1000°F  
Environment - Air

137.2      100.6      1000

Specimen Details: Unnotched  
0.250-inch diameter

No. of Heats/Lots: 1

Heat Treatment: 1650°F for 2 hours, oil  
quenched and 1300°F for  
16 hours, air cooled.

Equivalent Stress Equation:

$$\log N_f = 44.2 - 19.3 \log (S_{eq})$$

$$S_{eq} = S_{max} (1-R)^{0.57}$$

Standard Error of Estimate = 0.566

Standard Deviation in Life = 0.835

$$R^2 = 54.0\%$$

Surface Condition: Not given

Reference: 6.2.1.1.8

Sample Size = 18

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

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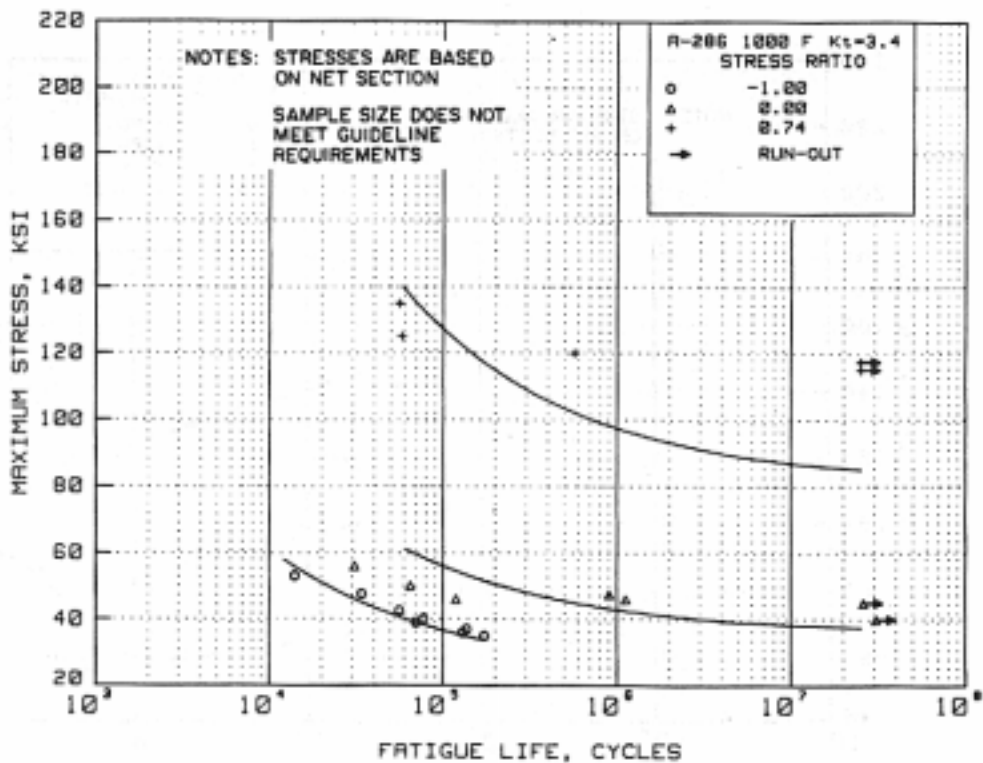


Figure 6.2.1.1.8(d). Best-fit S/N curves for notched,  $K_t = 3.4$ , A-286 alloy bat at 1000°F, longitudinal direction.

Correlative Information for Figure 6.2.1.1.8(d)

|                           |                                                                                                                                                  |                 |                  |
|---------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|------------------|
| <u>Product Form:</u>      | Bar, air melted                                                                                                                                  |                 |                  |
| <u>Properties:</u>        | <u>TUS, ksi</u>                                                                                                                                  | <u>TYS, ksi</u> | <u>Temp., °F</u> |
|                           | 137.2                                                                                                                                            | 100.6           | 1000             |
|                           |                                                                                                                                                  |                 | Unnotched        |
| <u>Specimen Details:</u>  | Notched, V-Groove, $K_t = 3.4$<br>0.375-inch gross diameter<br>0.250-inch net diameter<br>0.010-inch root radius, r<br>60° flank angle, $\omega$ |                 |                  |
| <u>Heat Treatment:</u>    | 1650°F for 2 hours, oil quenched and 1300°F for 16 hours, air cooled.                                                                            |                 |                  |
| <u>Surface Condition:</u> | As machined                                                                                                                                      |                 |                  |
| <u>Reference:</u>         | 6.2.1.1.8                                                                                                                                        |                 |                  |

|                                                      |
|------------------------------------------------------|
| <u>Test Parameters:</u>                              |
| Loading - Axial                                      |
| Frequency - 3600 cpm                                 |
| Temperature - 1000°F                                 |
| Environment - Air                                    |
| <u>No. of Heats/Lots:</u> 1                          |
| <u>Equivalent Stress Equation:</u>                   |
| $\text{Log } N_f = 7.86 - 2.19 \log (S_{eq} - 35.8)$ |
| $S_{eq} = S_{max} (1 - R)^{0.61}$                    |
| Standard Error of Estimate = 0.365                   |
| Standard Deviation in Life = 0.510                   |
| $R^2 = 48.7\%$                                       |
| <u>Sample Size</u> = 17                              |

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

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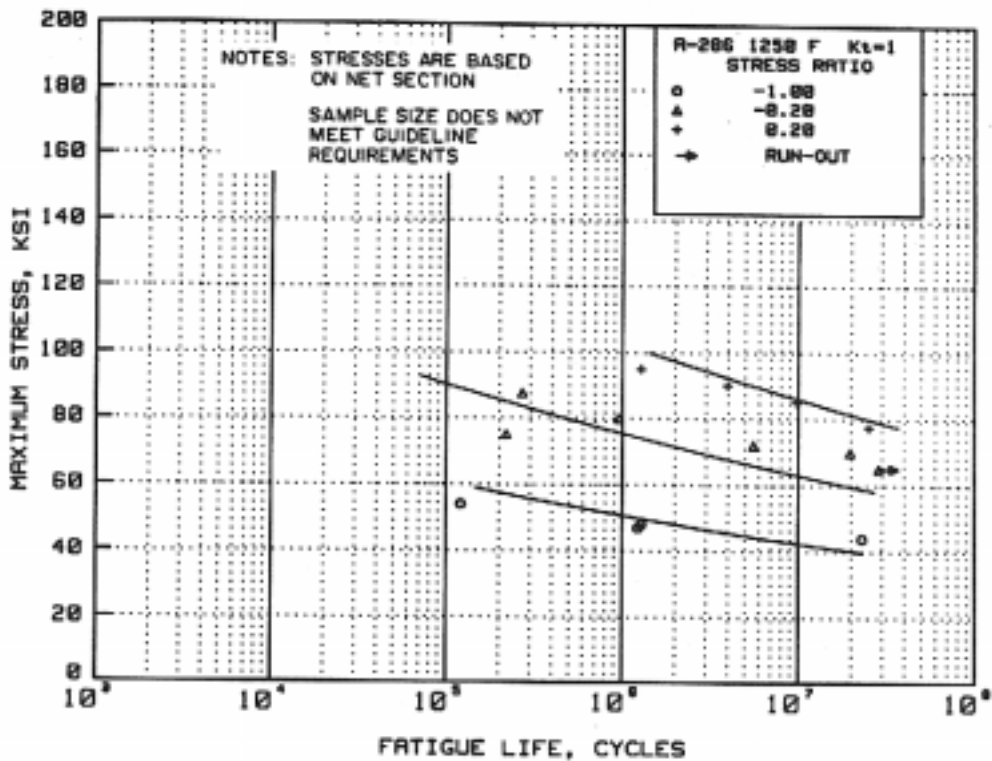


Figure 6.2.1.1.8(e). Best-fit S/N curves for unnotched A-286 bar at 1250°F, longitudinal direction.

Correlative Information for Figure 6.2.1.1.8(e)

Product Form: Bar, air melted

Properties: TUS, ksi TYS, ksi Temp., °F  
109.6 96.5 1250

Specimen Details: Unnotched  
0.250-inch diameter

Heat Treatment: 1650°F for 2 hours, oil  
quenched and 1300°F for  
16 hours, air cooled.

Surface Condition: Not given

Reference: 6.2.1.1.8

Test Parameters:

Loading - Axial  
Frequency - 3600 cpm  
Temperature - 1250°F  
Environment - Air

No. of Heats/Lots: 1

Equivalent Stress Equation:

$\log N_f = 30.8 - 12.8 \log (S_{eq})$   
 $S_{eq} = S_{max} (1-R)^{0.77}$   
Standard Error of Estimate = 0.513  
Standard Deviation in Life = 0.788  
 $R^2 = 57.6\%$

Sample Size = 13

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]



6.2.2 N-155 ALLOY

**6.2.2.0 Comments and Properties** — N-155 alloy, also known as Multimet, is designed for applications involving high stress up to 1500°F. It has good oxidation properties and good ductility and can be fabricated readily by conventional methods. This alloy has been used in many aircraft applications, including afterburner parts, combustion chambers, exhaust assemblies, turbine parts, and bolting.

N-155 is forged readily between 1650 and 2200°F. It is easily formed by conventional methods; intermediate anneals may be required to restore its ductility. This alloy is machinable in all conditions; low cutting speeds and ample flow of coolant are required. The weldability of N-155 is comparable to that of the austenitic stainless steels. The oxidation resistance of N-155 sheet is good up to 1500°F.

Some materials specifications for N-155 are presented in Table 6.2.2.0(a). Room-temperature mechanical and physical properties for N-155 sheet and tubing in the solution-treated (annealed) condition are presented in Table 6.2.2.0(b). Bars and forgings are not specified by room-temperature properties but have specific elevated-temperature requirements. The effect of temperature on physical properties is shown in Figure 6.2.2.0.

Table 6.2.2.0(a). Material Specifications for N-155 Alloy

| Specification | Form            | Condition                 |
|---------------|-----------------|---------------------------|
| AMS 5532      | Sheet           | Solution treated          |
| AMS 5585      | Tubing (welded) | Solution treated          |
| AMS 5768      | Bar and forging | Solution treated and aged |
| AMS 5769      | Bar and forging | Solution treated          |

**6.2.2.1 Solution-Treated Condition** — Elevated-temperature curves are presented in Figures 6.2.2.1.1(a) and (b), as well as 6.2.2.1.4(a) and (b). Stress-rupture properties are specified at 1500°F for sheet and at 1350°F for bars and forgings; the appropriate specifications should be consulted for detailed requirements.

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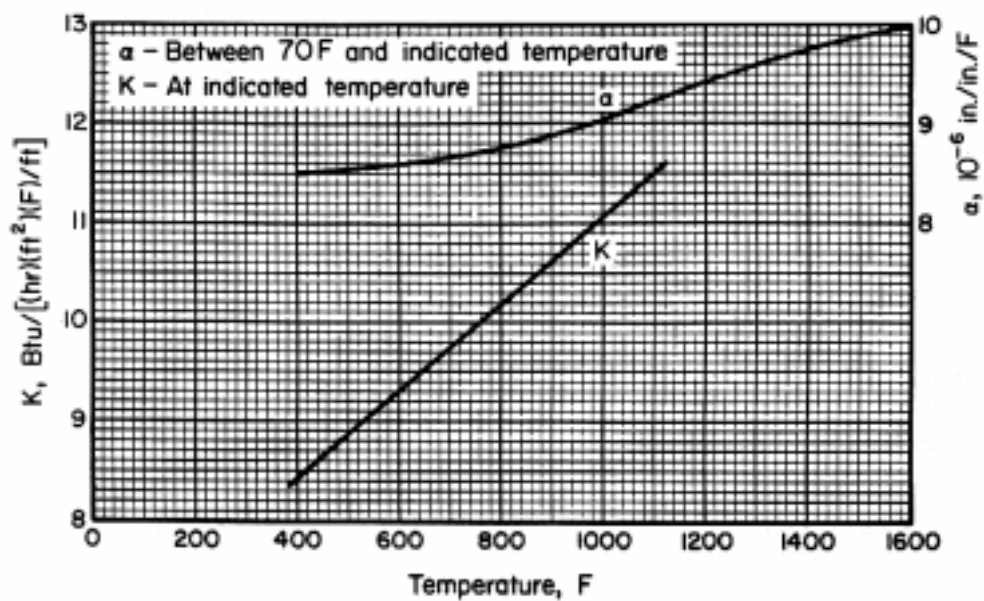


Figure 6.2.2.0. Effect of temperature on the physical properties of N-155 alloy.

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 6.2.2.0(b). Design Mechanical and Physical Properties of N-155 Alloy**

| Specification .....                          | AMS 5532                |                 | AMS 5585        |
|----------------------------------------------|-------------------------|-----------------|-----------------|
| Form .....                                   | Sheet                   | Strip and plate | Tubing          |
| Condition .....                              | Solution treated        |                 |                 |
| Thickness, in. ....                          | ≤0.187                  | ...             | ...             |
| Basis .....                                  | S <sup>a</sup>          | S <sup>a</sup>  | S               |
| Mechanical Properties:                       |                         |                 |                 |
| $F_{tu}$ , ksi:                              |                         |                 |                 |
| L .....                                      | ...                     | ...             | 100             |
| LT .....                                     | 100                     | 100             | ...             |
| $F_{ty}$ , ksi:                              |                         |                 |                 |
| L .....                                      | ...                     | ...             | 49 <sup>b</sup> |
| LT .....                                     | 49 <sup>b</sup>         | ...             | ...             |
| $F_{cy}$ , ksi:                              |                         |                 |                 |
| L .....                                      | ...                     | ...             | ...             |
| LT .....                                     | ...                     | ...             | ...             |
| $F_{su}$ , ksi .....                         | ...                     | ...             | ...             |
| $F_{bru}$ , ksi:                             |                         |                 |                 |
| (e/D = 1.5) .....                            | ...                     | ...             | ...             |
| (e/D = 2.0) .....                            | ...                     | ...             | ...             |
| $F_{bry}$ , ksi:                             |                         |                 |                 |
| (e/D = 1.5) .....                            | ...                     | ...             | ...             |
| (e/D = 2.0) .....                            | ...                     | ...             | ...             |
| e, percent:                                  |                         |                 |                 |
| L .....                                      | ...                     | ...             | <sup>c</sup>    |
| LT .....                                     | 40                      | 40              | ...             |
| $E$ , 10 <sup>3</sup> ksi .....              | 29.2                    |                 |                 |
| $E_c$ , 10 <sup>3</sup> ksi .....            | 29.2                    |                 |                 |
| $G$ , 10 <sup>3</sup> ksi .....              | 11.2                    |                 |                 |
| $\mu$ .....                                  | See Figure 6.2.2.1.4(b) |                 |                 |
| Physical Properties:                         |                         |                 |                 |
| $\omega$ , lb/in. <sup>3</sup> .....         | 0.300                   |                 |                 |
| $C$ , Btu/(lb)(°F) .....                     | 0.103 (70 to 212 °F)    |                 |                 |
| $K$ , Btu/[(hr)(ft <sup>2</sup> )(°F)/ft]    | See Figure 6.2.2.0      |                 |                 |
| $\alpha$ , 10 <sup>-6</sup> in./in./°F ..... | See Figure 6.2.2.0      |                 |                 |

a Test direction longitudinal for widths less than 9 inches: transverse for widths 9 inches and over.  
b Typical value reduced to minimum.  
c Strip = 35.  
Full section 0.625 thick = 40.  
Full section >0.625 thick = 30.

[VIEW INTERACTIVE GRAPH](#)

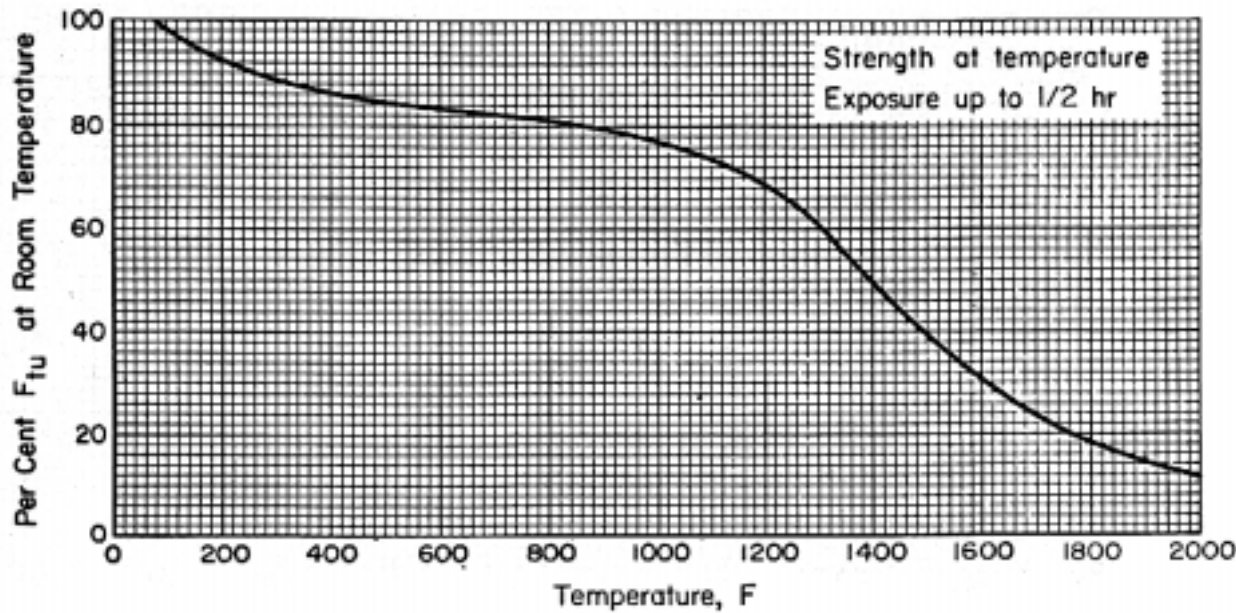


Figure 6.2.2.1.1(a). Effect of temperature on the tensile ultimate strength ( $F_{tu}$ ) of N-155 alloy.

[VIEW INTERACTIVE GRAPH](#)

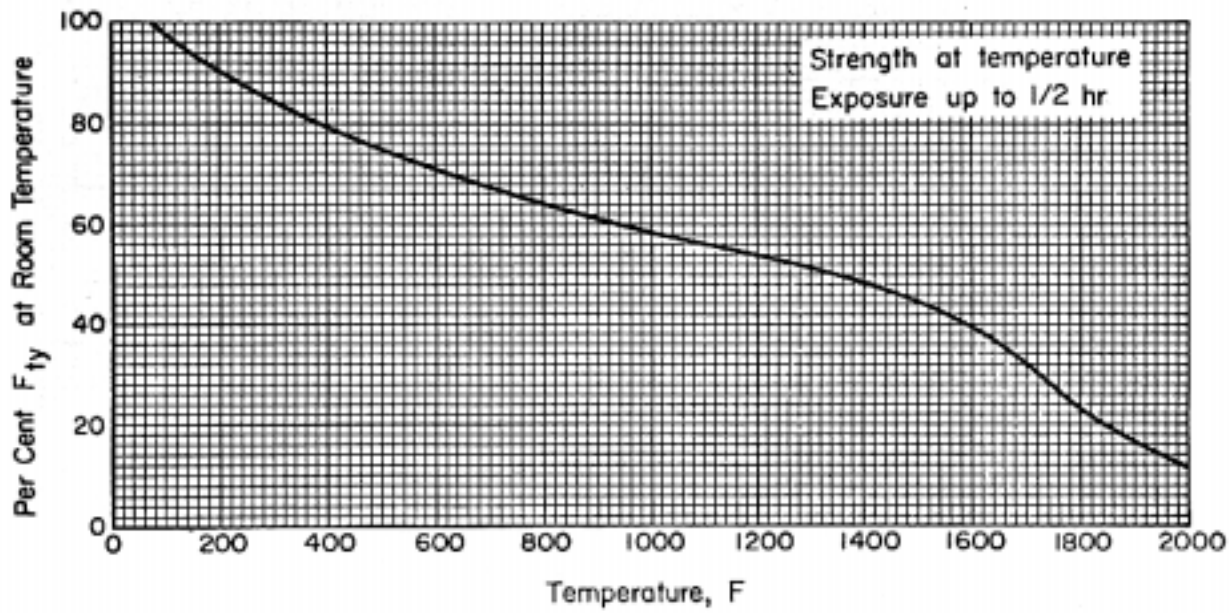


Figure 6.2.2.1.1(b). Effect of temperature on the tensile yield strength ( $F_{ty}$ ) of N-155 alloy.



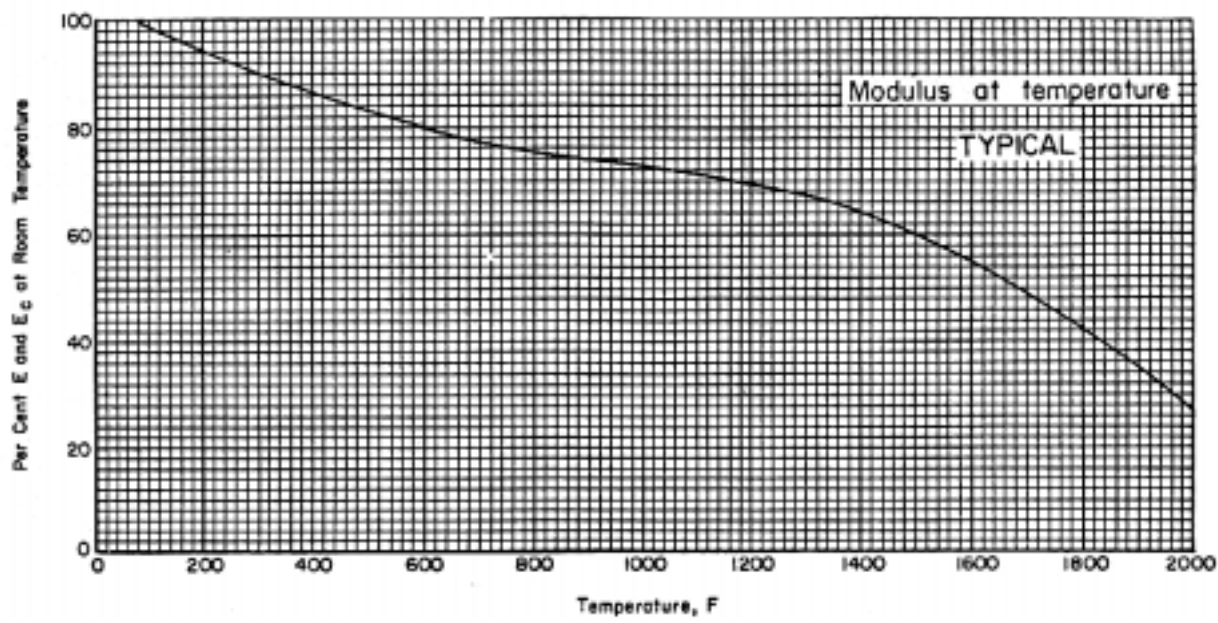


Figure 6.2.2.1.4(a). Effect of temperature on the tensile and compressive moduli (E and E<sub>c</sub>) of N-155 alloy.

[VIEW INTERACTIVE GRAPH](#)

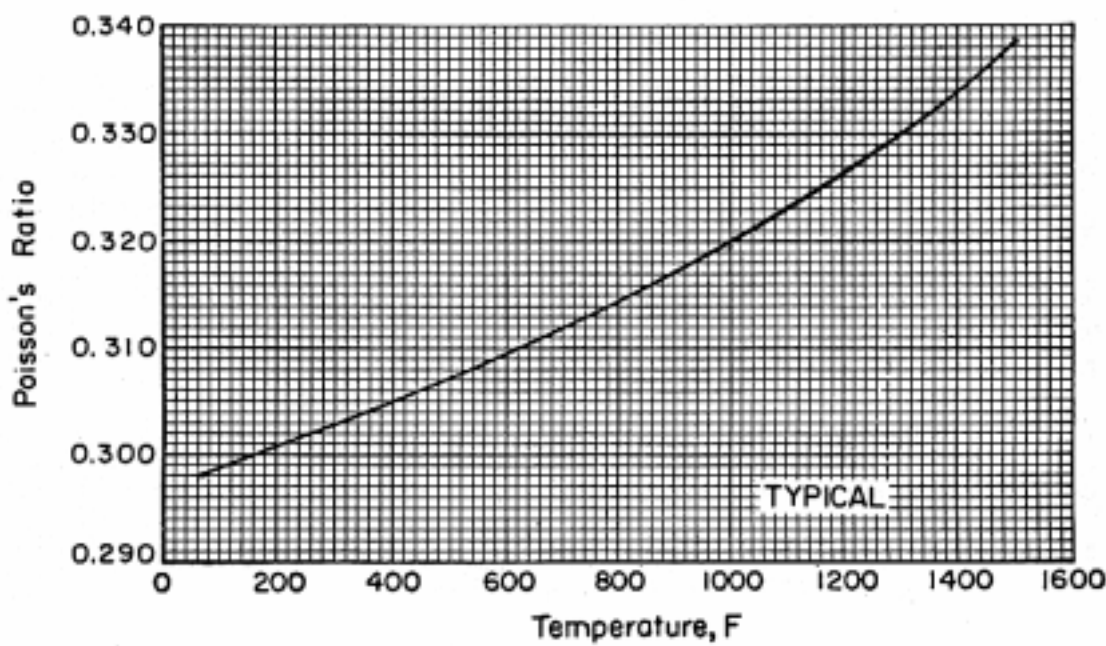


Figure 6.2.2.1.4(b). Effect of temperature on Poisson's ratio ( $\mu$ ) for N-155 alloy.

CHAPTER 7

MISCELLANEOUS ALLOYS AND HYBRID MATERIALS

7.1 GENERAL

This chapter contains the engineering properties and related characteristics of miscellaneous alloys and hybrid materials. In addition to the usual properties, some characteristics relating to the special uses of these alloys are described. For example, the electrical conductivity is reported for the bronzes and information is included on toxicity of particles of beryllium and its compounds, such as beryllium oxide.

The organization of this chapter is in sections by base metal and subdivided as shown in Table 7.1.

Table 7.1. Miscellaneous Alloys Index

| Section | Designation                                      |
|---------|--------------------------------------------------|
| 7.2     | <b>Beryllium</b>                                 |
| 7.2.1   | Standard Grade Beryllium                         |
| 7.3     | <b>Copper and Copper Alloys</b>                  |
| 7.3.1   | Manganese Bronzes                                |
| 7.3.2   | Copper Beryllium                                 |
| 7.4     | <b>Multiphase Alloys</b>                         |
| 7.4.1   | MP35N Alloy                                      |
| 7.4.2   | MP159 Alloy                                      |
| 7.5     | <b>Aluminum Alloy Sheet Laminates</b>            |
| 7.5.1   | 2024-T3 Aramid Fiber Reinforced Sheet Laminate   |
| 7.5.2   | 7475-T761 Aramid Fiber Reinforced Sheet Laminate |

7.2 BERYLLIUM

7.2.0 GENERAL

This section contains the engineering properties and related characteristics of beryllium used in aerospace structural applications. Beryllium is a lightweight, high modulus, moderate temperature capability metal that is used for specific aerospace applications. Structural designs utilizing beryllium sheet should allow for anisotropy, particularly the very low short transverse properties. Additional information on the fabrication of beryllium may be found in References 7.2.0(a) through (i).

7.2.1 STANDARD GRADE BERYLLIUM

**7.2.1.0 Comments and Properties** — Standard grade beryllium bars, rods, tubing, and machined shapes are produced from vacuum hot-pressed powder with 1½ percent maximum beryllium oxide content. These products are also available in numerous other compositions for special purposes but are not covered in this document. Sheet and plate are fabricated from vacuum hot-pressed powder with 2 percent maximum beryllium oxide content.

7.2.1.1 Manufacturing Considerations

*Hot Shaping* — Beryllium hot-pressed block can be forged and rolled but requires temperatures of 700°F and higher because of brittleness. A temperature range of 1000 to 1400°F is recommended. Hot shaping procedures are given in more detail in Reference 7.2.0(b).

*Forming* — Beryllium sheet should be formed at 1300 to 1350°F, holding at temperature no more than 1.5 hours, for minimum springback. Forming above 1450°F will result in a reduction in strength.

*Machining* — Carbide tools are most often used in machining beryllium. Mechanical metal removal techniques generally cause microcracks and metallographic twins. Finishing cuts are usually 0.002 to 0.005 inch in depth to minimize surface damage. Although most machining operations are performed without coolant, to avoid contamination of the chips, the use of coolant can reduce the depth of damage and give longer tool life. See Reference 7.2.0(c) for more information. Finish machining should be followed by chemical etching at least 0.002-inch from the surface to remove machining damage. See References 7.2.0(h) and (i). A combination of 1350°F stress relief followed by an 0.0005-inch etch may be necessary for close-tolerance parts. Damage-free metal removal techniques include chemical milling and electrochemical machining. The drilling of sheet may lead to delamination and breakout unless the drillhead is of the controlled torque type and the drills are carbide burr type.

*Joining* — Parts may be joined mechanically by riveting, but only by squeeze riveting to avoid damage to the beryllium, by bolting, threading, or by press fitting specifically designed to avoid damage. Parts also may be joined by brazing, soldering, braze welding, adhesive bonding, and diffusion bonding. Fusion welding is not recommended. Brazing may be accomplished with zinc, aluminum-silicon, or silver-base filler metals. Many elements, including copper, may cause embrittlement when used as brazing filler metals. However, specific manufacturing techniques have been developed by various beryllium fabricators to use many of the common braze materials. For each method of joining specific detailed procedures must be followed, Reference 7.2.0(f).

*Surface Treatment* — A surface treatment such as chemical etching to remove the machined surface of metal is recommended to ensure the specified properties. All design allowables herein represent material so treated. This surface treatment is especially important when beryllium is to be mechanically joined. References 7.2.0(d), (h), and (i) contain information on etching solutions and procedures.

*Toxicity Hazard* — Particles of beryllium and its compounds, such as beryllium oxide, are toxic, so special precautions to prevent inhalation must be taken. References 7.2.1.1(a) through (e) outline the hazard and methods to control it.

*Specifications and Properties* — Material specifications for standard grade beryllium are presented in Table 7.2.1.0(a).

Table 7.2.1.0(a). Material Specifications for Standard Grade Beryllium

| Specification | Form                                    |
|---------------|-----------------------------------------|
| AMS 7906      | Bar, rod, tubing, and mechanical shapes |
| AMS 7902      | Sheet and plate                         |

Room-temperature mechanical and physical properties are shown in Tables 7.2.1.0(b) and (c). Notch tensile test data are available in Reference 7.2.1.1(g). The effect of temperature on physical properties is shown in Figure 7.2.1.0.

**7.2.1.1. Hot-Pressed Condition** — The effect of temperature on the mechanical properties of hot-pressed beryllium is presented in Figures 7.2.1.1.1 and 7.2.1.1.4.

[Interactive Table - Design Properties](#)      [Interactive Table - Typical Properties](#)

**Table 7.2.1.0(b). Design Mechanical and Physical Properties of Beryllium Bar, Rod, Tubing, and Mechanical Shapes**

|                                      |                                       |
|--------------------------------------|---------------------------------------|
| Specification .....                  | AMS 7906                              |
| Form .....                           | Bar, rod, tubing, and machined shapes |
| Condition .....                      | Hot pressed (ground and etched)       |
| Thickness or diameter, in. ....      | ...                                   |
| Basis .....                          | S                                     |
| Mechanical Properties:               |                                       |
| $F_{tu}$ , ksi:                      |                                       |
| L .....                              | 47                                    |
| LT .....                             | 47                                    |
| $F_{ty}$ , ksi:                      |                                       |
| L .....                              | 35                                    |
| LT .....                             | 35                                    |
| $F_{cy}$ , ksi:                      |                                       |
| L .....                              | ...                                   |
| LT .....                             | ...                                   |
| $F_{su}$ , ksi .....                 | ...                                   |
| $F_{bru}$ , ksi:                     |                                       |
| (e/D = 1.5) .....                    | ...                                   |
| (e/D = 2.0) .....                    | ...                                   |
| $F_{bry}$ , ksi:                     |                                       |
| (e/D = 1.5) .....                    | ...                                   |
| (e/D = 2.0) .....                    | ...                                   |
| e, percent:                          |                                       |
| L .....                              | 2                                     |
| LT .....                             | 2                                     |
| $E$ , $10^3$ ksi .....               | 42                                    |
| $E_c$ , $10^3$ ksi .....             | 42                                    |
| $G$ , $10^3$ ksi .....               | 20                                    |
| $\mu$ .....                          | 0.10                                  |
| Physical Properties:                 |                                       |
| $\omega$ , lb/in. <sup>3</sup> ..... | 0.067                                 |
| C, K, and $\alpha$ .....             | See Figure 7.2.1.0                    |

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 7.2.1.0(c). Design Mechanical and Physical Properties of Beryllium Sheet and Plate**

|                                      |                                     |             |             |        |
|--------------------------------------|-------------------------------------|-------------|-------------|--------|
| Specification .....                  | AMS 7902                            |             |             |        |
| Form .....                           | Sheet                               | Plate       |             |        |
| Condition .....                      | Stress relieved (ground and etched) |             |             |        |
| Thickness or diameter, in. ....      | 0.020-0.250                         | 0.251-0.450 | 0.451-0.600 | ≥0.601 |
| Basis .....                          | S                                   | S           | S           | S      |
| Mechanical Properties:               |                                     |             |             |        |
| $F_{tu}$ , ksi:                      |                                     |             |             |        |
| L .....                              | 70                                  | 65          | 60          | 40     |
| LT .....                             | 70                                  | 65          | 60          | 40     |
| $F_{ty}$ , ksi:                      |                                     |             |             |        |
| L .....                              | 50                                  | 45          | 40          | 30     |
| LT .....                             | 50                                  | 45          | 40          | 30     |
| $F_{cy}$ , ksi:                      |                                     |             |             |        |
| L .....                              | ...                                 | ...         | ...         | ...    |
| LT .....                             | ...                                 | ...         | ...         | ...    |
| $F_{su}$ , ksi .....                 | ...                                 | ...         | ...         | ...    |
| $F_{bru}$ , ksi:                     |                                     |             |             |        |
| (e/D = 1.5) .....                    | ...                                 | ...         | ...         | ...    |
| (e/D = 2.0) .....                    | ...                                 | ...         | ...         | ...    |
| $F_{bry}$ , ksi:                     |                                     |             |             |        |
| (e/D = 1.5) .....                    | ...                                 | ...         | ...         | ...    |
| (e/D = 2.0) .....                    | ...                                 | ...         | ...         | ...    |
| e, percent:                          |                                     |             |             |        |
| L .....                              | 10                                  | 4           | 3           | 1      |
| LT .....                             | 10                                  | 4           | 3           | 1      |
| $E$ , 10 <sup>3</sup> ksi .....      | 42.5                                |             |             |        |
| $E_c$ , 10 <sup>3</sup> ksi .....    | 42.5                                |             |             |        |
| $G$ , 10 <sup>3</sup> ksi .....      | 20.0                                |             |             |        |
| $\mu$ .....                          | 0.10 (L and LT)                     |             |             |        |
| Physical Properties:                 |                                     |             |             |        |
| $\omega$ , lb/in. <sup>3</sup> ..... | 0.067                               |             |             |        |
| C, K, and $\alpha$ .....             | See Figure 7.2.1.0                  |             |             |        |

[VIEW INTERACTIVE GRAPH](#)

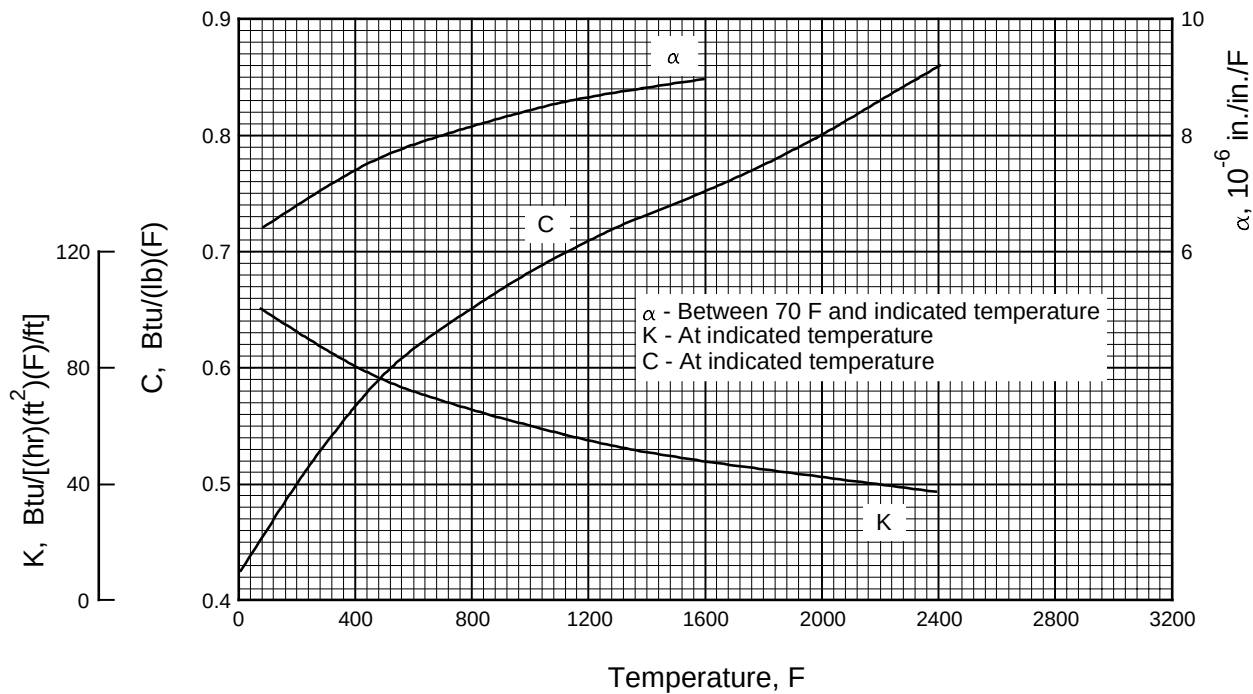


Figure 7.2.1.0. Effect of temperature on the physical properties of beryllium (2% maximum BeO).

[VIEW INTERACTIVE GRAPH](#)

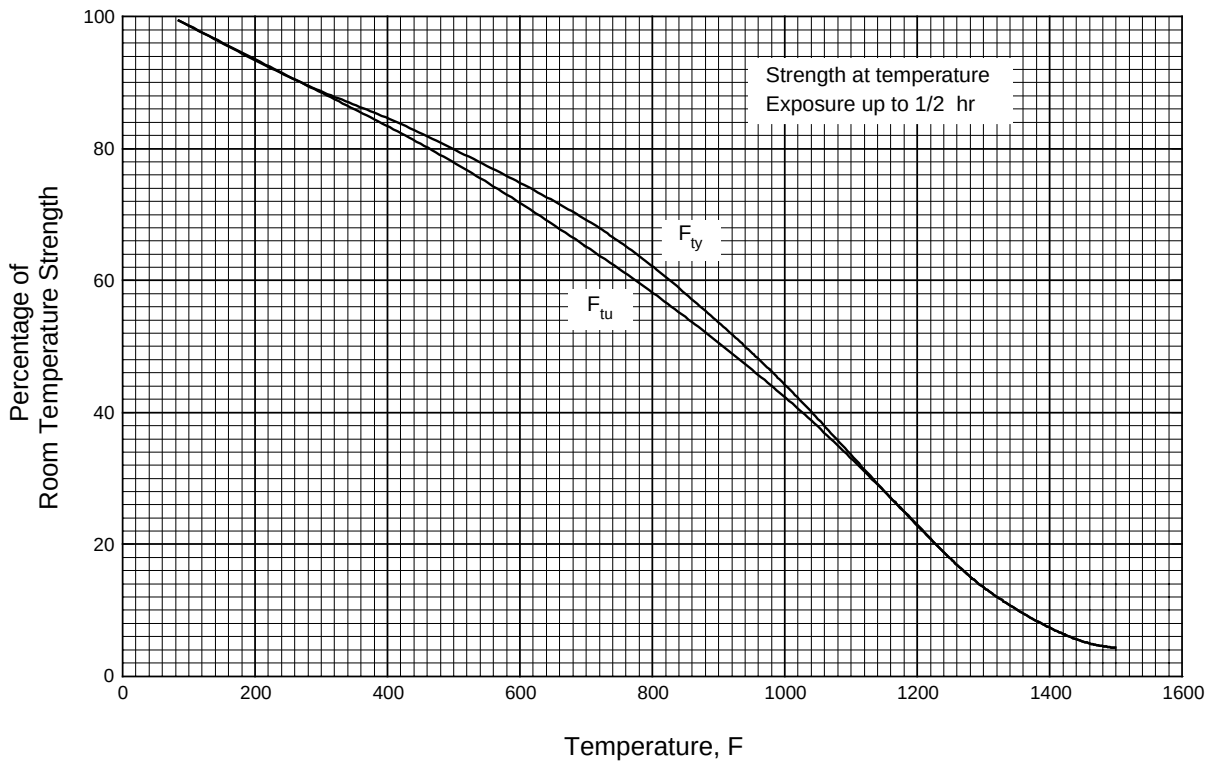


Figure 7.2.1.1.1. Effect of temperature on the tensile ultimate strength (F<sub>tu</sub>) and tensile yield strength (F<sub>ty</sub>) of hot-pressed beryllium bar, rod, tubing, and machined shapes.

[VIEW INTERACTIVE GRAPH](#)

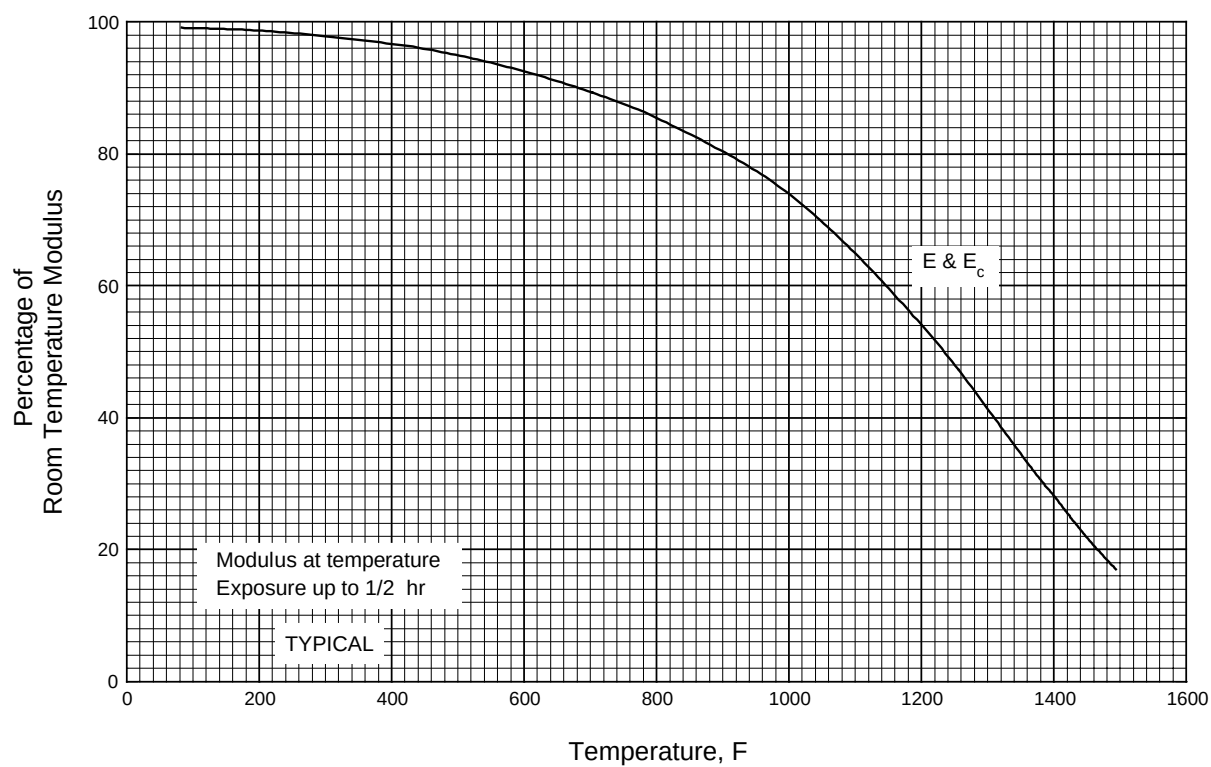


**Figure 7.2.1.1.4. Effect of temperature on the tensile and compressive moduli (E and E<sub>c</sub>) of hot-pressed beryllium bar, rod, tubing, and machined shapes.**

## 7.3 COPPER AND COPPER ALLOYS

### 7.3.0 GENERAL

The properties of major significance in designing with copper and copper alloys are electrical and thermal conductivity, corrosion resistance, and good bearing qualities (antigalling). Copper and copper alloys are non-magnetic and can be readily joined by welding, brazing and soldering. The use of copper alloys is usually predicated upon two or more of the above properties plus the ease of casting and hot and cold working into desirable shapes.

The thermally unstable range for copper and copper alloys generally begins somewhat above room temperature (150°F). Creep, stress relaxation and diminishing stress rupture strength are factors of concern above 150°F. Copper alloys frequently are used at temperatures up to 480°F. The range between 480 and 750°F is considered very high for copper alloys, since copper and many of its alloys begin to oxidize slightly above 350°F and protection may be required. Bronzes containing Al, Si, and Be oxidize to a lesser extent than the red copper alloys. Precipitation hardened alloys such as copper beryllium retain strength up to their aging temperatures of 500 to 750°F.

Copper alloys used for bearing and wear resistance applications include, in the order of their increasing strength and load-carrying capacity, copper-tin-lead, copper-tin, silicon bronze, manganese bronze, aluminum bronze, and copper beryllium. Copper beryllium and manganese bronzes are included in MIL-HDBK-5.

Copper-base bearing alloys are readily cast by a number of techniques: statically sand cast, centrifugally cast into tubular shapes, and continuously cast into various shapes. Tin bronze, sometimes called phosphor bronze because phosphorous is used to deoxidize the melt and improve castability, is a low-strength alloy. It is generally supplied as a static (sand) casting or centrifugal casting (tubular shapes from rotating graphite molds). Manganese bronze is considerably stronger than tin bronze, is easily cast in the foundry, has good toughness and is not heat treated. Aluminum bronze alloys, especially those with nickel, silicon, and manganese over 2 percent, respond to heat treatment, resulting in greater strength, and higher galling and fatigue limits than manganese bronze. Aluminum bronze is used in the static and centrifugal cast form or parts may be machined from wrought rod and bar stock. Copper beryllium is the highest strength copper-base bearing material, due to its response to precipitation hardening. Copper beryllium is also available in static and centrifugal cast form but is generally used as wrought shapes, such as extrusions, forgings, and mill shapes.

Copper beryllium, because of its high strength, is also useful as a spring material. In this application its high elastic limit, high fatigue strength as well as good electrical conductivity are significant. Copper beryllium resists softening up to 500°F, which is higher than other common copper alloys. Copper beryllium springs are usually fabricated from strip or wire. Consult References 7.3.0(a) through (c) for more information.



7.3.1 MANGANESE BRONZES

**7.3.1.0 Comments and Properties** — The manganese bronzes are also known as the high-strength yellow brasses and leaded high-strength yellow brasses. These alloys contain zinc as the principal alloying element with smaller amounts of iron, aluminum, manganese, nickel, and lead present. These bronzes are easily cast.

Some material specifications for manganese bronzes are presented in Table 7.3.1.0(a). A cross index to CDA and former QQ-C-390 designations is presented in Table 7.3.1.0(b). Room-temperature mechanical properties are shown in Tables 7.3.1.0(c) and (d).

**Table 7.3.1.0(a). Material Specifications for Manganese Bronzes**

| Specification | Form    |
|---------------|---------|
| AMS 4860      | Casting |
| AMS 4862      | Casting |

**Table 7.3.1.0(b) Cross Index**

| Copper Alloy UNS No. | CDA Alloy No. | Former QQ-C-390 Alloy No. |
|----------------------|---------------|---------------------------|
| C86300               | 863           | C7                        |
| C86500               | 865           | C3                        |

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 7.3.1.0(c). Design Mechanical and Physical Properties of C86500 Manganese Bronze**

|                                                 |                              |
|-------------------------------------------------|------------------------------|
| Specification .....                             | AMS 4860                     |
| Form .....                                      | Sand and centrifugal casting |
| Condition .....                                 | As cast                      |
| Location within casting .....                   | Any area                     |
| Basis .....                                     | S                            |
| Mechanical Properties:                          |                              |
| $F_{tu}$ , ksi .....                            | 65 <sup>a</sup>              |
| $F_{ty}$ , ksi .....                            | 25 <sup>a</sup>              |
| $F_{cy}$ , ksi .....                            | ...                          |
| $F_{su}$ , ksi .....                            | ...                          |
| $F_{bru}$ , ksi:                                |                              |
| (e/D = 1.5) .....                               | ...                          |
| (e/D = 2.0) .....                               | ...                          |
| $F_{bry}$ , ksi:                                |                              |
| (e/D = 1.5) .....                               | ...                          |
| (e/D = 2.0) .....                               | ...                          |
| $e$ , percent .....                             | 20 <sup>a</sup>              |
| $E$ , 10 <sup>3</sup> ksi .....                 | 15.0                         |
| $E_c$ , 10 <sup>3</sup> ksi .....               | ...                          |
| $G$ , 10 <sup>3</sup> ksi .....                 | ...                          |
| $\mu$ .....                                     | ...                          |
| Physical Properties:                            |                              |
| $\omega$ , lb/in. <sup>3</sup> .....            | 0.301                        |
| $C$ , Btu/(lb)(°F) .....                        | 0.09 (at 68 °F)              |
| $K$ , Btu/[(hr)(ft <sup>2</sup> )(°F)/ft] ..... | 50 (at 68 °F)                |
| $\alpha$ , 10 <sup>-6</sup> in./in/°F .....     | 11.3 (68 to 212 °F)          |
| Electrical conductivity, % IACS .....           | 22.0                         |

a When specified, conformance to tensile property requirements is determined by testing specimens cut from casting.

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 7.3.1.0(d). Design Mechanical and Physical Properties of C86300 Manganese Bronze**

|                                              |                              |
|----------------------------------------------|------------------------------|
| Specification .....                          | AMS 4862                     |
| Form .....                                   | Sand and centrifugal casting |
| Condition .....                              | As cast                      |
| Location within casting .....                | Any area                     |
| Basis .....                                  | S                            |
| Mechanical Properties:                       |                              |
| $F_{tu}$ , ksi .....                         | 110 <sup>a</sup>             |
| $F_{ty}$ , ksi .....                         | 60 <sup>a</sup>              |
| $F_{cy}$ , ksi .....                         | ...                          |
| $F_{su}$ , ksi .....                         | ...                          |
| $F_{bru}$ , ksi:                             |                              |
| (e/D = 1.5) .....                            | ...                          |
| (e/D = 2.0) .....                            | ...                          |
| $F_{bry}$ , ksi:                             |                              |
| (e/D = 1.5) .....                            | ...                          |
| (e/D = 2.0) .....                            | ...                          |
| e, percent .....                             | 12 <sup>a</sup>              |
| E, 10 <sup>3</sup> ksi .....                 | 14.2                         |
| $E_c$ , 10 <sup>3</sup> ksi .....            | ...                          |
| G, 10 <sup>3</sup> ksi .....                 | ...                          |
| $\mu$ .....                                  | ...                          |
| Physical Properties:                         |                              |
| $\omega$ , lb/in. <sup>3</sup> .....         | 0.283                        |
| C, Btu/(lb)(°F) .....                        | 0.09 (at 68°F)               |
| K, Btu/[(hr)(ft <sup>2</sup> )(°F)/ft] ..... | 20.5 (at 68°F)               |
| $\alpha$ , 10 <sup>-6</sup> in./in/°F .....  | 12.0 (68 to 500°F)           |
| Electrical conductivity, % IACS .....        | 8.0                          |

a When specified, conformance to tensile property requirements is determined by testing specimens cut from casting.

7.3.2 COPPER BERYLLIUM

**7.3.2.0 Comments and Properties** — Copper beryllium refers to a family of copper-base alloys containing beryllium and cobalt or nickel which cause the alloys to be precipitation hardenable. Data for only one high-strength alloy, designated C17200, which contains 1.90 percent (nominal) beryllium, are presented in this section. This alloy is suitable for parts requiring high strength, good wear, and corrosion resistance. Alloy C17200 is available in the form of rod, bar, shapes, mechanical tubing, strip, and casting.

*Manufacturing Considerations* — The heat treatable tempers of rod and bar are designated TB00 (AMS 4650) for solution-treated or TD04 (AMS 4651) for solution-treated plus cold worked conditions. After fabrication operations, the material may be strengthened by precipitation heat treatment (aging). Rod and bar are also available from the mill in the TF00 (AMS 4533) and TH04 (AMS 4534) conditions. Mechanical tubing is available from the mill in TF00 (AMS 4535) condition. Machining operations on rod, bar, and tubing are usually performed on material in the TF00 or (TH04) conditions. This eliminates the volumetric shrinkage of 0.02 percent, which occurs during precipitation hardening, as a factor in maintaining final dimensional tolerances. This material has good machinability in all conditions.

Strip is also available in the heat treatable condition. Parts are stamped or formed in a heat treatable temper and subsequently precipitation heat treated. For strip, the heat treatable tempers are designated TB00 (AMS 4530, ASTM B194), TD01 (ASTM B194), TD02 (AMS 4532, ASTM B194), and TD04 (ASTM B194), indicating a progressively greater amount of cold work by the mill. When parts produced from these tempers are precipitation heat treated by the user, the designations become TF00, TH01, TH02, and TH04, respectively. Strip is also available from the mill for the hardened conditions. Design values for these conditions are not included.

*Environmental Considerations* — The copper beryllium alloys have good corrosion resistance and are not susceptible to hydrogen embrittlement. The maximum service temperature for C17200 copper beryllium products is 500°F for up to 100 hours.

*Specifications and Properties* — A cross-index to previous and current temper designations for C17200 alloy is presented in Table 7.3.2.0(a).

**Table 7.3.2.0(a). Cross-Index to Prevoius and Current Temper Designations for C17200 Copper Beryllium**

| Previous Temper | Current ASTM Temper |
|-----------------|---------------------|
| A               | TB00                |
| AT              | TF00                |
| ¼H              | TD01                |
| ¼HT             | TH01                |
| ½H              | TD02                |
| ½HT             | TH02                |
| H               | TD04                |
| HT              | TH04                |

Material specifications for alloy C17200 are presented in Table 7.3.2.0(b). Room-temperature mechanical properties are shown in Tables 7.3.2.0(c) through (g). The effect of temperature on physical properties is depicted in Figure 7.3.2.0.

**Table 7.3.2.0(b). Material Specifications for C17200 Copper Beryllium Alloy**

| Specification         | Form                                  |
|-----------------------|---------------------------------------|
| ASTM B194             | Strip (TB00, TD01, TD02, TD04)        |
| AMS 4530 <sup>a</sup> | Strip (TB00)                          |
| AMS 4532 <sup>a</sup> | Strip (TD02)                          |
| AMS 4650              | Bar, rod, shapes, and forgings (TB00) |
| AMS 4533              | Bar and rod (TF00)                    |
| AMS 4535              | Mechanical tubing (TF00)              |
| AMS 4651              | Bar and rod (TD04)                    |
| AMS 4534              | Bar and rod (TH04)                    |

a Noncurrent specification.

The temper index for C17200 alloy is as follows:

| <u>Section</u> | <u>Temper</u> |
|----------------|---------------|
| 7.3.2.1        | TF00          |
| 7.3.2.2        | TH04          |

**7.3.2.1 TF00 Temper** — Typical tensile and compressive stress-strain and tangent-modulus curves are presented in Figures 7.3.2.1.6(a) and (b).

**7.3.2.2 TH04 Temper** — Typical tensile and compressive stress-strain and tangent-modulus curves are presented in Figure 7.3.2.2.6.

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 7.3.2.0(c). Design Mechanical and Physical Properties of Copper Beryllium Strip**

| Specification .....                  | ASTM B194<br>AMS 4530 <sup>a</sup> | ASTM B194 | ASTM B194<br>AMS 4532 <sup>a</sup> | ASTM B194 |
|--------------------------------------|------------------------------------|-----------|------------------------------------|-----------|
| Form .....                           | Strip                              |           |                                    |           |
| Condition .....                      | TF00                               | TH01      | TH02                               | TH04      |
| Thickness, in. ....                  | ≤0.188                             | ≤0.188    | ≤0.188                             | ≤0.188    |
| Basis .....                          | S                                  | S         | S                                  | S         |
| Mechanical Properties:               |                                    |           |                                    |           |
| $F_{tu}$ , ksi:                      |                                    |           |                                    |           |
| L .....                              | 165                                | 175       | 185                                | 190       |
| LT .....                             | ...                                | ...       | ...                                | ...       |
| $F_{ty}$ , ksi:                      |                                    |           |                                    |           |
| L .....                              | 140                                | 150       | 160                                | 165       |
| LT .....                             | ...                                | ...       | ...                                | ...       |
| $F_{cy}^b$ , ksi: (Estimate)         |                                    |           |                                    |           |
| L .....                              | 140                                | 150       | 160                                | 165       |
| LT .....                             | 140                                | 150       | 160                                | 165       |
| $F_{su}^b$ , ksi (Estimate) .....    | 90                                 | 90        | 92                                 | 95        |
| $F_{bru}^b$ , ksi: (Estimate)        |                                    |           |                                    |           |
| (e/D = 1.5) .....                    | 214                                | 227       | 240                                | 247       |
| (e/D = 2.0) .....                    | 280                                | 297       | 314                                | 323       |
| $F_{bry}^b$ , ksi: (Estimate)        |                                    |           |                                    |           |
| (e/D = 1.5) .....                    | 196                                | 210       | 224                                | 231       |
| (e/D = 2.0) .....                    | 210                                | 225       | 240                                | 247       |
| $e$ , percent:                       |                                    |           |                                    |           |
| L .....                              | 3                                  | 2.5       | 1                                  | 1         |
| $E$ , 10 <sup>3</sup> ksi .....      | 18.5                               |           |                                    |           |
| $E_c$ , 10 <sup>3</sup> ksi .....    | ...                                |           |                                    |           |
| $G$ , 10 <sup>3</sup> ksi .....      | 7.3                                |           |                                    |           |
| $\mu$ .....                          | 0.27                               |           |                                    |           |
| Physical Properties:                 |                                    |           |                                    |           |
| $\omega$ , lb/in. <sup>3</sup> ..... | 0.298                              |           |                                    |           |
| $C$ , $K$ , and $\alpha$ .....       | See Figure 7.3.2.0 for TF00 temper |           |                                    |           |

a Noncurrent specification.

b These properties do not represent values derived from tests, but are estimates.

Table 7.3.2.0(d). Design Mechanical and Physical Properties of C17200 Copper Beryllium Rod and Bar

|                                      |                       |                |                |             |             |
|--------------------------------------|-----------------------|----------------|----------------|-------------|-------------|
| Specification .....                  | AMS 4650 and AMS 4533 |                |                |             |             |
| Form .....                           | Rod and bar           |                |                |             |             |
| Condition .....                      | TF00                  |                |                |             |             |
| Thickness, in. ....                  | ≤1.500                | 1.501-2.000    | 2.001-3.000    | 3.001-3.500 | 3.501-4.000 |
| Basis .....                          | S                     | S              | S              | S           | S           |
| Mechanical Properties:               |                       |                |                |             |             |
| $F_{tu}$ , ksi:                      |                       |                |                |             |             |
| L .....                              | 165                   | 165            | 165            | 165         | 165         |
| ST .....                             | ...                   | 158            | 158            | 158         | 158         |
| $F_{ty}$ , ksi:                      |                       |                |                |             |             |
| L .....                              | 140                   | 140            | 140            | 140         | 140         |
| ST .....                             | ...                   | 137            | 137            | 137         | 137         |
| $F_{cy}$ , ksi:                      |                       |                |                |             |             |
| L .....                              | 150                   | 149            | 145            | 143         | 139         |
| ST .....                             | ...                   | 142            | 142            | 142         | 142         |
| $F_{su}$ , ksi .....                 | ...                   | 94             | 94             | 94          | 94          |
| $F_{bru}^a$ , ksi:                   |                       |                |                |             |             |
| (e/D = 1.5) .....                    | 226                   | 226            | 226            | 226         | 226         |
| (e/D = 2.0) .....                    | 290                   | 290            | 290            | 290         | 290         |
| $F_{bry}^a$ , ksi:                   |                       |                |                |             |             |
| (e/D = 1.5) .....                    | 200                   | 200            | 200            | 200         | 200         |
| (e/D = 2.0) .....                    | 225                   | 225            | 225            | 225         | 225         |
| e, percent:                          |                       |                |                |             |             |
| L .....                              | 4 <sup>b</sup>        | 4 <sup>b</sup> | 4 <sup>b</sup> | 3           | 3           |
| $E$ , 10 <sup>3</sup> ksi .....      | 18.5                  |                |                |             |             |
| $E_c$ , 10 <sup>3</sup> ksi .....    | 18.7                  |                |                |             |             |
| $G$ , 10 <sup>3</sup> ksi .....      | 7.3                   |                |                |             |             |
| $\mu$ .....                          | 0.27                  |                |                |             |             |
| Physical Properties:                 |                       |                |                |             |             |
| $\omega$ , lb/in. <sup>3</sup> ..... | 0.298                 |                |                |             |             |
| C, K, and $\alpha$ .....             | See Figure 7.3.2.0    |                |                |             |             |

a Bearing values are “dry pin” values per Section 1.4.7.1.  
b AMS 4650 specifies  $e$  = 3 percent.

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 7.3.2.0(e). Design Mechanical and Physical Properties of C17200 Copper Beryllium Rod and Bar**

|                                      |             |             |             |             |
|--------------------------------------|-------------|-------------|-------------|-------------|
| Specification .....                  | AMS 4651    |             |             |             |
| Form .....                           | Rod and bar |             |             |             |
| Condition .....                      | TH04        |             |             |             |
| Thickness, in. ....                  | ≤0.375      | 0.376-1.000 | 1.001-1.500 | 1.501-2.000 |
| Basis .....                          | S           | S           | S           | S           |
| Mechanical Properties:               |             |             |             |             |
| $F_{tu}$ , ksi:                      |             |             |             |             |
| L .....                              | 185         | 180         | 175         | 175         |
| ST .....                             | ...         | ...         | ...         | 169         |
| $F_{ty}$ , ksi:                      |             |             |             |             |
| L .....                              | 145         | 145         | 145         | 145         |
| ST .....                             | ...         | ...         | ...         | 140         |
| $F_{cy}$ , ksi:                      |             |             |             |             |
| L .....                              | ...         | 148         | 148         | 148         |
| ST .....                             | ...         | ...         | ...         | 154         |
| $F_{su}$ , ksi .....                 | ...         | 89          | 90          | 93          |
| $F_{bru}^a$ , ksi:                   |             |             |             |             |
| (e/D = 1.5) .....                    | ...         | 242         | 235         | 235         |
| (e/D = 2.0) .....                    | ...         | 306         | 298         | 298         |
| $F_{bry}^a$ , ksi:                   |             |             |             |             |
| (e/D = 1.5) .....                    | ...         | 207         | 207         | 207         |
| (e/D = 2.0) .....                    | ...         | 225         | 225         | 225         |
| $e$ , percent:                       |             |             |             |             |
| L .....                              | 1           | 1           | 2           | 2           |
| $E$ , 10 <sup>3</sup> ksi .....      | 18.5        |             |             |             |
| $E_c$ , 10 <sup>3</sup> ksi .....    | 18.7        |             |             |             |
| $G$ , 10 <sup>3</sup> ksi .....      | 7.3         |             |             |             |
| $\mu$ .....                          | 0.27        |             |             |             |
| Physical Properties:                 |             |             |             |             |
| $\omega$ , lb/in. <sup>3</sup> ..... | 0.298       |             |             |             |
| $C$ , $K$ , and $\alpha$ .....       | ...         |             |             |             |

a Bearing values are “dry pin” values per Section 1.4.7.1.



**Table 7.3.2.0(f). Design Mechanical and Physical Properties of C17200 Copper Beryllium Rod and Bar**

|                                      |             |     |             |     |                  |     |             |     |             |     |             |     |
|--------------------------------------|-------------|-----|-------------|-----|------------------|-----|-------------|-----|-------------|-----|-------------|-----|
| Specification .....                  | AMS 4534    |     |             |     |                  |     |             |     |             |     |             |     |
| Form .....                           | Rod and bar |     |             |     |                  |     |             |     |             |     |             |     |
| Condition .....                      | TH04        |     |             |     |                  |     |             |     |             |     |             |     |
| Thickness, in. ....                  | ≤0.375      |     | 0.376-0.999 |     | 1.000-1.499      |     | 1.500-1.999 |     | 2.000-2.499 |     | 2.500-3.000 |     |
| Basis .....                          | A           | B   | A           | B   | A                | B   | A           | B   | A           | B   | A           | B   |
| Mechanical Properties:               |             |     |             |     |                  |     |             |     |             |     |             |     |
| $F_{tu}$ , ksi:                      |             |     |             |     |                  |     |             |     |             |     |             |     |
| L .....                              | 182         | 188 | 180         | 186 | 177 <sup>a</sup> | 184 | 177         | 183 | 175         | 181 | 172         | 178 |
| ST .....                             | ...         | ... | ...         | ... | ...              | ... | 167         | 173 | 168         | 174 | 167         | 173 |
| $F_{ty}$ , ksi:                      |             |     |             |     |                  |     |             |     |             |     |             |     |
| L .....                              | 157         | 165 | 154         | 162 | 150 <sup>a</sup> | 162 | 150         | 158 | 147         | 155 | 145         | 152 |
| ST .....                             | ...         | ... | ...         | ... | ...              | ... | 145         | 153 | 142         | 150 | 140         | 147 |
| $F_{cy}$ , ksi:                      |             |     |             |     |                  |     |             |     |             |     |             |     |
| L .....                              | ...         | ... | 157         | 166 | 153              | 164 | 153         | 162 | 150         | 158 | 148         | 155 |
| ST .....                             | ...         | ... | ...         | ... | ...              | ... | 160         | 168 | 156         | 165 | 154         | 162 |
| $F_{su}$ , ksi .....                 | ...         | ... | 89          | 92  | 91               | 95  | 94          | 97  | 95          | 98  | 94          | 96  |
| $F_{bru}^b$ , ksi:                   |             |     |             |     |                  |     |             |     |             |     |             |     |
| (e/D = 1.5) .....                    | ...         | ... | 242         | 250 | 238              | 247 | 238         | 246 | 235         | 243 | 231         | 239 |
| (e/D = 2.0) .....                    | ...         | ... | 306         | 317 | 302              | 313 | 302         | 312 | 298         | 308 | 293         | 303 |
| $F_{bry}^b$ , ksi:                   |             |     |             |     |                  |     |             |     |             |     |             |     |
| (e/D = 1.5) .....                    | ...         | ... | 220         | 231 | 214              | 228 | 214         | 226 | 210         | 221 | 207         | 217 |
| (e/D = 2.0) .....                    | ...         | ... | 239         | 251 | 233              | 248 | 233         | 245 | 228         | 240 | 225         | 236 |
| e, percent (S-basis):                |             |     |             |     |                  |     |             |     |             |     |             |     |
| L .....                              | 3           | ... | 3           | ... | 3                | ... | 3           | ... | 3           | ... | 3           | ... |
| $E$ , 10 <sup>3</sup> ksi .....      | 18.5        |     |             |     |                  |     |             |     |             |     |             |     |
| $E_c$ , 10 <sup>3</sup> ksi .....    | 18.7        |     |             |     |                  |     |             |     |             |     |             |     |
| $G$ , 10 <sup>3</sup> ksi .....      | 7.3         |     |             |     |                  |     |             |     |             |     |             |     |
| $\mu$ .....                          | 0.27        |     |             |     |                  |     |             |     |             |     |             |     |
| Physical Properties:                 |             |     |             |     |                  |     |             |     |             |     |             |     |
| $\omega$ , lb/in. <sup>3</sup> ..... | 0.298       |     |             |     |                  |     |             |     |             |     |             |     |
| C, K, and $\alpha$ .....             | ...         |     |             |     |                  |     |             |     |             |     |             |     |

a S-basis. A values are  $F_{tu}(L) = 178$  ksi and  $F_{ty} = 152$  ksi.  
b Bearing values are “dry pin” values per Section 1.4.7.1.

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 7.3.2.0(g). Design Mechanical and Physical Properties of C17200 Copper Beryllium Mechanical Tubing**

|                                      |                    |     |              |     |
|--------------------------------------|--------------------|-----|--------------|-----|
| Specification .....                  | AMS 4535           |     |              |     |
| Form .....                           | Mechanical tubing  |     |              |     |
| Condition .....                      | TF00               |     |              |     |
| Outside Diameter, in. ....           | ≤2.499             |     | 2.500-12.000 |     |
| Wall Thickness, in. ....             | ≤0.749             |     | 0.750-2.000  |     |
| Basis .....                          | A                  | B   | A            | B   |
| Mechanical Properties:               |                    |     |              |     |
| $F_{tu}$ , ksi:                      |                    |     |              |     |
| L .....                              | 161                | 167 | 161          | 167 |
| LT .....                             | ...                | ... | 157          | 163 |
| $F_{ty}$ , ksi:                      |                    |     |              |     |
| L .....                              | 126                | 136 | 126          | 136 |
| LT .....                             | ...                | ... | 124          | 134 |
| $F_{cy}$ , ksi:                      |                    |     |              |     |
| L .....                              | 134                | 145 | 134          | 145 |
| LT .....                             | ...                | ... | 135          | 146 |
| $F_{su}$ , ksi .....                 | 92                 | 95  | 92           | 95  |
| $F_{bru}^a$ , ksi:                   |                    |     |              |     |
| (e/D = 1.5) .....                    | 228                | 237 | 228          | 237 |
| (e/D = 2.0) .....                    | 287                | 298 | 287          | 298 |
| $F_{bry}^a$ , ksi:                   |                    |     |              |     |
| (e/D = 1.5) .....                    | 183                | 197 | 183          | 197 |
| (e/D = 2.0) .....                    | 206                | 222 | 206          | 222 |
| e, percent (S-basis):                |                    |     |              |     |
| L .....                              | 3                  | ... | 3            | ... |
| $E$ , 10 <sup>3</sup> ksi .....      | 18.5               |     |              |     |
| $E_c$ , 10 <sup>3</sup> ksi .....    | 18.7               |     |              |     |
| $G$ , 10 <sup>3</sup> ksi .....      | 7.3                |     |              |     |
| $\mu$ .....                          | 0.27               |     |              |     |
| Physical Properties:                 |                    |     |              |     |
| $\omega$ , lb/in. <sup>3</sup> ..... | 0.298              |     |              |     |
| C, Btu/(lb)(°F) .....                | See Figure 7.3.2.0 |     |              |     |

a Bearing values are “dry pin” values per Section 1.4.7.1.

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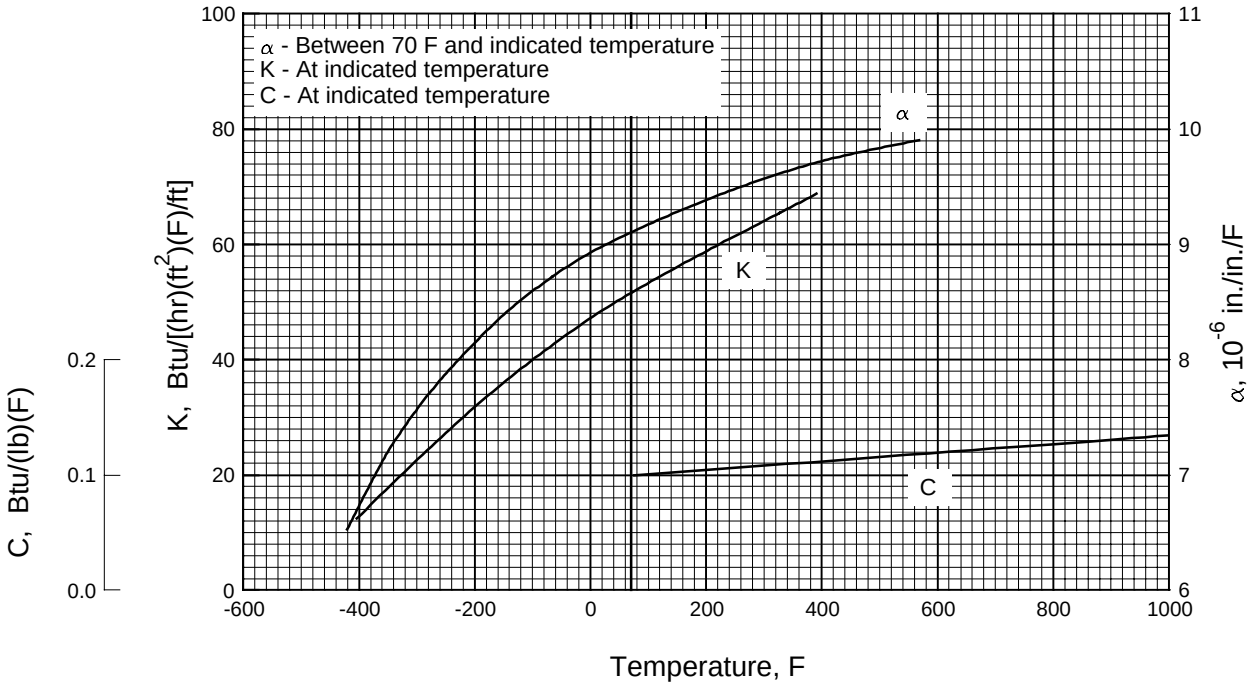


**Figure 7.3.2.0. Effect of temperature physical properties of copper beryllium (TF00).**

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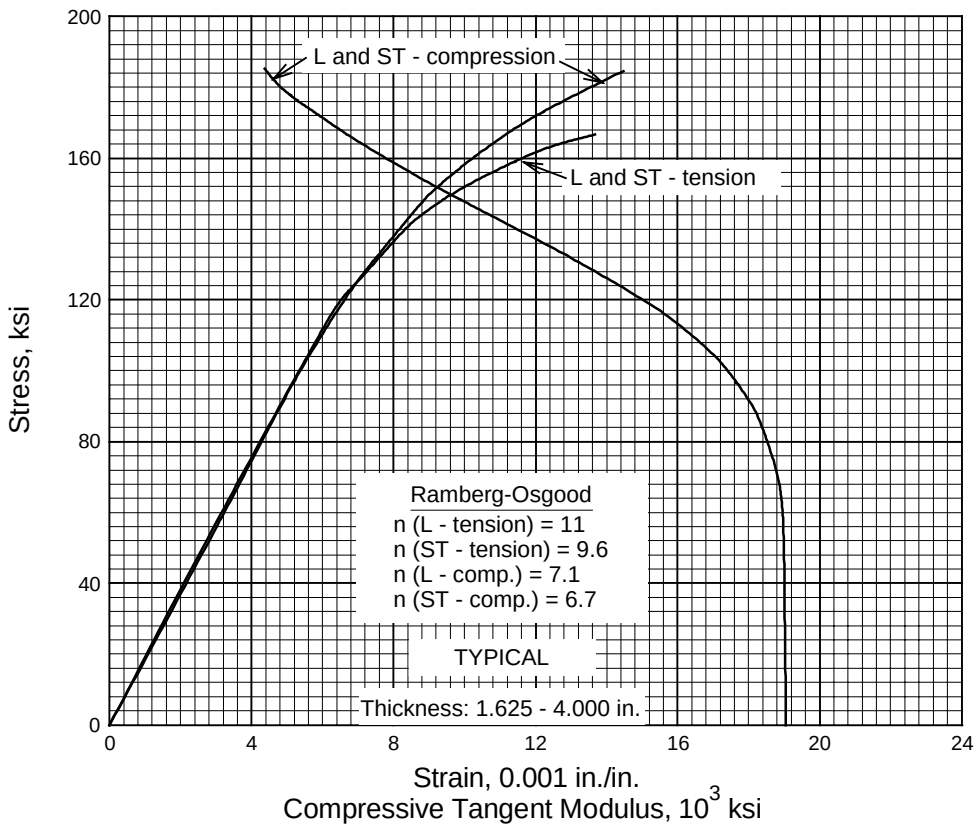


**Figure 7.3.2.1.6(a). Typical tensile and compressive stress-strain and compressive tangent-modulus curves for C17200 copper beryllium bar and rod in TF00 temper.**

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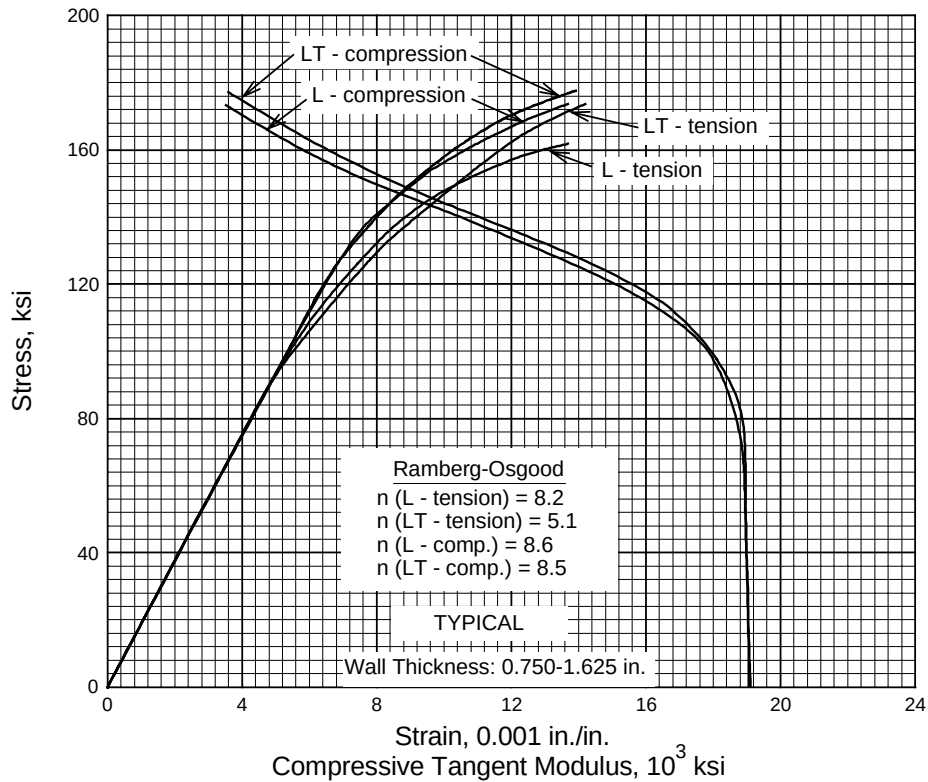


Figure 7.3.2.1.6(b). Typical tensile and compressive stress-strain and compressive tangent-modulus curves for C17200 copper beryllium mechanical tubing TF00 temper.

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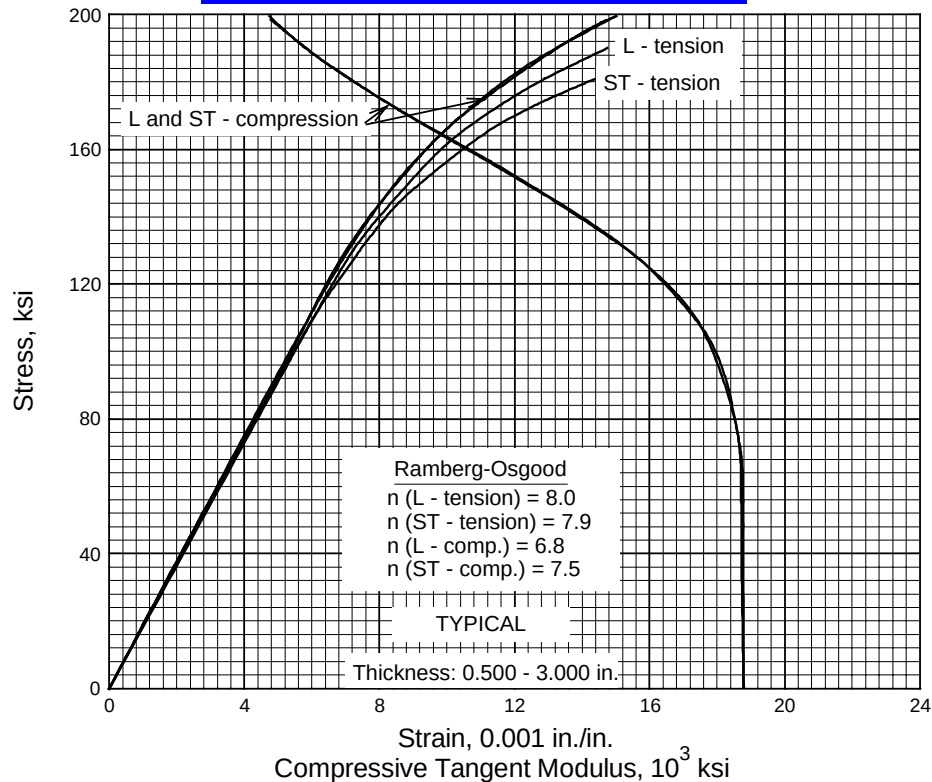


Figure 7.3.2.2.6. Typical tensile and compressive stress-strain and compressive tangent-modulus curves for C17200 copper beryllium bar and rod in TH04 temper.

7.4 MULTIPHASE ALLOYS

7.4.0 GENERAL

This section contains the engineering properties of the “Multiphase” alloys. These alloys, based on the quaternary of cobalt, nickel, chromium, and molybdenum, can be work-strengthened and aged to ultrahigh strengths with good ductility and corrosion resistance.

7.4.1 MP35N ALLOY

**7.2.1.0 Comments and Properties** — MP35N is a vacuum induction, vacuum arc remelted alloy which can be work-strengthened and aged to ultrahigh strengths. This alloy is suitable for parts requiring ultrahigh strength, good ductility and excellent corrosion and oxidation resistance up to 700°F.

*Manufacturing Considerations* — The work hardening characteristics of MP35N are similar to 304 stainless steel. Drawing, swaging, rolling, and shear forming are excellent deforming methods for work strengthening the alloy. The machinability of MP35N is similar to the nickel-base alloys.

*Environmental Considerations* — MP35N has excellent corrosion, crevice corrosion and stress corrosion resistance in seawater. Due to the passivity of MP35N, a galvanically active coating, such as aluminum or cadmium, may be required to prevent galvanic corrosion of aluminum joints. Initial tests have indicated that MP35N does not appear to be susceptible to hydrogen embrittlement.

Short time exposure to temperatures above 700°F causes a decrease in ductility (elongation and reduction of area) at temperature. Mechanical properties at room temperature are not affected significantly by unstressed exposure to temperatures up to 50 degrees below the aging temperature (1000 to 2000°F) for up to 100 hours.

*Heat Treatment* — After work strengthening, MP35N is aged at 1000 to 1200°F for 4 to 4½ hours and air cooled.

Material specifications for MP35N are presented in Table 7.4.1.0(a). The room-temperature mechanical and physical properties for MP35N are presented in Tables 7.4.1.0(b) and (c). The effect of temperature on physical properties is shown in Figure 7.4.1.0.

Table 7.4.1.0(a). Material Specifications for MP35N Alloy

| Specification | Form                                        |
|---------------|---------------------------------------------|
| AMS 5844      | Bar (solution treated, and cold drawn)      |
| AMS 5845      | Bar (solution treated, cold drawn and aged) |

**7.4.1.1 Cold Worked and Aged Condition** — Elevated temperature curves for various mechanical properties are shown in Figures 7.4.1.1.1, 7.4.1.1.4 (a) and (b), and 7.4.1.1.5. Typical tensile stress-strain curves at room and elevated temperatures are shown in Figure 7.4.1.1.6.

**Table 7.4.1.0(b). Design Mechanical and Physical Properties of MP35N Alloy Bar**

|                                      |                                        |             |             |     |
|--------------------------------------|----------------------------------------|-------------|-------------|-----|
| Specification .....                  | AMS 5845                               |             |             |     |
| Form .....                           | Bar                                    |             |             |     |
| Condition .....                      | Solution treated, cold drawn, and aged |             |             |     |
| Diameter, in. <sup>a</sup> .....     | ≤0.800                                 | 0.801-1.000 | 1.001-1.750 |     |
| Basis .....                          | A                                      | B           | S           | S   |
| Mechanical Properties:               |                                        |             |             |     |
| $F_{tu}$ , ksi:                      |                                        |             |             |     |
| L .....                              | 260 <sup>b</sup>                       | 275         | 260         | 260 |
| LT .....                             | ...                                    | ...         | ...         | ... |
| $F_{ty}$ , ksi:                      |                                        |             |             |     |
| L .....                              | 230 <sup>c</sup>                       | 266         | 230         | 230 |
| LT .....                             | ...                                    | ...         | ...         | ... |
| $F_{cy}$ , ksi:                      |                                        |             |             |     |
| L .....                              | ...                                    | ...         | ...         | ... |
| LT .....                             | ...                                    | ...         | ...         | ... |
| $F_{su}$ , ksi .....                 | 145                                    | 147         | 145         | ... |
| $F_{bru}$ , ksi:                     |                                        |             |             |     |
| (e/D = 1.5) .....                    | ...                                    | ...         | ...         | ... |
| (e/D = 2.0) .....                    | ...                                    | ...         | ...         | ... |
| $F_{bry}$ , ksi:                     |                                        |             |             |     |
| (e/D = 1.5) .....                    | ...                                    | ...         | ...         | ... |
| (e/D = 2.0) .....                    | ...                                    | ...         | ...         | ... |
| $e$ , percent (S basis):             |                                        |             |             |     |
| L .....                              | 8                                      | ...         | 8           | 8   |
| $RA$ , percent (S basis):            |                                        |             |             |     |
| L .....                              | 35                                     | ...         | 35          | 35  |
| $E$ , 10 <sup>3</sup> ksi .....      | 34.0                                   |             |             |     |
| $E_c$ , 10 <sup>3</sup> ksi .....    | ...                                    |             |             |     |
| $G$ , 10 <sup>3</sup> ksi .....      | 11.7                                   |             |             |     |
| $\mu$ .....                          | ...                                    |             |             |     |
| Physical Properties:                 |                                        |             |             |     |
| $\omega$ , lb/in. <sup>3</sup> ..... | 0.304                                  |             |             |     |
| $C$ , Btu/(lb)(°F) .....             | 0.18 (32 to 70°F)                      |             |             |     |
| $K$ and $\alpha$ .....               | See Figure 7.4.1.0                     |             |             |     |

a Tensile specimens are located at T/2 location for bars 0.800 inch and under in diameter or distance between parallel sides and at T/4 location of larger size bars. The strength of bar, especially large diameter, may vary significantly from center to surface; consequently, caution should be exercised in machining parts from bars over 0.800 inch in diameter since strengths may be lower than design values depending on depth of material removed from surface.

b The  $T_{99}$  value of 266 ksi is higher than specification minimum.

c The  $T_{99}$  value of 256 ksi is higher than specification minimum.

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 7.4.1.0(c). Design Mechanical and Physical Properties of MP35N Alloy Bar**

|                                      |                                 |             |
|--------------------------------------|---------------------------------|-------------|
| Specification .....                  | AMS 5844                        |             |
| Form .....                           | Bar                             |             |
| Condition .....                      | Solution treated and cold drawn |             |
| Diameter, in. <sup>a</sup> .....     | ≤1.000                          | 1.001-1.750 |
| Basis .....                          | S                               | S           |
| Mechanical Properties:               |                                 |             |
| $F_{tu}$ , ksi:                      |                                 |             |
| L .....                              | 260                             | 260         |
| LT .....                             | ...                             | ...         |
| $F_{ty}$ , ksi:                      |                                 |             |
| L .....                              | 230                             | 230         |
| LT .....                             | ...                             | ...         |
| $F_{cy}$ , ksi:                      |                                 |             |
| L .....                              | ...                             | ...         |
| LT .....                             | ...                             | ...         |
| $F_{su}$ , ksi .....                 | 145                             | ...         |
| $F_{bru}$ , ksi:                     |                                 |             |
| (e/D = 1.5) .....                    | ...                             | ...         |
| (e/D = 2.0) .....                    | ...                             | ...         |
| $F_{bry}$ , ksi:                     |                                 |             |
| (e/D = 1.5) .....                    | ...                             | ...         |
| (e/D = 2.0) .....                    | ...                             | ...         |
| $e$ , percent:                       |                                 |             |
| L .....                              | 8                               | 8           |
| $RA$ , percent:                      |                                 |             |
| L .....                              | 35                              | 35          |
| $E$ , 10 <sup>3</sup> ksi .....      | 34.0                            |             |
| $E_c$ , 10 <sup>3</sup> ksi .....    | ...                             |             |
| $G$ , 10 <sup>3</sup> ksi .....      | 11.7                            |             |
| $\mu$ .....                          | ...                             |             |
| Physical Properties:                 |                                 |             |
| $\omega$ , lb/in. <sup>3</sup> ..... | 0.304                           |             |
| $C$ , Btu/(lb)(°F) .....             | 0.18 (32 to 70°F)               |             |
| $K$ and $\alpha$ .....               | See Figure 7.4.1.0              |             |

a Tensile specimens are located at T/2 location for bars 0.800 inch and under in diameter or distance between parallel sides and at T/4 location for larger size bars. The strength of bar, especially large diameter may vary significantly from center to surface; consequently, caution should be exercised in machining parts from bars over 0.800 inch in diameter since strengths may be lower than design values depending on depth of material removed from surface.

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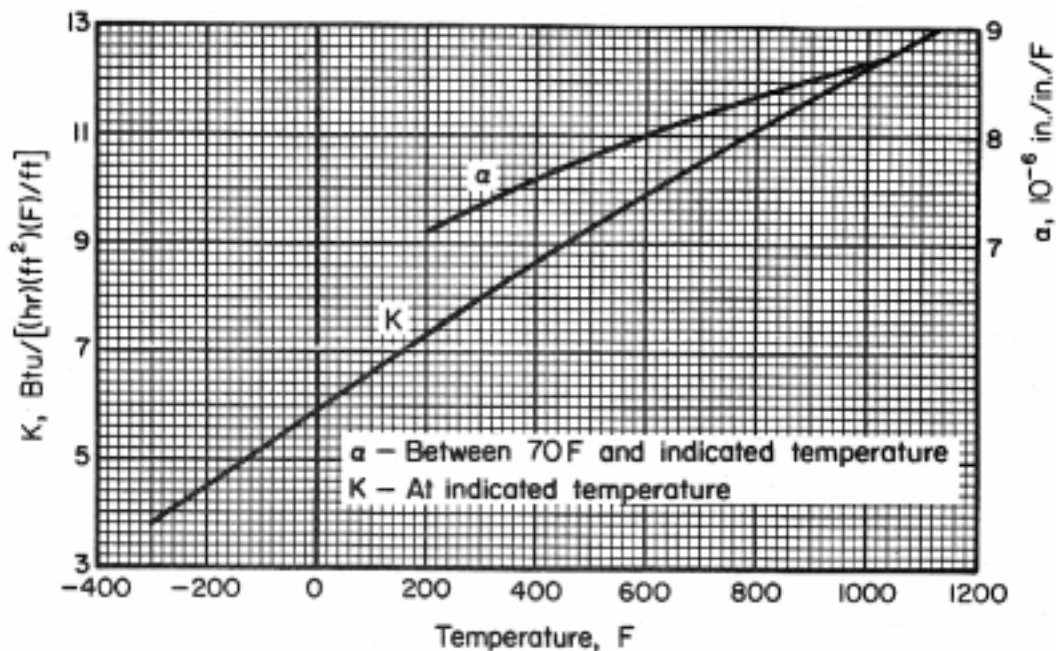


Figure 7.4.1.0. Effect of temperature physical properties of MP35N alloy.

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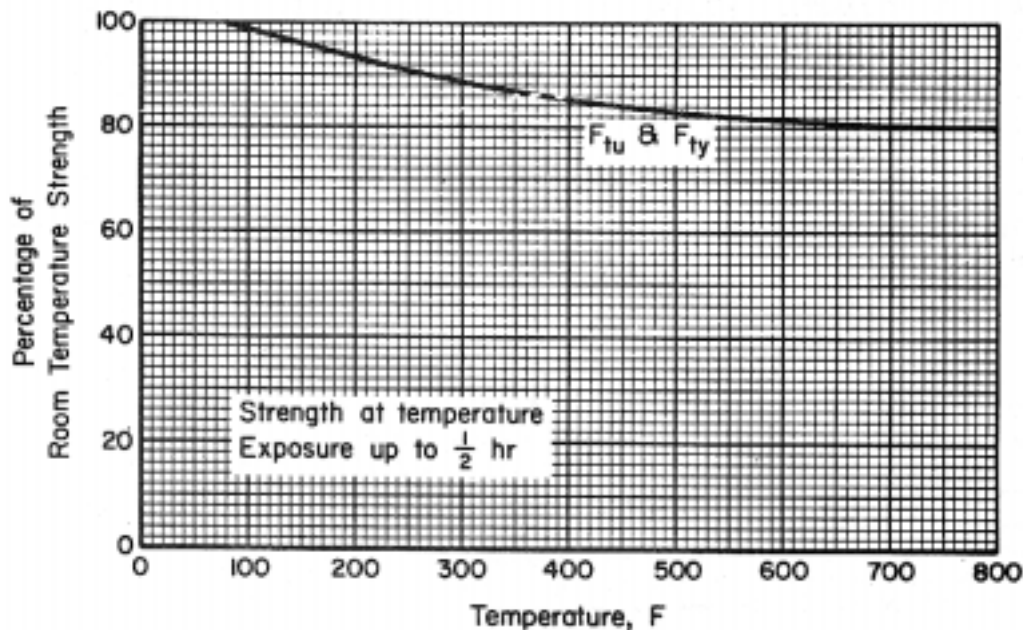


Figure 7.4.1.1.1. Effect of temperature on the tensile ultimate strength ( $F_{tu}$ ) and the tensile yield strength ( $F_{ty}$ ) of cold worked and aged MP35N bar,  $F_{tu} = 260 \text{ ksi}$ .



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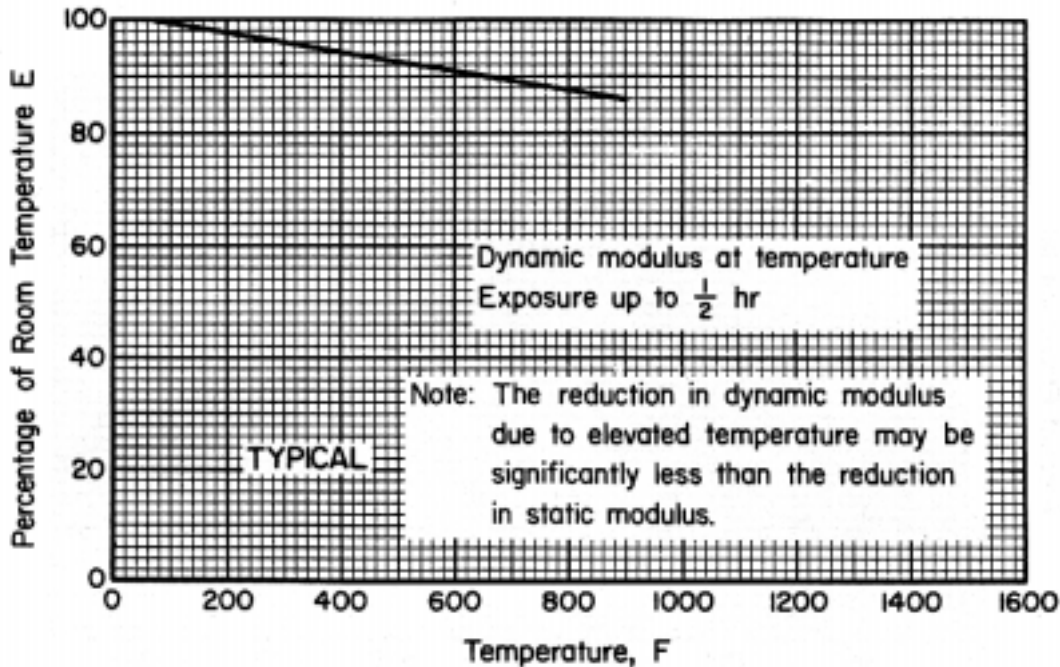


Figure 7.4.1.1.4(a). Effect of temperature on the dynamic tensile modulus (E) of MP35N alloy bar.

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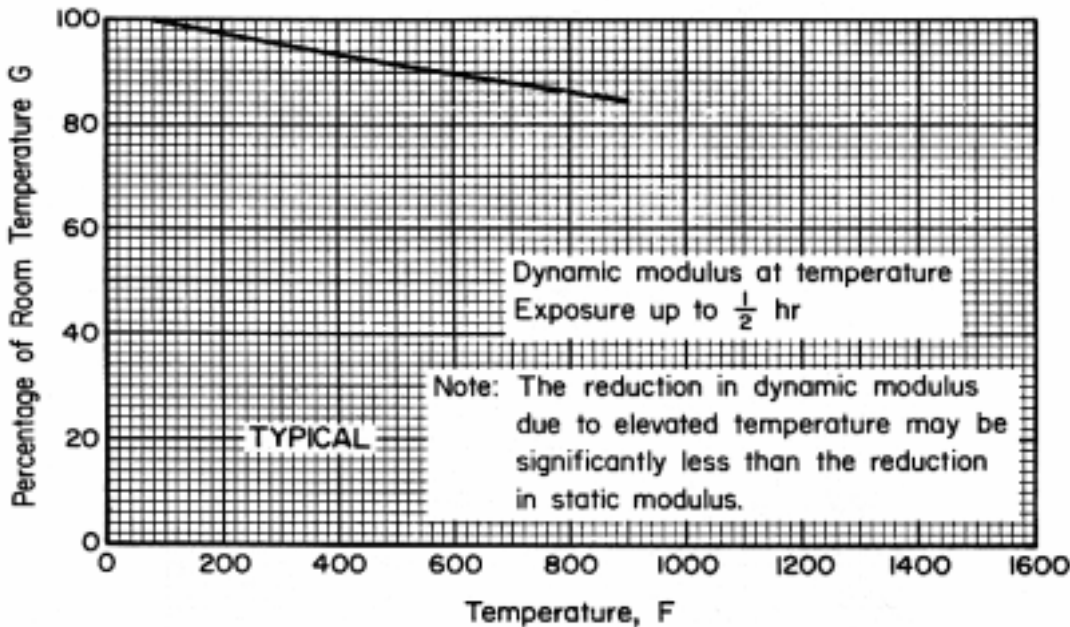


Figure 7.4.1.1.4(b) Effect of temperature on the dynamic shear modulus (G) of MP35N alloy bar.

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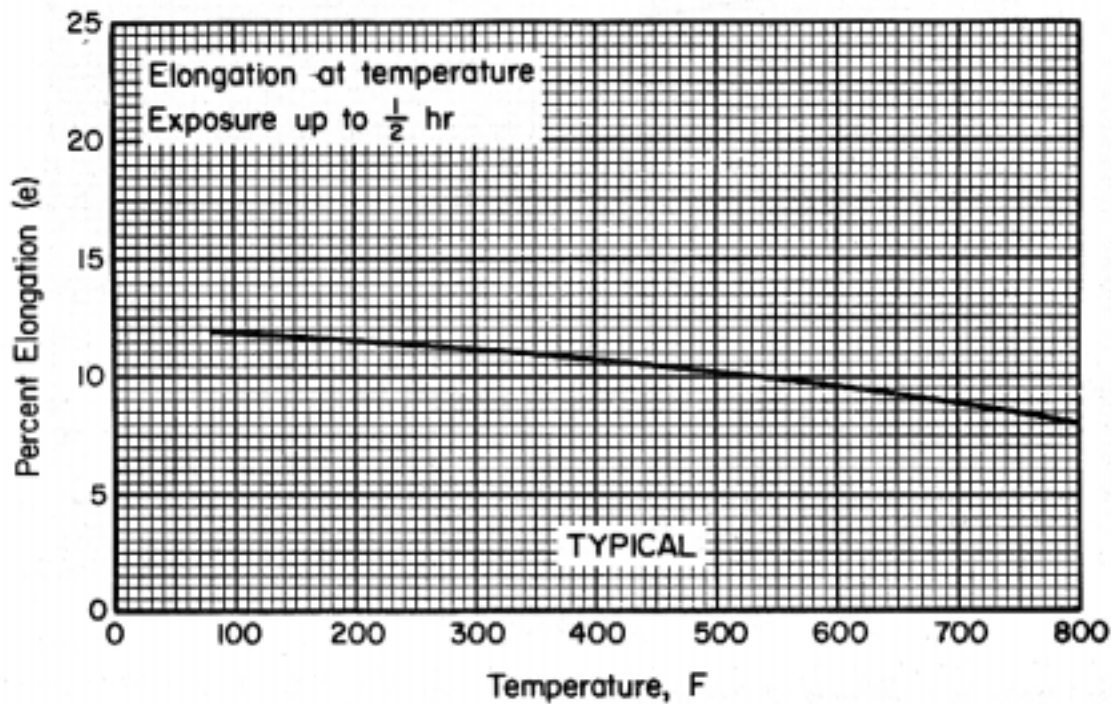


Figure 7.4.1.1.5. Effect of temperature on the elongation (e) of cold worked and aged MP35N bar,  $F_{tu} = 260$  ksi.

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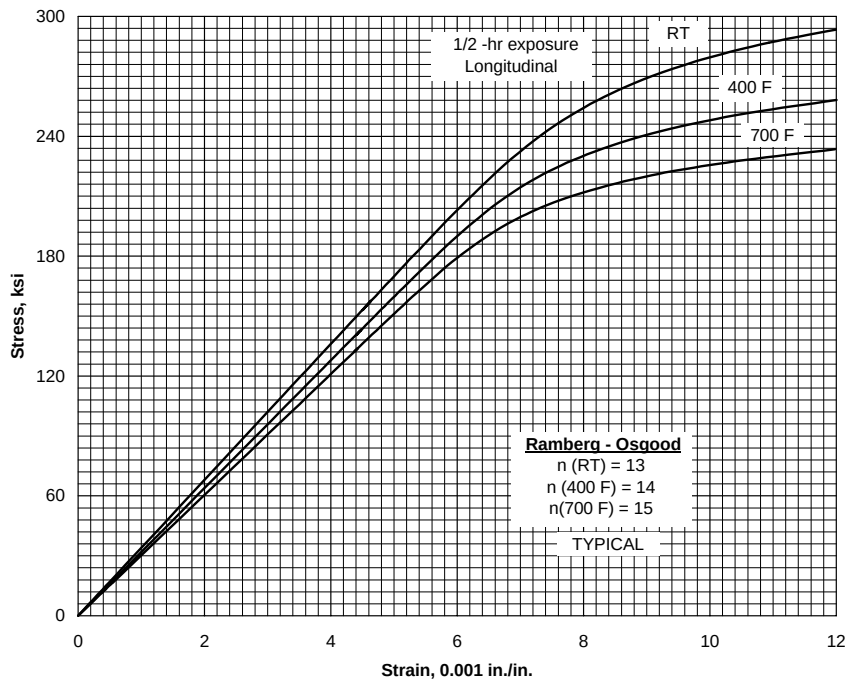


Figure 7.4.1.1.6. Typical tensile stress-strain curves at room and elevated temperatures for cold worked and aged MP35N bar,  $F_{tu} = 260$  ksi.

7.4.2 MP159 ALLOY

**7.4.2.0 Comments and Properties** — MP159 is a vacuum induction, vacuum arc remelted alloy, based on cobalt, nickel, chromium, iron, and molybdenum, which can be work-strengthened and aged to ultrahigh strength. This alloy is suitable for parts requiring ultrahigh strength, good ductility, and excellent corrosion and oxidation resistance up to 1100°F. The alloy maintains its ultrahigh strength very well at temperatures up to 1100°F.

*Manufacturing Considerations* — The work hardening characteristics of MP159 are similar to MP35N and 304 stainless steel. Drawing, swaging, rolling, and shear forming are excellent deforming methods for work strengthening the alloy. The machinability of MP159 is similar to MP35N and the nickel-base alloys.

*Environmental Considerations* — MP159 has excellent corrosion, crevice corrosion, and stress corrosion resistance in various hostile environments. Due to the passivity of MP159, a galvanically active coating, such as aluminum or cadmium, may be required to prevent galvanic corrosion of aluminum joints. Initial tests have indicated that MP159 does not appear to be susceptible to hydrogen embrittlement.

*Heat Treatment* — After work strengthening, MP159 is aged at 1200 to 1250°F ± 25 °F for 4 to 4½ hours and air cooled.

Material specifications for MP159 are presented in Table 7.4.2.0(a). The room temperature mechanical and physical properties for MP159 are presented in Tables 7.4.2.0(b) and (c). The effect of temperature on thermal expansion is shown in Figure 7.4.2.0.

**Table 7.3.1.0(a). Material Specifications for MP159 Alloy**

| Specification | Form                                         |
|---------------|----------------------------------------------|
| AMS 5842      | Bar (solution treated and cold drawn)        |
| AMS 5843      | Bar (solution treated, cold drawn, and aged) |

**7.4.2.1 Cold Worked and Aged Condition** — The effect of temperature on tension modulus of elasticity and shear modulus is presented in Figure 7.4.2.1.4. A typical stress-strain curve at room temperature is shown in Figure 7.4.2.1.6.

**Table 7.4.2.0(b). Design Mechanical and Physical Properties of MP159 Alloy Bar**

|                                                  |                                        |     |                  |     |             |
|--------------------------------------------------|----------------------------------------|-----|------------------|-----|-------------|
| Specification .....                              | AMS 5843                               |     |                  |     |             |
| Form .....                                       | Bar                                    |     |                  |     |             |
| Condition .....                                  | Solution treated, cold drawn, and aged |     |                  |     |             |
| Diameter, in. <sup>a</sup> .....                 | ≤0.500                                 |     | 0.501-0.800      |     | 0.801-1.750 |
| Basis .....                                      | A                                      | B   | A                | B   | S           |
| Mechanical Properties:                           |                                        |     |                  |     |             |
| <i>F<sub>tu</sub></i> , ksi:                     |                                        |     |                  |     |             |
| L .....                                          | 260 <sup>b</sup>                       | 269 | 260 <sup>b</sup> | 269 | 260         |
| LT .....                                         | ...                                    | ... | ...              | ... | ...         |
| <i>F<sub>ty</sub></i> , ksi:                     |                                        |     |                  |     |             |
| L .....                                          | 250 <sup>c</sup>                       | 262 | 250 <sup>c</sup> | 262 | 250         |
| LT .....                                         | ...                                    | ... | ...              | ... | ...         |
| <i>F<sub>cy</sub></i> , ksi:                     |                                        |     |                  |     |             |
| L .....                                          | ...                                    | ... | ...              | ... | ...         |
| LT .....                                         | ...                                    | ... | ...              | ... | ...         |
| <i>F<sub>su</sub></i> , ksi .....                | 131                                    | 144 | ...              | ... | ...         |
| <i>F<sub>bru</sub></i> , ksi:                    |                                        |     |                  |     |             |
| (e/D = 1.5) .....                                | ...                                    | ... | ...              | ... | ...         |
| (e/D = 2.0) .....                                | ...                                    | ... | ...              | ... | ...         |
| <i>F<sub>brp</sub></i> , ksi:                    |                                        |     |                  |     |             |
| (e/D = 1.5) .....                                | ...                                    | ... | ...              | ... | ...         |
| (e/D = 2.0) .....                                | ...                                    | ... | ...              | ... | ...         |
| <i>e</i> , percent (S basis):                    |                                        |     |                  |     |             |
| L .....                                          | 6                                      | ... | 6                | ... | 6           |
| <i>RA</i> , percent (S basis):                   |                                        |     |                  |     |             |
| L .....                                          | 32                                     | ... | 32               | ... | 32          |
| <i>E</i> , 10 <sup>3</sup> ksi .....             | 35.3                                   |     |                  |     |             |
| <i>E<sub>c</sub></i> , 10 <sup>3</sup> ksi ..... | ...                                    |     |                  |     |             |
| <i>G</i> , 10 <sup>3</sup> ksi .....             | 11.3                                   |     |                  |     |             |
| <i>μ</i> .....                                   | 0.37 (solution treated condition)      |     |                  |     |             |
| Physical Properties:                             |                                        |     |                  |     |             |
| <i>ω</i> , lb/in. <sup>3</sup> .....             | 0.302                                  |     |                  |     |             |
| <i>C</i> and <i>K</i> .....                      | ...                                    |     |                  |     |             |
| <i>α</i> , 10 <sup>-6</sup> in./in./°F .....     | See Figure 7.4.2.0                     |     |                  |     |             |

a Tensile specimens are located at T/2 location for bars 0.800 inch and under in diameter or distance between parallel sides and at T/4 location for larger size bars. The strength of bar, especially large diameter, may vary machining parts from bars over 0.800-inch in diameter since strengths may be lower than design values depending on depth of material removed from surface.

b S-Basis. The rounded *T<sub>99</sub>* value of 265 ksi is higher than specification minimum.

c S-Basis. The rounded *T<sub>99</sub>* value of 253 ksi is higher than specification minimum.

[Interactive Table - Design Properties](#)

[Interactive Table - Typical Properties](#)

**Table 7.4.2.0(c). Design Mechanical and Physical Properties of MP159 Alloy Bar**

|                                              |                                        |             |
|----------------------------------------------|----------------------------------------|-------------|
| Specification .....                          | AMS 5842                               |             |
| Form .....                                   | Bar                                    |             |
| Condition .....                              | Solution treated, cold drawn, and aged |             |
| Diameter, in. <sup>a</sup> .....             | ≤0.500                                 | 0.501-1.750 |
| Basis .....                                  | S                                      | S           |
| Mechanical Properties:                       |                                        |             |
| $F_{tw}$ , ksi:                              |                                        |             |
| L .....                                      | 260                                    | 260         |
| LT .....                                     | ...                                    | ...         |
| $F_{ty}$ , ksi:                              |                                        |             |
| L .....                                      | 250                                    | 250         |
| LT .....                                     | ...                                    | ...         |
| $F_{cy}$ , ksi:                              |                                        |             |
| L .....                                      | ...                                    | ...         |
| LT .....                                     | ...                                    | ...         |
| $F_{su}$ , ksi .....                         | 131                                    | ...         |
| $F_{bru}$ , ksi:                             |                                        |             |
| (e/D = 1.5) .....                            | ...                                    | ...         |
| (e/D = 2.0) .....                            | ...                                    | ...         |
| $F_{bry}$ , ksi:                             |                                        |             |
| (e/D = 1.5) .....                            | ...                                    | ...         |
| (e/D = 2.0) .....                            | ...                                    | ...         |
| $e$ , percent:                               |                                        |             |
| L .....                                      | 6                                      | 6           |
| $RA$ , percent:                              |                                        |             |
| L .....                                      | 32                                     | 32          |
| $E$ , 10 <sup>3</sup> ksi .....              | 35.3                                   |             |
| $E_c$ , 10 <sup>3</sup> ksi .....            | ...                                    |             |
| $G$ , 10 <sup>3</sup> ksi .....              | 11.3                                   |             |
| $\mu$ .....                                  | 0.37 (solution treated condition)      |             |
| Physical Properties:                         |                                        |             |
| $\omega$ , lb/in. <sup>3</sup> .....         | 0.302                                  |             |
| $C$ and $K$ .....                            | ...                                    |             |
| $\alpha$ , 10 <sup>-6</sup> in./in./°F ..... | See Figure 7.4.2.0                     |             |

a Tensile specimens are located at T/2 location for bars 0.800 inch and under in diameter or distance between parallel sides and at T/4 location for larger size bars. The strength of bar, especially large diameter may vary significantly from center to surface; consequently, caution should be exercised in machining parts from bars over 0.800 inch in diameter since strengths may be lower than design values depending on depth of material removed from surface.



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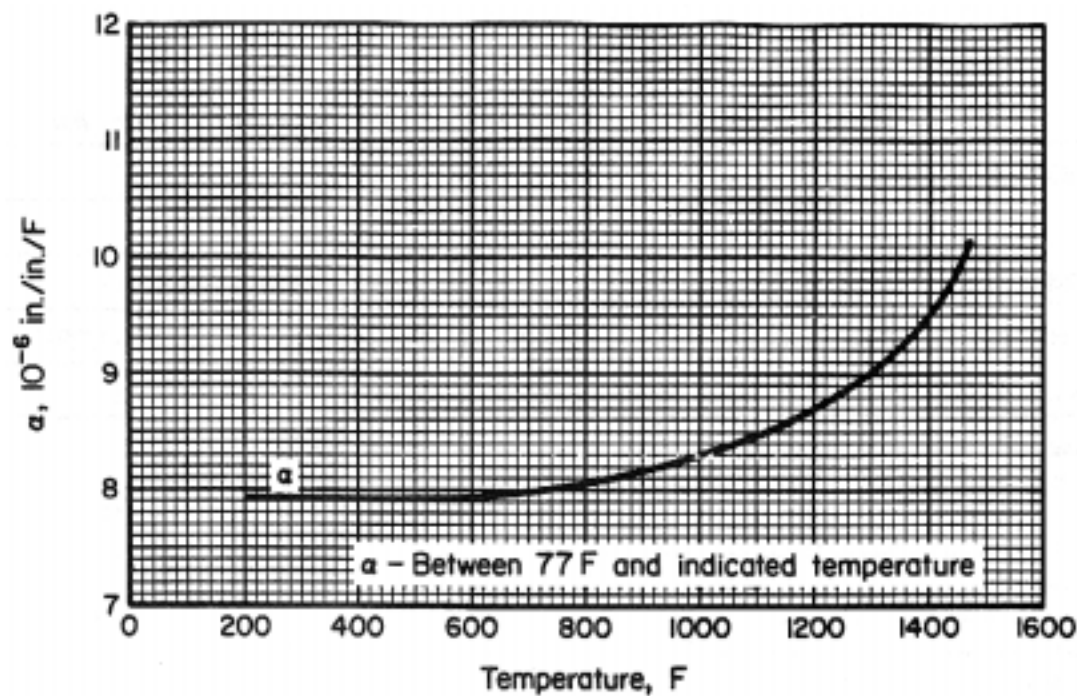


Figure 7.4.2.0. Effect of temperature on thermal expansion ( $\alpha$ ) of MP159 alloy bar.

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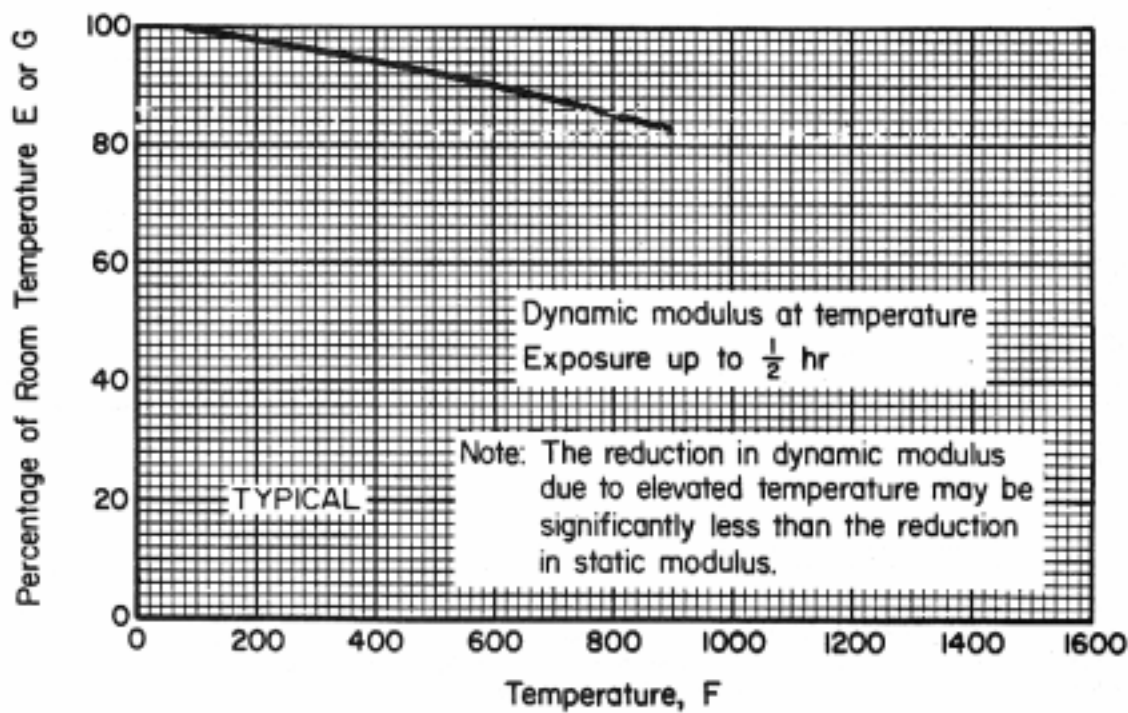


Figure 7.4.2.1.4. Effect of temperature on tensile modulus (E) and shear modulus (G) of MP159 alloy bar.

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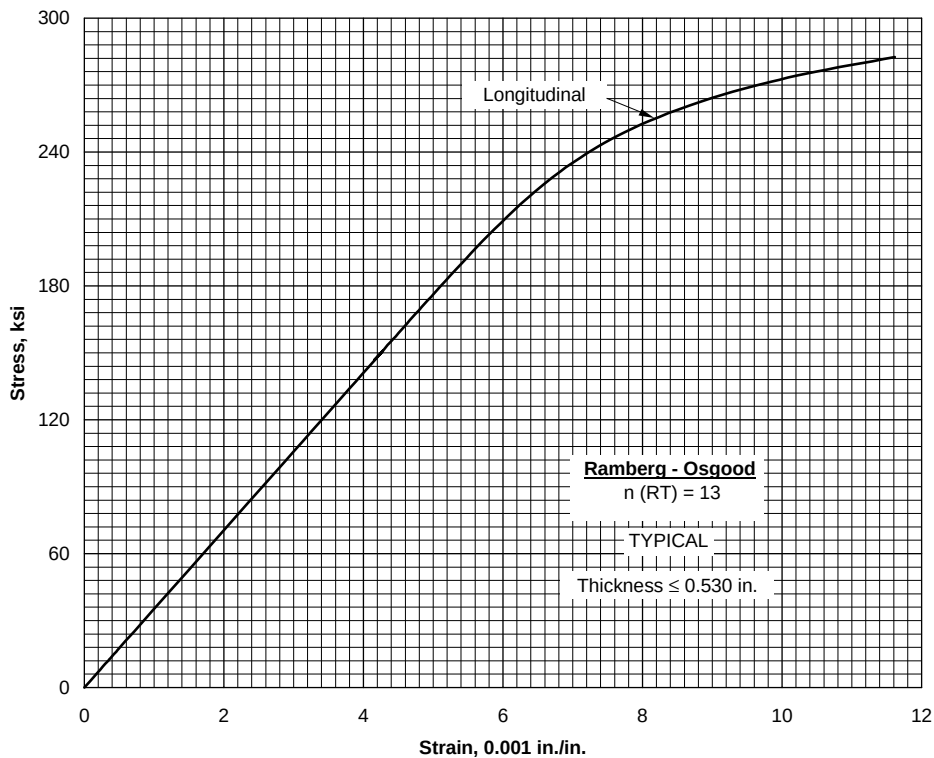


Figure 7.4.2.1.6. Typical tensile stress-strain curve at room temperature for cold worked and aged MP159 alloy bar.

## 7.5 ALUMINUM ALLOYS SHEET LAMINATES

### 7.5.0 GENERAL

This section contains the engineering properties of aluminum alloy sheet laminates. These products consist of thin high-strength aluminum alloy sheets alternating with fiber layers impregnated with adhesive. These sheet laminates provide a very efficient structure for certain applications and exhibit excellent fatigue resistance.

Tensile and compressive properties for the aluminum alloy sheet laminates were determined using test specimens similar to those used for testing conventional aluminum alloy sheet with one exception. The Iosipescu shear specimen was the most appropriate configuration for the determination of shear strength. Shear yield strength and shear ultimate strength were determined using the Iosipescu test procedure. Shear yield strength was determined at 0.2% offset from load-deformation curves. Bearing tests were conducted according to ASTM E 238, which is applicable to conventional aluminum alloy products. Bearing specimens exhibited several different types of failure and bearing strength was influenced by failure mode. Consequently, a more suitable bearing test procedure for aramid fiber reinforced aluminum alloy sheet laminates is currently being developed. However, the design values for bearing strength determined according to ASTM E 238 are conservative and are considered suitable for design. These sheet laminates exhibit low elongation as measured by the tensile test. Consequently, a more realistic measure of ductility is total strain at failure,  $\epsilon_v$ , defined as the measure of strain determined from the tensile load-deformation curve at specimen failure. This measurement includes both elastic and plastic strains. The minimum total strain at failure value from the material specification shall be presented in the room temperature design allowable table. These sheet laminates are generally anisotropic. Therefore, design values for each grain orientation of the aluminum alloy sheet shall be presented for all mechanical properties, except  $F_{su}$  and  $F_{sy}$ . The longitudinal direction is parallel to the rolling direction of the aluminum alloy sheet or length of sheet laminate, while the long transverse direction is  $90^\circ$  to the longitudinal direction or parallel to the width of the sheet laminate. The design values for  $F_{cy}$ ,  $F_{sy}$ ,  $F_{su}$ ,  $F_{bry}$ , and  $F_{bru}$  were derived conventionally in accordance with the guidelines.

### 7.5.1 2024-T3 ARAMID FIBER REINFORCED SHEET LAMINATE

**7.5.1.0 Comments and Properties** — This product consists of thin 2024-T3 sheets alternating with aramid fiber layers embedded in a special resin. Nominal thickness of aluminum sheet is 0.012 inch with a prepreg nominal thickness of 0.0085 inch. The primary advantage of this product is the significant improvement in fatigue and fatigue crack growth properties compared to conventional aluminum alloy structures. The product also has good damping capacity and resistance to impact. Compared to 7475-T761 aramid fiber-reinforced sheet laminate, this product has better formability and damage tolerance characteristics.

*Manufacturing Considerations* — This product can be fabricated by conventional metal practices for machining, sawing, drilling, joining with fasteners and can be inspected by conventional procedures.

*Environmental Considerations* — This product has good corrosion resistance. The maximum service temperature is  $200^\circ\text{F}$ .

*Specification and Properties* — A material specification is presented in Table 7.5.1.0(a). Room-temperature mechanical properties are presented in Table 7.5.1.0(b).



**Table 7.5.1.0(a). Material Specification for 2024-T3  
Aramid Fiber Reinforced Sheet Laminate**

| Specification | Form           |
|---------------|----------------|
| AMS 4254      | Sheet laminate |

**7.5.1.5 T3 Temper** — Typical tensile and compressive stress-strain and tangent-modulus curves are shown in Figures 7.5.1.1.6(a) through (l).

**Table 7.5.1.0(b). Design Mechanical and Physical Properties of 2024-T3 Aluminum Alloy, Aramid Fiber Reinforced, Sheet Laminate**

|                                      |                                        |       |       |       |
|--------------------------------------|----------------------------------------|-------|-------|-------|
| Specification .....                  | AMS 4254                               |       |       |       |
| Form .....                           | Aramid fiber reinforced sheet laminate |       |       |       |
| Laminate lay-up .....                | 2/1                                    | 3/2   | 4/3   | 5/4   |
| Nominal thickness, in. ....          | 0.032                                  | 0.053 | 0.074 | 0.094 |
| Basis .....                          | S                                      | S     | S     | S     |
| Mechanical Properties:               |                                        |       |       |       |
| $F_{tu}$ , ksi:                      |                                        |       |       |       |
| L .....                              | 90                                     | 96    | 101   | 101   |
| LT .....                             | 48                                     | 44    | 43    | 42    |
| $F_{ty}$ , ksi:                      |                                        |       |       |       |
| L .....                              | 48                                     | 49    | 49    | 49    |
| LT .....                             | 33                                     | 30    | 30    | 30    |
| $F_{cy}$ , ksi:                      |                                        |       |       |       |
| L .....                              | 35                                     | 35    | 34    | 33    |
| LT .....                             | 33                                     | 30    | 30    | 30    |
| $F_{su}^a$ , ksi .....               | b                                      | b     | b     | b     |
| $F_{sy}^a$ , ksi .....               | 16                                     | 15    | 14    | 14    |
| $F_{bru}^c$ , ksi:                   |                                        |       |       |       |
| L (e/D = 1.5) .....                  | 78                                     | 73    | 73    | 68    |
| LT (e/D = 1.5) .....                 | 89                                     | 84    | 80    | 75    |
| L (e/D = 2.0) .....                  | 93                                     | 86    | 83    | 77    |
| LT (e/D = 2.0) .....                 | 95                                     | 89    | 81    | 76    |
| $F_{bry}^c$ , ksi:                   |                                        |       |       |       |
| L (e/D = 1.5) .....                  | 53                                     | 52    | 51    | 50    |
| LT (e/D = 1.5) .....                 | 56                                     | 52    | 52    | 52    |
| L (e/D = 2.0) .....                  | 63                                     | 63    | 61    | 59    |
| LT (e/D = 2.0) .....                 | 66                                     | 61    | 61    | 60    |
| $\epsilon_r^d$ , percent:            |                                        |       |       |       |
| L .....                              | 2                                      | 2     | 2     | 2     |
| LT .....                             | 12                                     | 12    | 12    | 14    |
| $E$ , $10^3$ ksi:                    |                                        |       |       |       |
| L .....                              | 9.9                                    | 9.9   | 9.7   | 9.6   |
| LT .....                             | 8.1                                    | 7.5   | 7.1   | 7.0   |
| $E_c$ , $10^3$ ksi:                  |                                        |       |       |       |
| L .....                              | 9.5                                    | 9.4   | 9.3   | 9.1   |
| LT .....                             | 8.0                                    | 7.5   | 7.2   | 7.0   |
| $G$ , $10^3$ ksi:                    |                                        |       |       |       |
| L .....                              | 2.7                                    | 2.5   | 2.4   | 2.2   |
| LT .....                             | 2.6                                    | 2.4   | 2.4   | 2.2   |
| $\mu$ :                              |                                        |       |       |       |
| L .....                              | 0.33                                   | 0.34  | 0.34  | 0.32  |
| LT .....                             | 0.29                                   | 0.27  | 0.26  | 0.25  |
| Physical Properties:                 |                                        |       |       |       |
| $\omega$ , lb/in. <sup>3</sup> ..... | 0.086                                  | 0.084 | 0.082 | 0.081 |
| C, K, and $\alpha$ .....             | ...                                    | ...   | ...   | ...   |

a Shear values determined from data obtained using Iosipescu shear specimens.  
b Shear ultimate strengths not determinable due to excessive deflection of specimen.  
c Bearing values are “dry pin” values per Section 1.4.7.1 determined in accordance with ASTM E238.  
d Total (elastic plus plastic) strain at failure determined from stress-strain curve.

1 December 1998

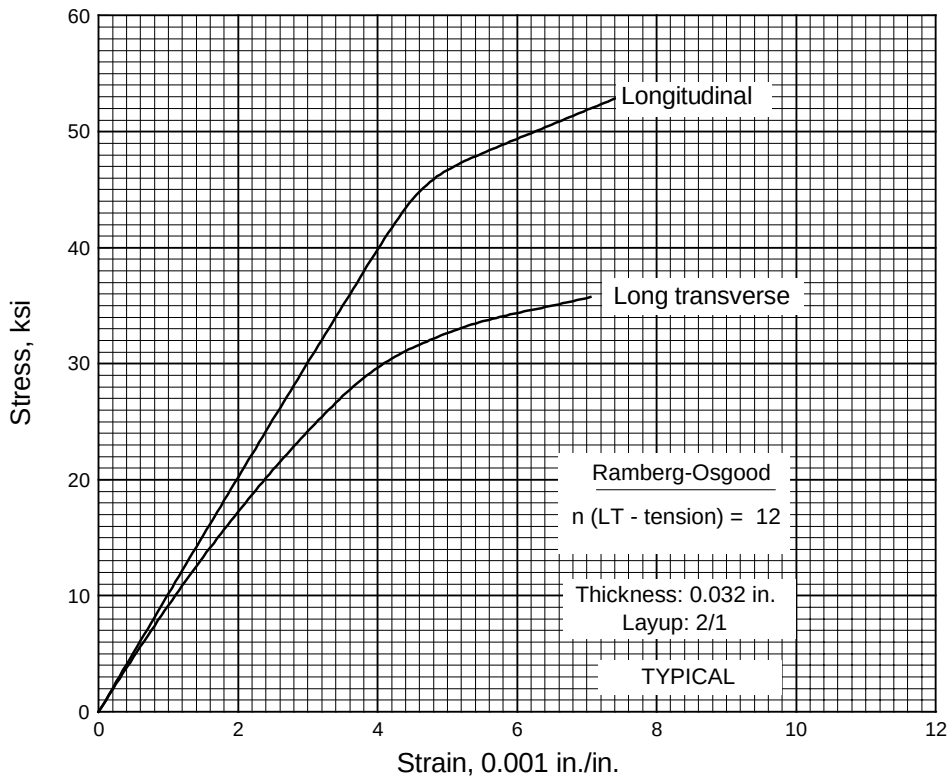
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Figure 7.5.1.1.6(a). Typical tensile stress-strain curves for 2024-T3 aluminum alloy, aramid fiber-reinforced, sheet laminate.

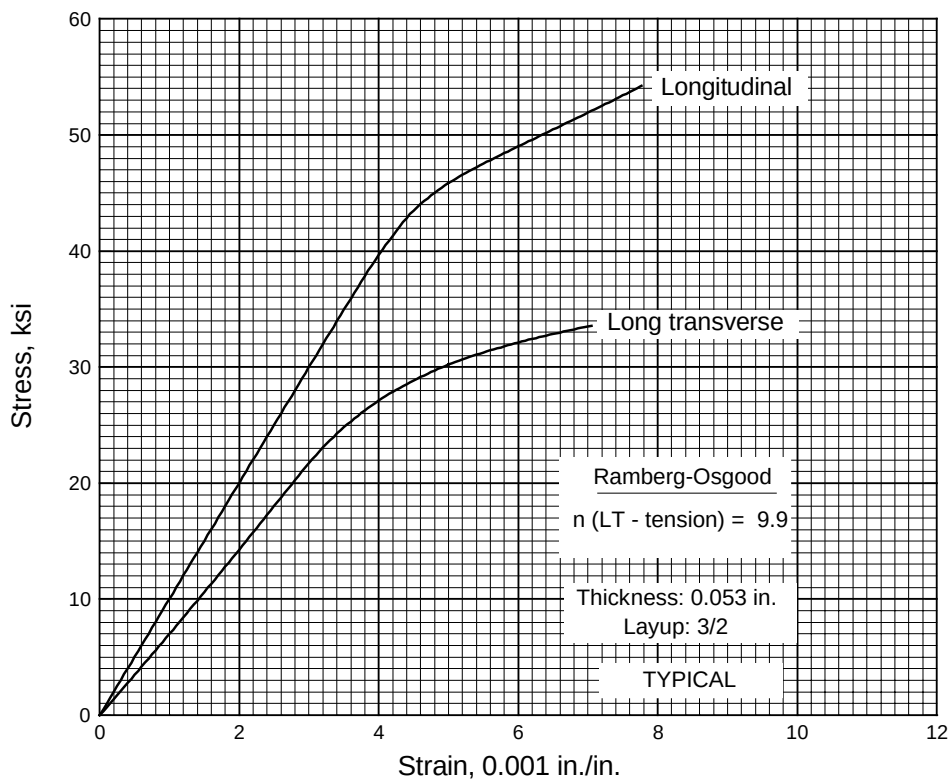
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Figure 7.5.1.1.6(b). Typical tensile stress-strain curves for 2024-T3 aluminum alloy, aramid fiber-reinforced, sheet laminate.

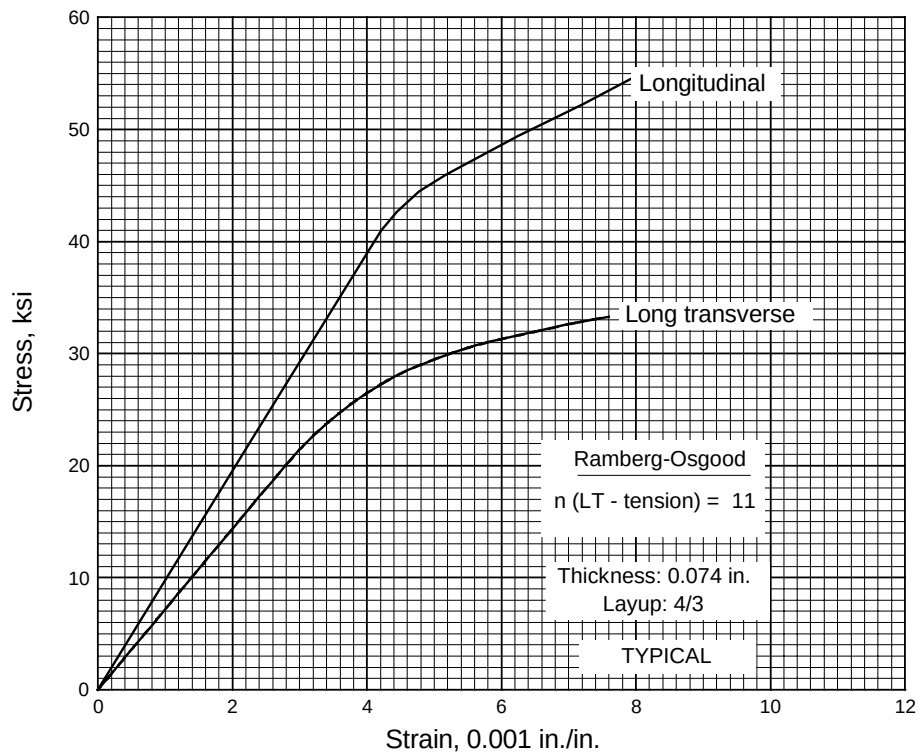


Figure 7.5.1.1.6(c). Typical tensile stress-strain curves for 2024-T3 aluminum alloy, aramid fiber-reinforced, sheet laminate.

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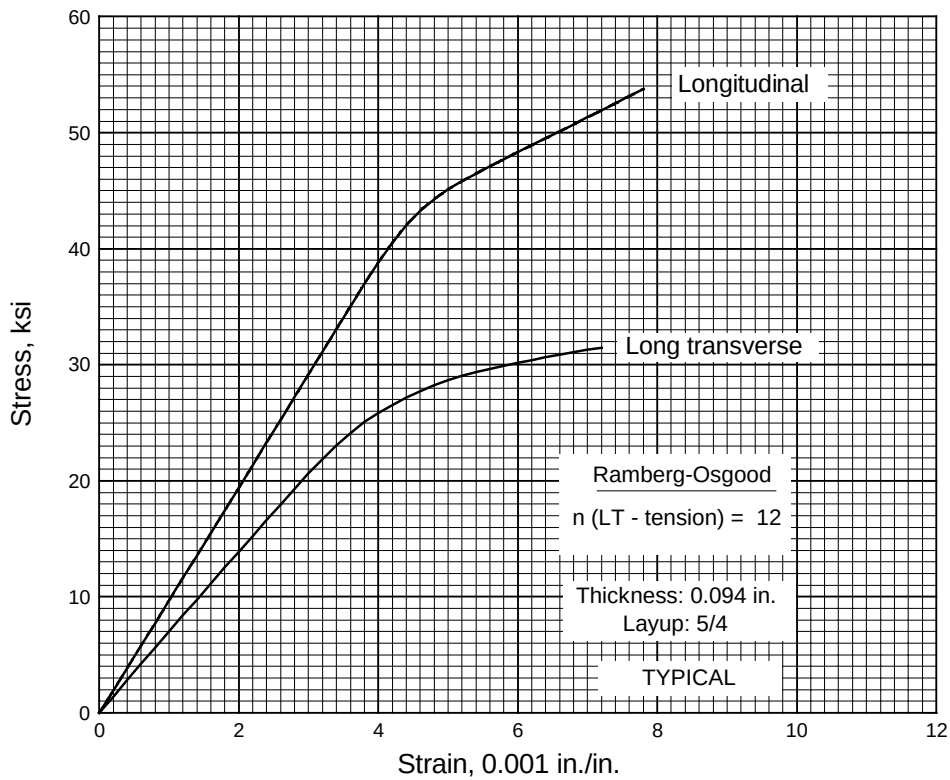


Figure 7.5.1.1.6(d). Typical tensile stress-strain curves for 2024-T3 aluminum alloy, aramid fiber-reinforced, sheet laminate.

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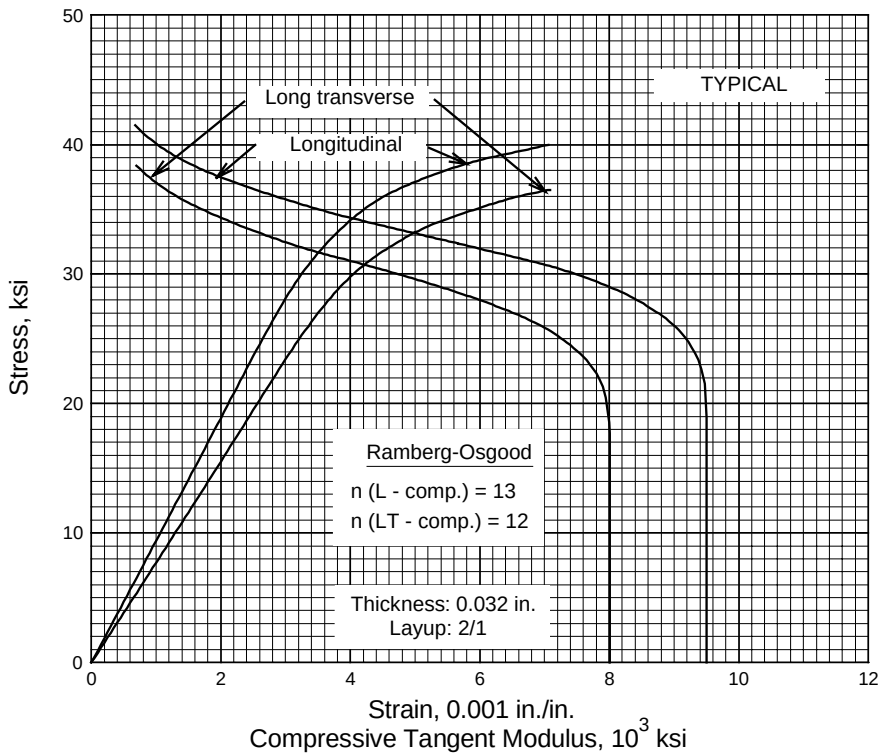


Figure 7.5.1.1.6(e). Typical compressive stress-strain and compressive tangent-modulus curves for 2024-T3 aluminum alloy, aramid fiber-reinforced, sheet laminate.

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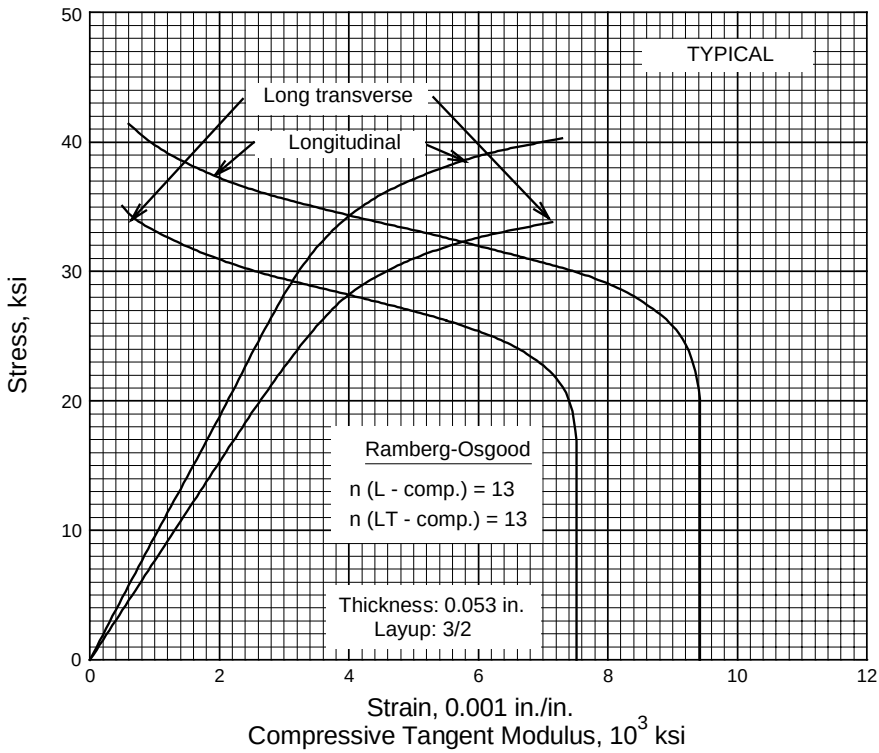


Figure 7.5.1.1.6(f). Typical compressive stress-strain and compressive tangent-modulus curves for 2024-T3 aluminum alloy, aramid fiber-reinforced, sheet laminate.

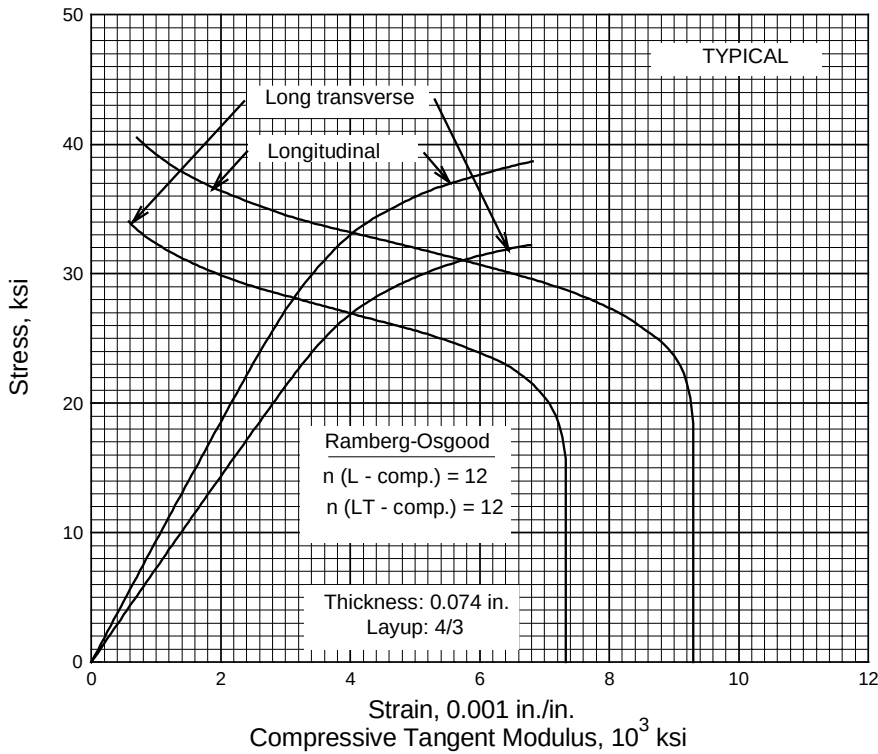


Figure 7.5.1.1.6(g). Typical compressive stress-strain and compressive tangent-modulus curves for 2024-T3 aluminum alloy, aramid fiber-reinforced, sheet laminate.

[VIEW INTERACTIVE GRAPH](#)

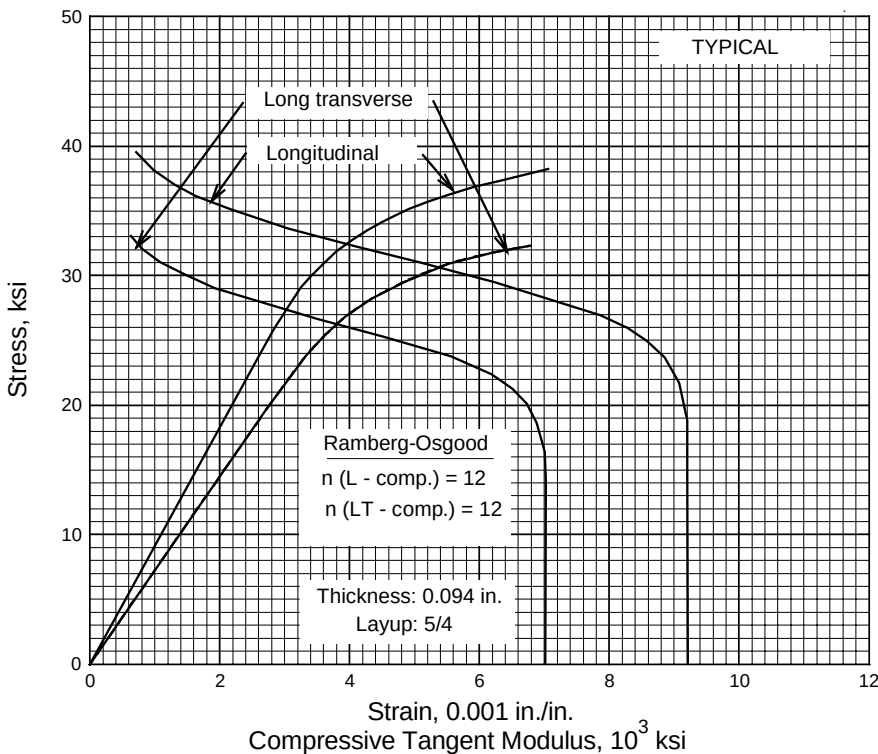


Figure 7.5.1.1.6(h). Typical compressive stress-strain and compressive tangent-modulus curves for 2024-T3 aluminum alloy, aramid fiber-reinforced, sheet laminate.

[VIEW INTERACTIVE GRAPH](#)

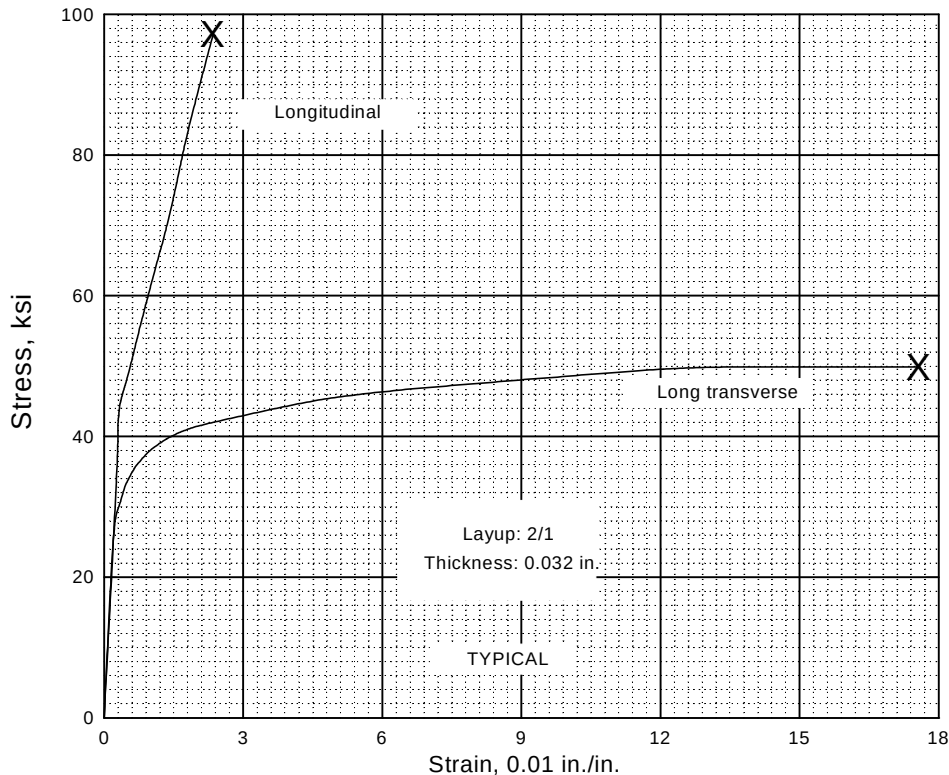


Figure 7.5.1.1.6(i). Typical tensile stress-strain curves (full range) for 2024-T3 aluminum alloy, aramid fiber-reinforced, sheet laminate.

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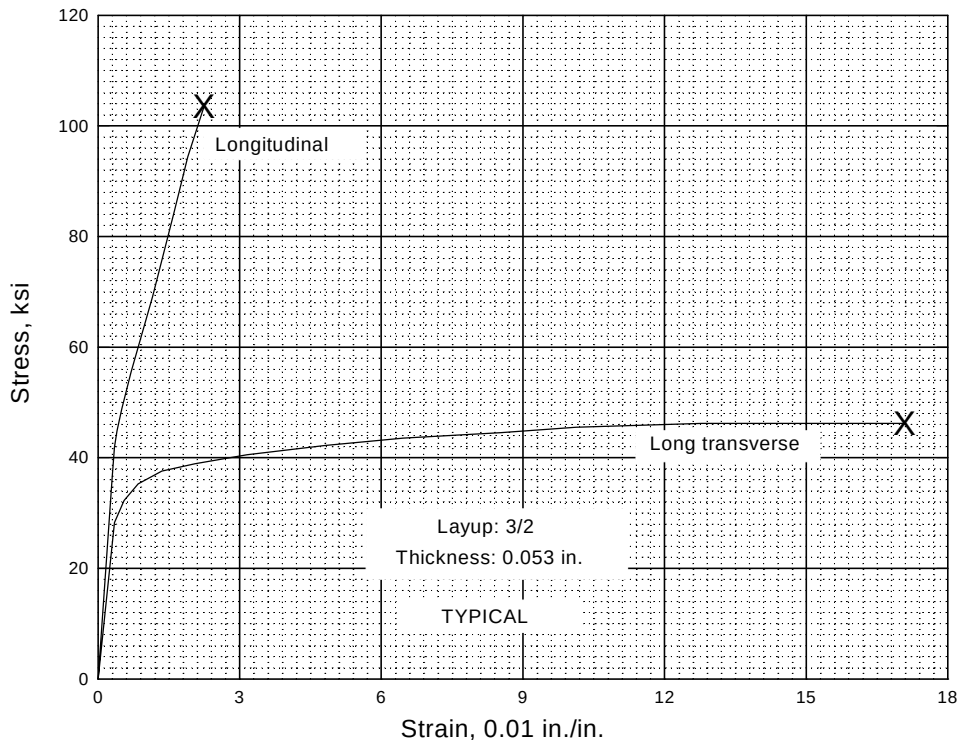


Figure 7.5.1.1.6(j). Typical tensile stress-strain curves (full range) for 2024-T3 aluminum alloy, aramid fiber-reinforced, sheet laminate.

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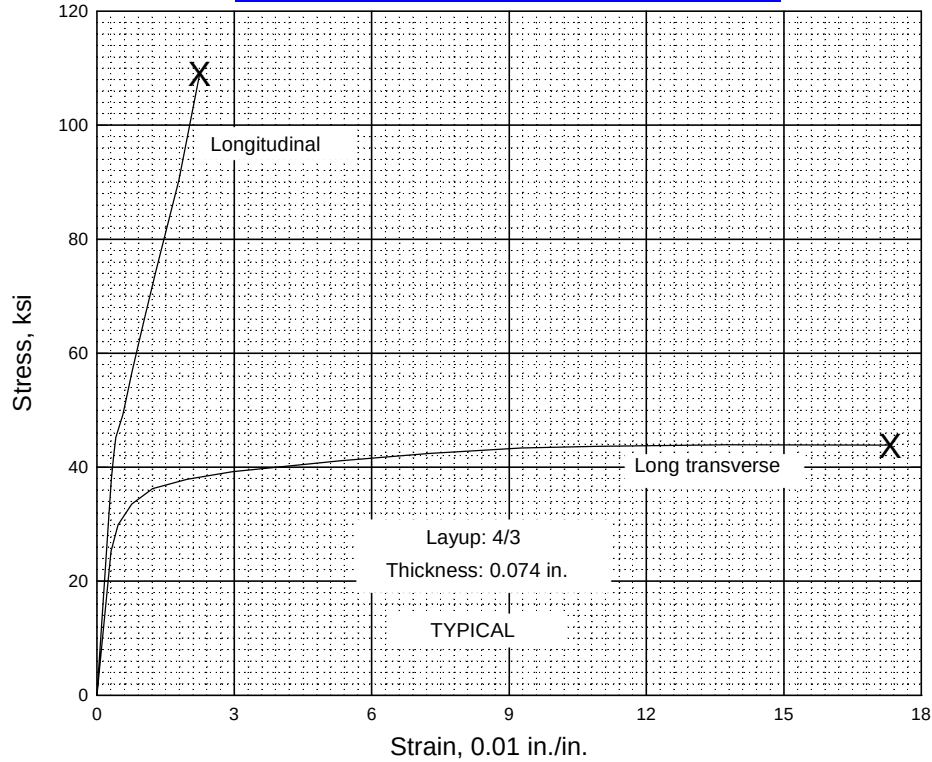


Figure 7.5.1.1.6(k). Typical tensile stress-strain curves (full range) for 2024-T3 aluminum alloy, aramid fiber-reinforced, sheet laminate.

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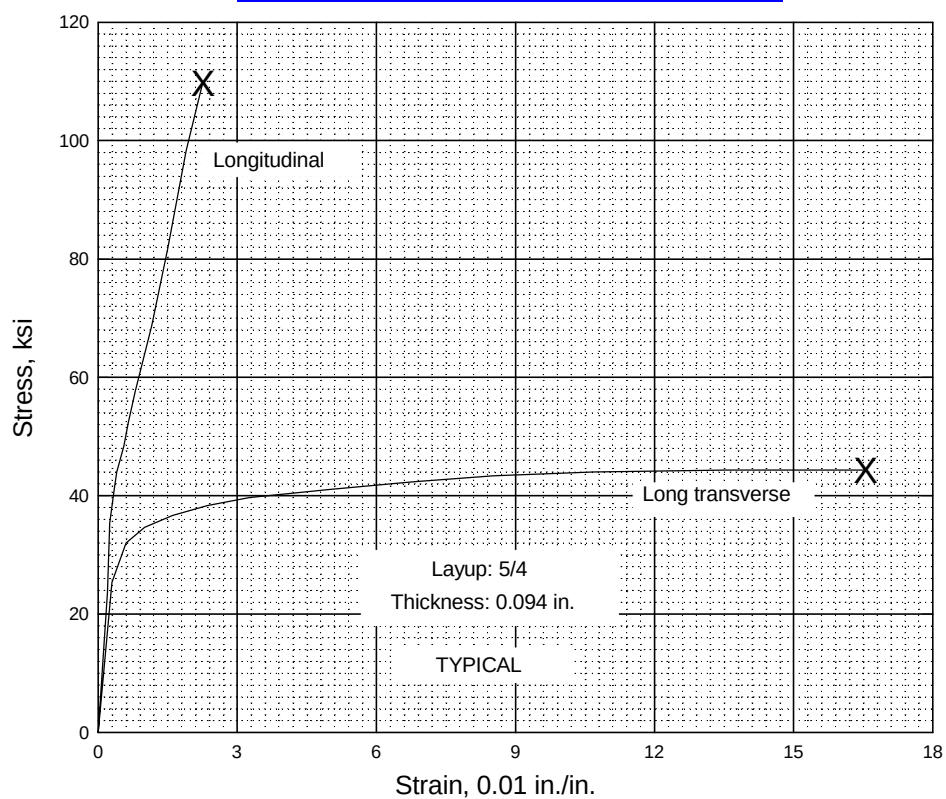


Figure 7.5.1.1.6(l). Typical tensile stress-strain curves (full range) for 2024-T3 aluminum alloy, aramid fiber-reinforced, sheet laminate.



7.5.2 7475-T761 ARAMID FIBER REINFORCED SHEET LAMINATE

**7.5.2.0 Comments and Properties** — This product consists of thin 7475-T761 sheets alternating with aramid fiber layers embedded in a special resin. Nominal thickness of aluminum sheet is 0.012 inch with a prepreg nominal thickness of 0.0085 inch. The primary advantage of this product is the significant improvement in fatigue and fatigue crack growth properties compared to conventional aluminum alloy structures. The product also has good damping capacity and resistance to impact.

*Manufacturing Considerations* — This product can be fabricated by conventional metal practices for machining, sawing, drilling, joining with fasteners and can be inspected by conventional procedures.

*Environmental Considerations* — This product has good corrosion resistance. The maximum service temperature is 200°F.

*Specifications and Properties* — A material specification is presented in Table 7.5.2.0(a). Room-temperature mechanical properties are presented in Table 7.5.2.0(b).

**Table 7.5.2.0(a). Material Specification for 7475-T761  
Aramid Fiber Reinforced Sheet Laminate**

| Specification | Form           |
|---------------|----------------|
| AMS 4302      | Sheet laminate |

**7.5.2.5 T761 Temper** — Tensile and compressive stress-strain and tangent modulus curves are shown in Figures 7.5.2.1.6(a) through (f). Full-range tensile stress-strain curves are presented in Figures 7.5.2.1.6(g) through (j).

**Table 7.5.2.0(b). Design Mechanical and Physical Properties of 7475-T761 Aluminum Alloy, Aramid fiber Reinforced, Sheet Laminate**

|                                      |                                        |       |       |       |
|--------------------------------------|----------------------------------------|-------|-------|-------|
| Specification .....                  | AMS 4302                               |       |       |       |
| Form .....                           | Aramid fiber reinforced sheet laminate |       |       |       |
| Laminate lay-up .....                | 2/1                                    | 3/2   | 4/3   | 5/4   |
| Nominal thickness, in. ...           | 0.032                                  | 0.053 | 0.074 | 0.094 |
| Basis .....                          | S                                      | S     | S     | S     |
| Mechanical Properties:               |                                        |       |       |       |
| $F_{tu}$ , ksi:                      |                                        |       |       |       |
| L .....                              | 103                                    | 111   | 114   | 116   |
| LT .....                             | 56                                     | 51    | 50    | 48    |
| $F_{ty}$ , ksi:                      |                                        |       |       |       |
| L .....                              | 76                                     | 82    | 82    | 84    |
| LT .....                             | 48                                     | 43    | 42    | 40    |
| $F_{cy}$ , ksi:                      |                                        |       |       |       |
| L .....                              | 46                                     | 46    | 44    | 44    |
| LT .....                             | 51                                     | 48    | 47    | 45    |
| $F_{su}^a$ , ksi .....               | 35                                     | 33    | 33    | 32    |
| $F_{sy}^a$ , ksi .....               | 24                                     | 23    | 22    | 21    |
| $F_{bru}^b$ , ksi:                   |                                        |       |       |       |
| L (e/D = 1.5) .....                  | 91                                     | 83    | 84    | 82    |
| LT (e/D = 1.5) .....                 | 96                                     | 85    | 86    | 80    |
| L (e/D = 2.0) .....                  | 104                                    | 87    | 88    | 84    |
| LT (e/D = 2.0) .....                 | 108                                    | 88    | 86    | 80    |
| $F_{bry}^b$ , ksi:                   |                                        |       |       |       |
| L (e/D = 1.5) .....                  | 73                                     | 70    | 66    | 69    |
| LT (e/D = 1.5) .....                 | 76                                     | 69    | 69    | 67    |
| L (e/D = 2.0) .....                  | 83                                     | 81    | 77    | 79    |
| LT (e/D = 2.0) .....                 | 84                                     | 76    | 75    | 72    |
| $e_t^c$ , percent:                   |                                        |       |       |       |
| L .....                              | 1.5                                    | 1.8   | 1.7   | 1.8   |
| LT .....                             | 6.1                                    | 6.4   | 6.3   | 6.6   |
| $E$ , $10^3$ ksi:                    |                                        |       |       |       |
| L .....                              | 9.8                                    | 9.9   | 10.0  | 9.8   |
| LT .....                             | 7.7                                    | 7.1   | 6.7   | 6.7   |
| $E_c$ , $10^3$ ksi:                  |                                        |       |       |       |
| L .....                              | 9.6                                    | 9.6   | 9.6   | 9.7   |
| LT .....                             | 7.8                                    | 7.3   | 7.0   | 6.9   |
| $G$ , $10^3$ ksi:                    |                                        |       |       |       |
| L .....                              | 2.8                                    | 2.6   | 2.3   | 2.3   |
| LT .....                             | 2.6                                    | 2.4   | 2.3   | 2.3   |
| $\mu$ :                              |                                        |       |       |       |
| L .....                              | 0.35                                   | 0.35  | 0.35  | 0.35  |
| LT .....                             | 0.25                                   | 0.25  | 0.25  | 0.25  |
| Physical Properties:                 |                                        |       |       |       |
| $\omega$ , lb/in. <sup>3</sup> ..... | 0.085                                  | 0.083 | 0.082 | 0.081 |
| $C$ , $K$ , and $\alpha$ .....       | ...                                    | ...   | ...   | ...   |

a Shear values determined from data obtained using Iosipescu shear specimens.  
b Bearing values are “dry pin” values per Section 1.4.7.1 determined in accordance with ASTM E 238.  
c Total (elastic plus plastic) strain at failure determined from stress-strain curve. Values are minimum but not included in AMS 4302.

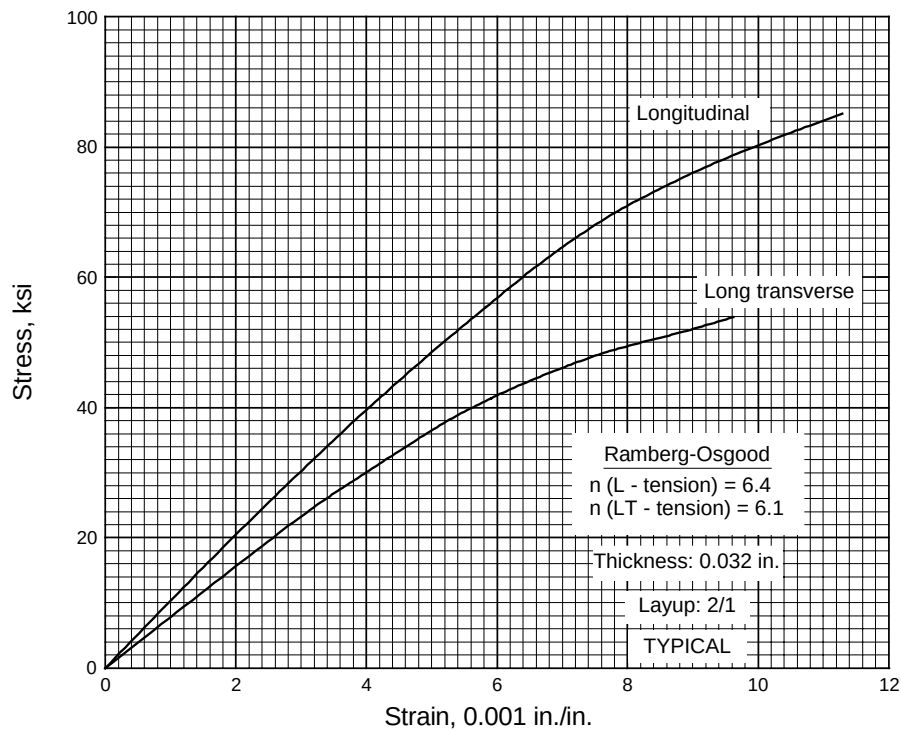


Figure 7.5.2.1.6(a). Typical tensile stress-strain curves for 7475-T761 aluminum alloy, aramid fiber-reinforced, sheet laminate.

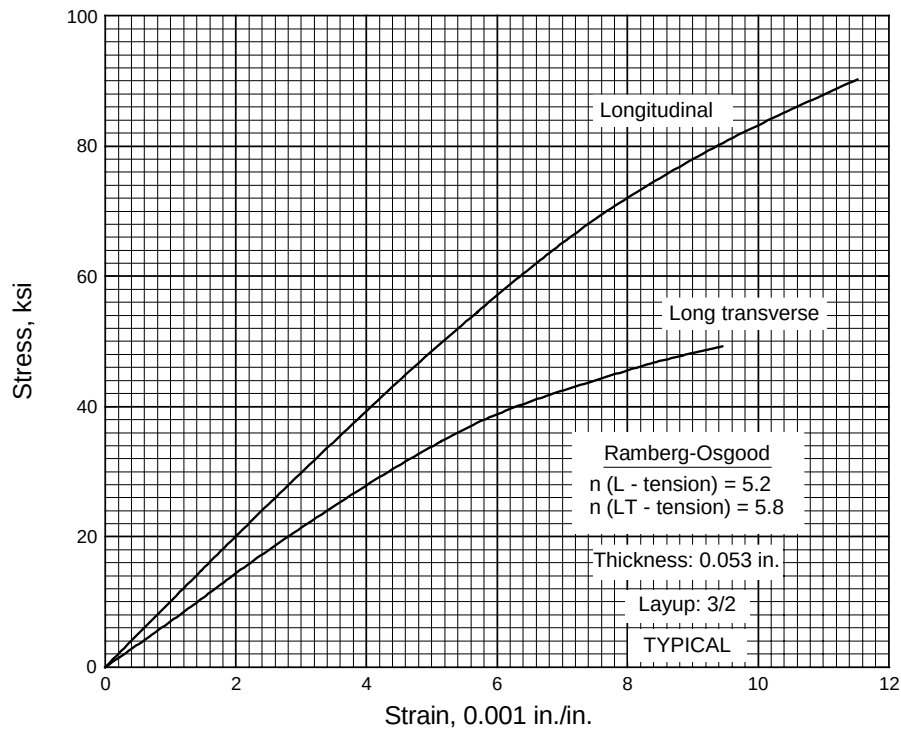


Figure 7.5.2.1.6(b). Typical tensile stress-strain curves for 7475-T761 aluminum alloy, aramid fiber-reinforced, sheet laminate.

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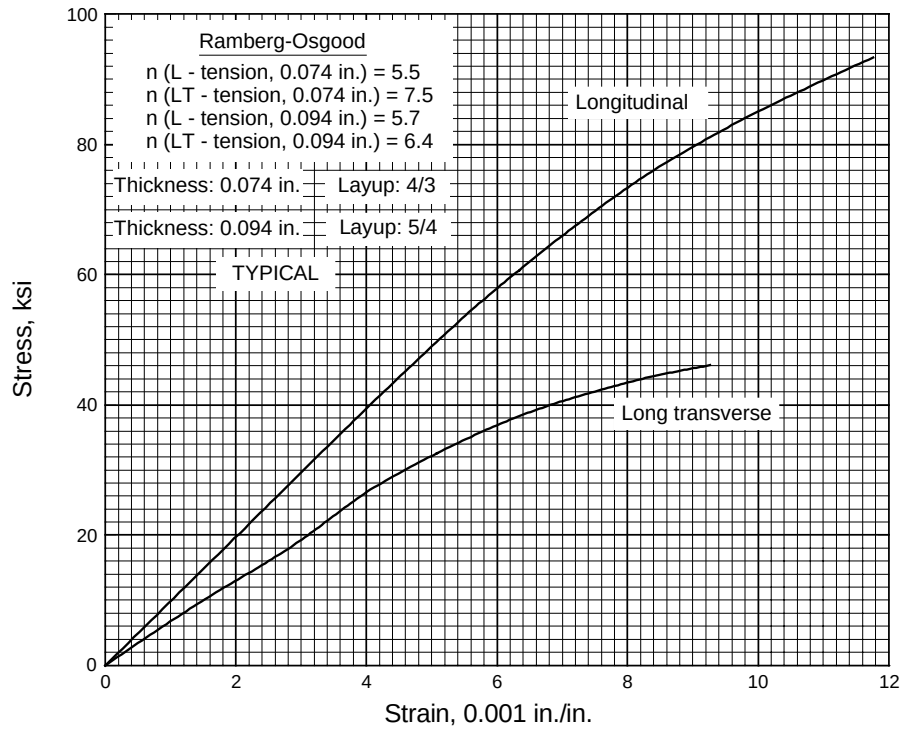


Figure 7.5.2.1.6(c). Typical tensile stress-strain curves for 7475-T761 aluminum alloy, aramid fiber-reinforced, sheet laminate.

[VIEW INTERACTIVE GRAPH](#)

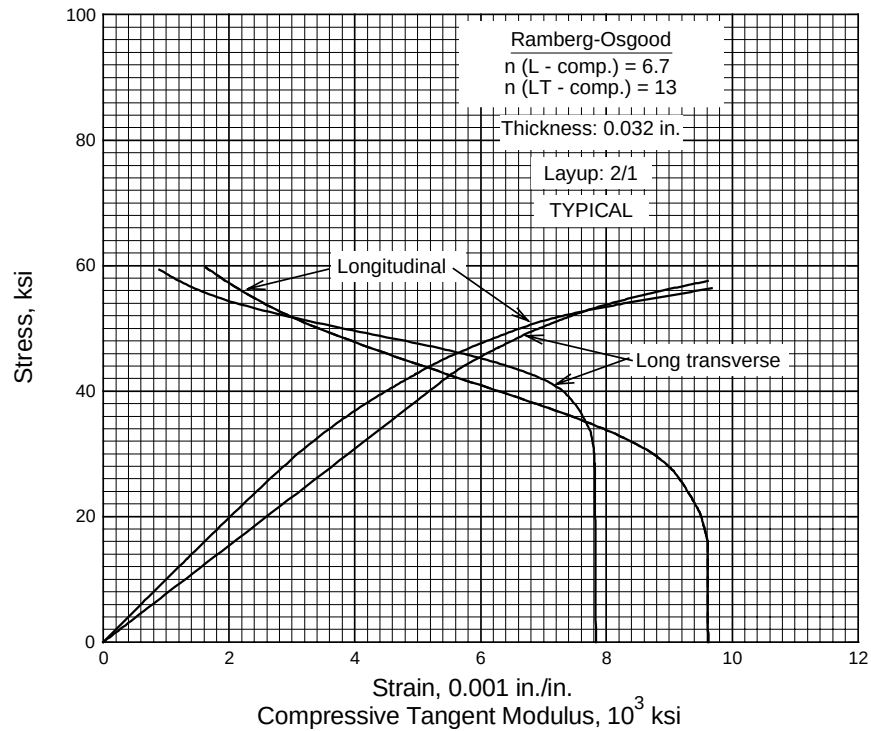


Figure 7.5.2.1.6(d). Typical compressive stress-strain and compressive tangent-modulus curves for 7475-T761 aluminum alloy, aramid fiber-reinforced, sheet laminate.

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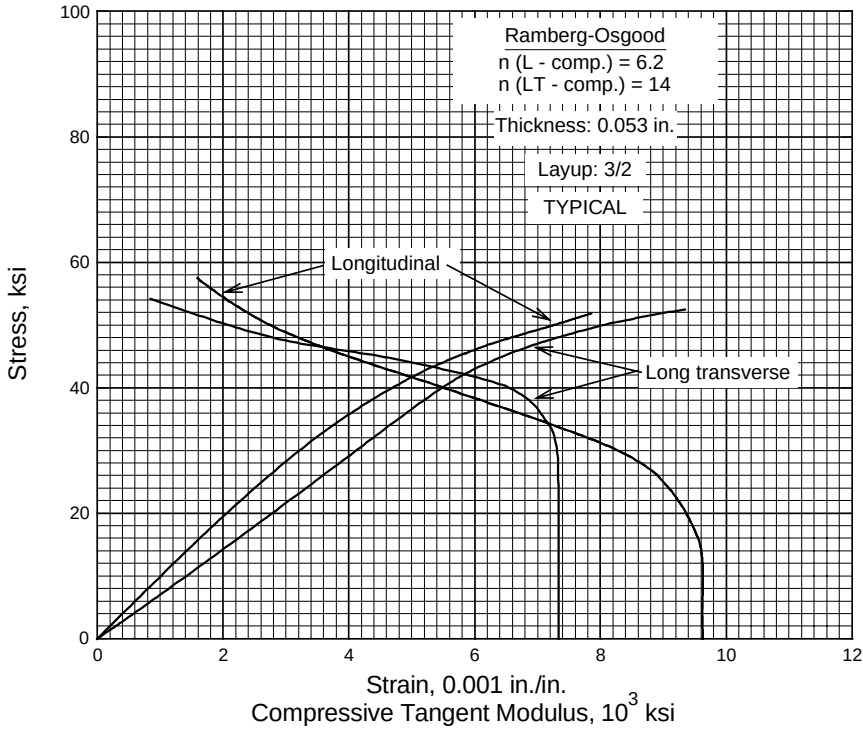


Figure 7.5.2.1.6(e). Typical compressive stress-strain and compressive tangent-modulus curves for 7475-T761 aluminum alloy, aramid fiber-reinforced, sheet laminate.

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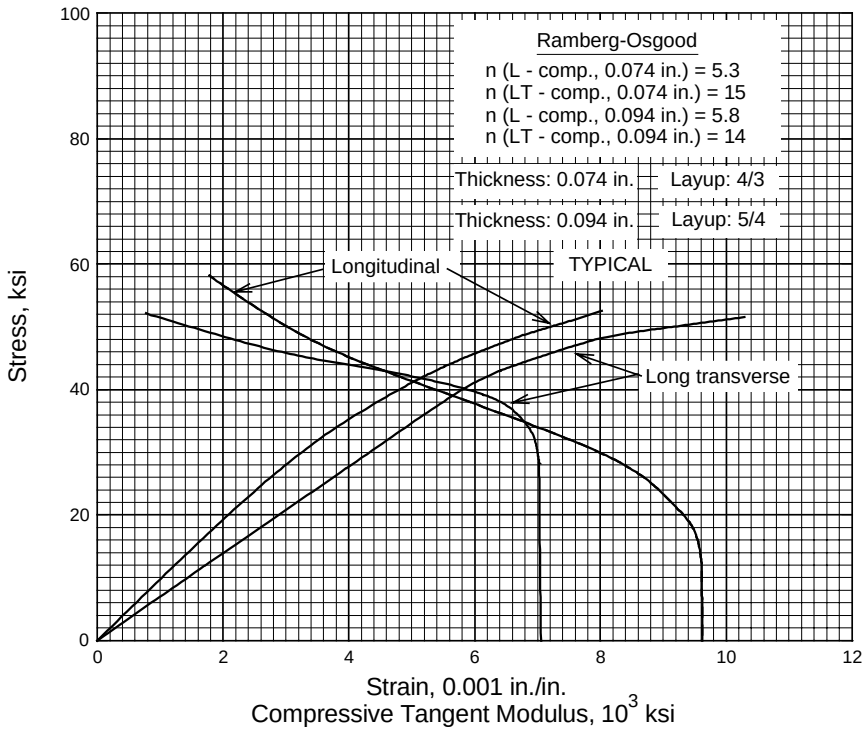


Figure 7.5.2.1.6(f). Typical compressive stress-strain and compressive tangent-modulus curves for 7475-T761 aluminum alloy, aramid fiber-reinforced, sheet laminate.

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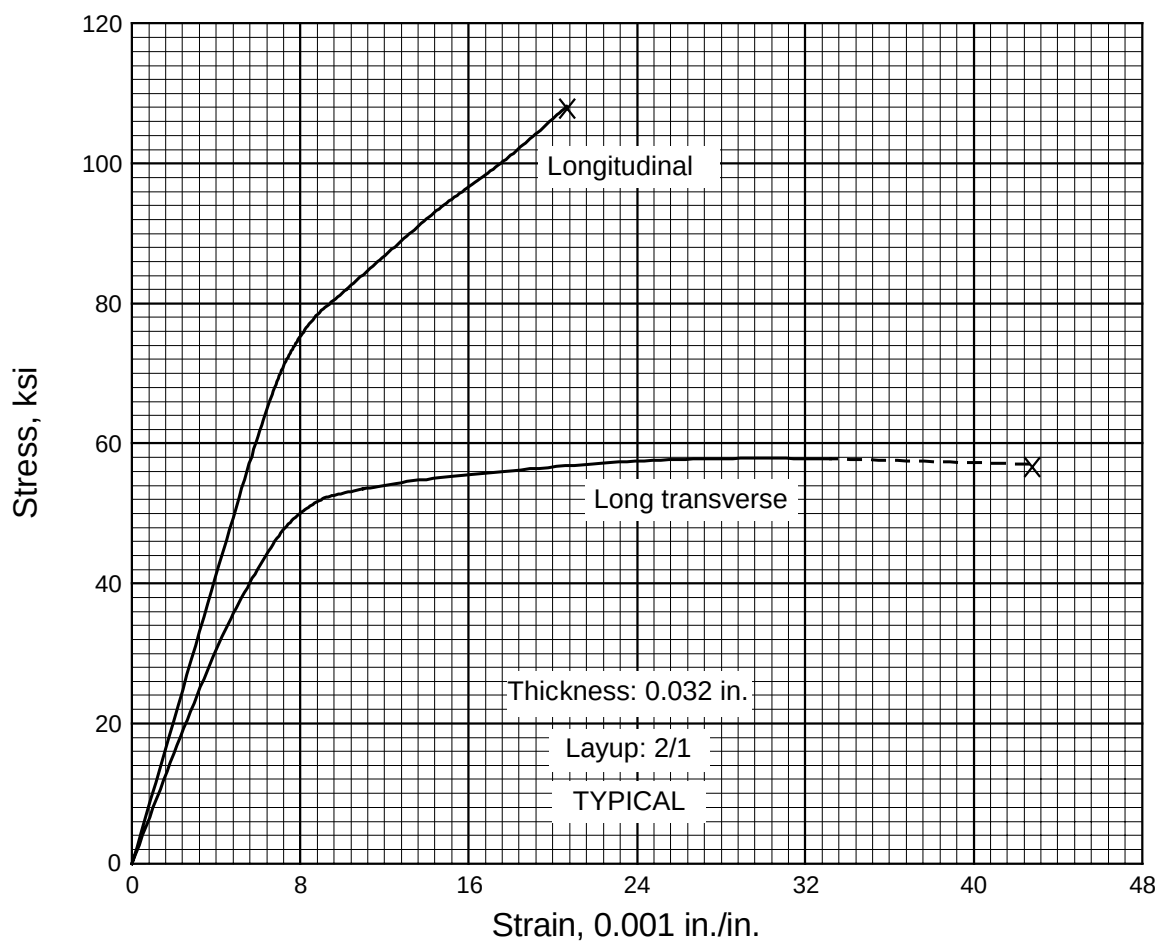


Figure 7.5.2.1.6(g). Typical tensile stress-strain curves (full range) for 7475-T761 aluminum alloy, aramid fiber-reinforced, sheet laminate.

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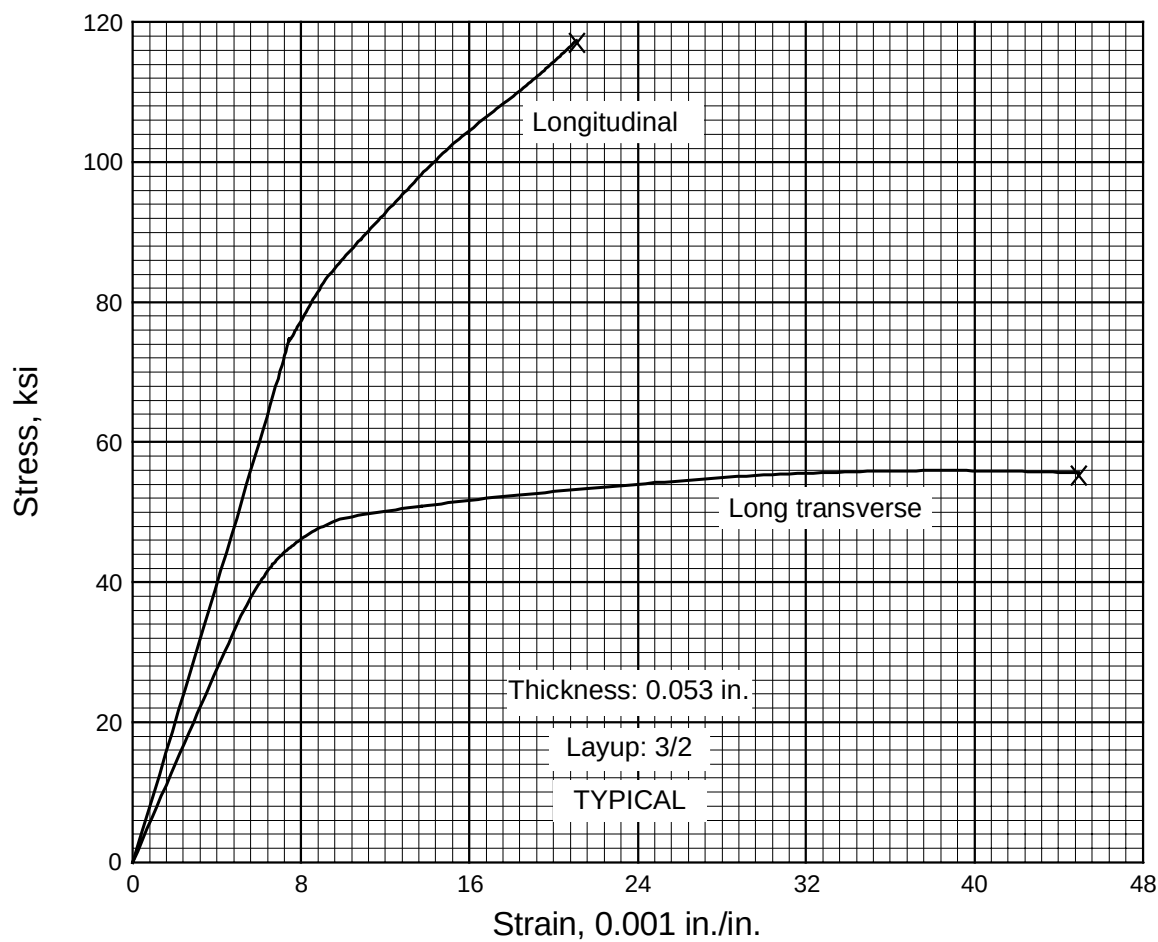


Figure 7.5.2.1.6(h). Typical tensile stress-strain curves (full range) for 7475-T761 aluminum alloy, aramid fiber-reinforced, sheet laminate.

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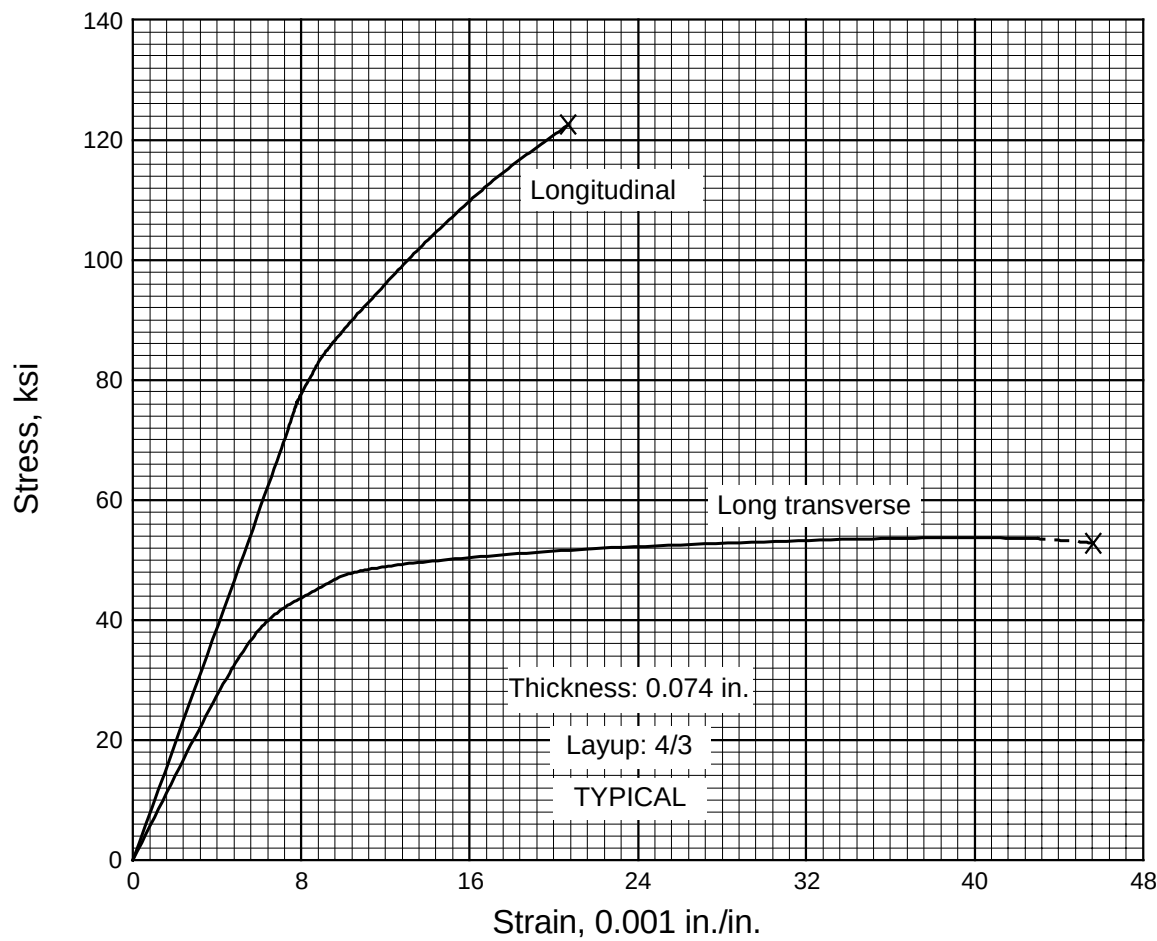


Figure 7.5.2.1.6(i). Typical tensile stress-strain curves (full range) for 7475-T761 aluminum alloy, aramid fiber-reinforced, sheet laminate.



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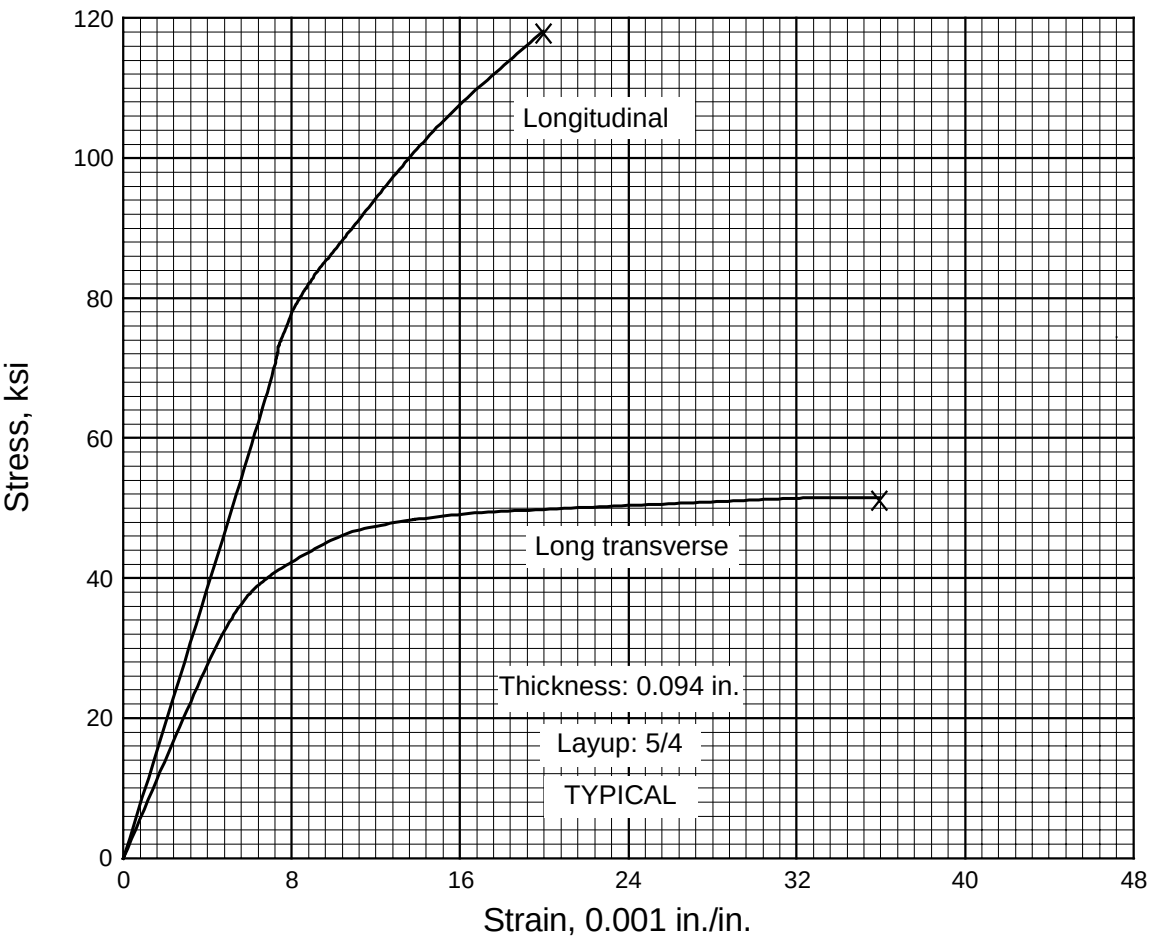


**Figure 7.5.2.1.6(j). Typical tensile stress-strain curves (full range) for 7475-T761 aluminum alloy, aramid fiber-reinforced, sheet laminate.**

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- 7.3.0(b) “The Selection and Application of Copper Alloy Castings,” by the ASM Committee on Copper Alloy Castings, ASM Metals Handbook, Vol. 1, 8th Edition, pp. 972-983 (1961).
- 7.3.0(c) CDA Standard Handbook, “Part 2—Wrought Mill Producers Alloy Data,” and “Part 7—Cast Products Data,” Copper Development Association, New York.

CHAPTER 8

STRUCTURAL JOINTS

This chapter, while comprising three major sections, primarily is concerned with joint allowables. Section 8.1 is concerned with mechanically fastened joints; Section 8.2, with metallurgical joints (various welding and brazing processes). Section 8.3 contains information for structural component data; it is concerned with bearings, pulleys, and cables.

With particular reference to Section 8.1, the introductory section (8.1.1) contains fastener indexes that can be used as a quick reference to locate a specific table of joint allowables. Following this introductory section are five sections comprising the five major fastener categories, as shown in Table 8.0.1.

Table 8.0.1. Structural Joints Index (Fastener Type)

| Section | Fastener Type           |
|---------|-------------------------|
| 8.1.2   | Solid Rivets            |
| 8.1.2.1 | Protruding head         |
| 8.1.2.2 | Flush head              |
| 8.1.3   | Blind fasteners         |
| 8.1.3.1 | Protruding head         |
| 8.1.3.2 | Flush head              |
| 8.1.4   | Swaged collar fasteners |
| 8.1.4.1 | Protruding head         |
| 8.1.4.2 | Flush head              |
| 8.1.5   | Threaded fasteners      |
| 8.1.5.1 | Protruding head         |
| 8.1.5.2 | Flush head              |
| 8.1.6   | Special fasteners       |
| 8.1.6.1 | Fastener sleeves        |

In each of the five major sections, there are subsections that describe the factors to be considered in determining the strength of fasteners and joints. After each major section, pertinent tables are presented.

Similarly, Section 8.2 has an introductory section (8.2.1), followed by two major sections comprising different metallurgical joints as shown in Table 8.0.2.

Table 8.0.2. Structural Joints Index (Joining Methods)

| Section | Joining Methods    |
|---------|--------------------|
| 8.2.2   | Welded joints      |
| 8.2.2.1 | Fusion             |
| 8.2.2.2 | Flush and pressure |
| 8.2.2.3 | Spot and seam      |
| 8.2.3   | Brazing            |
| 8.2.3.1 | Copper             |
| 8.2.3.2 | Silver             |

Following each 4-digit section, applicable tables and figures for the particular section are presented.

8.1 MECHANICALLY FASTENED JOINTS

To determine the strength of mechanically fastened joints, it is necessary to know the strength of the individual fasteners (both by itself, and when installed in various thicknesses of the various materials). In most cases, failures in such joints occur by tensile failure of the fasteners, shearing of the fasteners and by bearing and/or tearing of the sheet or plate.

**8.1.1 Introduction and Fastener Indexes** — Five categories of mechanical fasteners are presently contained in this Handbook, generically defined as follows:

*Solid Rivets* — Solid rivets are defined as one piece fasteners installed by mechanically upsetting one end.

*Blind Fasteners* — Blind fasteners are usually multiple piece devices that can be installed in a joint which is accessible from one side only. When a blind fastener is being installed, a self-contained mechanical, chemical, or other feature forms an upset on its inaccessible or blind side. These fasteners must be destroyed to be removed. This fastener category includes such fasteners as blind rivets, blind bolts, etc.

*Swaged Collar Fasteners* — Swaged collar fasteners are multiple piece fasteners, usually consisting of a solid pin and a malleable collar which is swaged or formed onto the pin to clamp the joint. This fastener usually is permanently installed. This fastener class includes such fasteners as “Hi-Shear” rivets, “Lockbolts”, and “Cherrybucks”.

*Threaded Fasteners* — Fasteners in this category are considered to be any threaded part (or parts) that after assembly in a joint can be easily removed without damage to the fastener or to the material being joined. This classification includes bolts, screws, and a wide assortment of proprietary fasteners.

*Special Fasteners* — As the name implies, this category of fastener is less commonly used in primary aircraft structure than the four categories listed above. Examples of such fastening systems are sleeves, inserts, panel fasteners, etc.

In the following 3-digit sections, descriptive information is presented relative to the establishment of design allowables in joints containing these four categories of fasteners. Following each such section are the various tables of joint allowables or associated information for computing joint allowables as described.

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Tables 8.1.1(a) through (e) are fastener indexes that list the joint allowables tables for each fastener category. These indexes are provided to make it easier to locate the allowables table for a given fastener and sheet material combination. Each of the indexes generally is similarly structured in the following manner. The left-hand column describes the fastener by referring to the MS or NAS part number or to a vendor part number when the fastener is not covered by either series. The second column contains the table number for the allowables table for each fastener. The fastener column has been so arranged that when protruding head and countersunk head fasteners are included in a given fastener index table, the protruding head tables appear first in the second column. The third column identifies generally the base material of the fastener. Generic terms usually are used, such as steel, aluminum, titanium, etc. The fourth column identifies the specific sheet or plate material.

It is recommended that Section 9.4.1 be reviewed in its entirety since it contains detailed information on the generation and analysis of joint data that results in the joint allowables tables contained in this section.

**8.1.1.1 Fastener Shear Strengths** — Fastener shear strengths accepted and documented by the aerospace industry and government agencies are listed in Table 8.1.1.1. Some existing tables in MIL-HDBK-5 may reflect other values; however, new fastener proposals will be classified in accordance with the above-noted table.

**8.1.1.2 Edge Distance Requirements** — The joint allowables in MIL-HDBK-5 are based on joint tests having edge distances of twice the nominal hole diameter, 2D. Therefore, the allowables are applicable only to joints having 2D edge distance.

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**Table 8.1.1(a). Fastener Index for Solid Rivets**

| Fastener Identification <sup>a</sup> | Table Number | Rivet Material | Sheet Material         | Page No. |
|--------------------------------------|--------------|----------------|------------------------|----------|
| Rivet Hole Size                      | 8.1.2(a)     | ...            | ...                    | 8-10     |
| Shear Strength of Solid Rivets       | 8.1.2(b)     | ...            | ...                    | 8-11     |
| Unit Bearing Strength                | 8.1.2.1(a)   | ...            | ...                    | 8-12     |
| Shear Strength Corection Factors     | 8.1.2.1(b)   | Aluminum       | ...                    | 8-13     |
| NAS1198 (MC) <sup>b</sup>            | 8.1.2.1(c)   | A-286          | A-286                  | 8-14     |
| MS20427M (MC)                        | 8.1.2.2(a)   | Monel          | AISI 301/302           | 8-15     |
| MS20427M (D) <sup>b</sup>            | 8.1.2.2(b)   | Monel          | AISI 301/302           | 8-16     |
| MS20426AD (D)                        | 8.1.2.2(c)   | Aluminum       | Aluminum               | 8-17     |
| MS20426D (D)                         | 8.1.2.2(d)   | Aluminum       | Aluminum               | 8-18     |
| MS20426DD (D)                        | 8.1.2.2(e)   | Aluminum       | Aluminum               | 8-19     |
| MS20426 (MC)                         | 8.1.2.2(f)   | Aluminum       | Clad 2024-T42          | 8-20     |
| MS20426B (MC)                        | 8.1.2.2(g)   | Aluminum       | AZ31B-H24              | 8-21     |
| MS20427M (MC)                        | 8.1.2.2(h)   | Monel          | Com Pure Titanium      | 8-22     |
| BRFS-D (MC)                          | 8.1.2.2(i)   | Aluminum       | Clad 2024-T3           | 8-23     |
| BRFS-AD (MC)                         | 8.1.2.2(j)   | Aluminum       | Clad 2024-T3           | 8-24     |
| BRFS-DD (MC)                         | 8.1.2.2(k)   | Aluminum       | Clad 2024-T3           | 8-25     |
| BRFS-T (MC)                          | 8.1.2.2(l)   | Ti-45Cb        | Clad 7075-T6/Ti-6Al-4V | 8-26     |
| MS14218E                             | 8.1.2.2(m)   | Aluminum       | Clad 2024-T3           | 8-27     |
| NAS1097E (MC)                        | 8.1.2.2(n)   | Aluminum       | Clad 2024-T3/7075-T6   | 8-28     |
| MS14218AD (MC)                       | 8.1.2.2(o)   | Aluminum       | Clad 2024-T3           | 8-29     |
| MS14219E (MC)                        | 8.1.2.2(p)   | Aluminum       | Clad 2024-T3           | 8-30     |
| MS14219E (MC)                        | 8.1.2.2(q)   | Aluminum       | Clad 7075-T6           | 8-31     |
| MS20426E                             | 8.1.2.2(r)   | Aluminum       | Clad 2024-T3           | 8-32     |
| MS20426E                             | 8.1.2.2(s)   | Aluminum       | Clad 7075-T6           | 8-33     |
| AL905KE (MC)                         | 8.1.2.2(t)   | Aluminum       | Clad 2024-T3           | 8-33a    |

a In some cases, entries in this table identify the subject matter in certain tables.

b MC, machine countersunk holes; D, dimpled holes.

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**Table 8.1.1(b). Fastener Index for Blind Fasteners**

| Fastener Identification                              | Table Number              | Fastener Sleeve Material | Sheet or Plate Material | Page No. |
|------------------------------------------------------|---------------------------|--------------------------|-------------------------|----------|
| <u>Protruding-head, Friction-Lock Blind Rivets</u>   |                           |                          |                         |          |
| CR 6636                                              | 8.1.3.1.1(a)              | A-286                    | Various                 | 8-35     |
| MS20600M                                             | 8.1.3.1.1(b)              | Monel                    | AISI 301                | 8-36     |
| MS20600M                                             | 8.1.3.1.1(c)              | Monel                    | Clad 2024-T3/7075-T6    | 8-37     |
| MS20600AD and MS20602AD                              | 8.1.3.1.1(d)              | Aluminum                 | Clad 2024-T3            | 8-38     |
| MS20600B                                             | 8.1.3.1.1(e)              | Aluminum                 | AZ31B-H24               | 8-39     |
| <u>Protruding-head, Mechanical-Lock Blind Rivets</u> |                           |                          |                         |          |
| NAS1398C                                             | 8.1.3.1.2(a)              | A-286                    | Alloy Steel             | 8-40     |
| CR 2643                                              | 8.1.3.1.2(a)              | A-286                    | Alloy Steel             | 8-40     |
| NAS1398 MS or MW                                     | 8.1.3.1.2(b)              | Monel                    | AISI 301-½ Hard         | 8-41     |
| NAS1398 MS or MW                                     | 8.1.3.1.2(c)              | Monel                    | Clad 7075-T6            | 8-42     |
| NAS1398B                                             | 8.1.3.1.2(d) <sub>1</sub> | Aluminum                 | Clad 2024-T3            | 8-43     |
| NAS1398D                                             | 8.1.3.1.2(d) <sub>1</sub> | Aluminum                 | Clad 2024-T3            | 8-43     |
| NAS1738B and NAS1738E                                | 8.1.3.1.2(d) <sub>2</sub> | Aluminum                 | Clad 2024-T3            | 8-44     |
| NAS1398B                                             | 8.1.3.1.2(e)              | Aluminum                 | AZ31B-H24               | 8-45     |
| NAS1738B and NAS1738E                                | 8.1.3.1.2(e)              | Aluminum                 | AZ31B-H24               | 8-45     |
| CR 2A63                                              | 8.1.3.1.2(f)              | Aluminum                 | Clad 2024-T81           | 8-46     |
| CR 4623                                              | 8.1.3.1.2(g)              | A-286                    | Clad 7075-T6            | 8-47     |
| CR 4523                                              | 8.1.3.1.2(h)              | Monel                    | Clad 7075-T6            | 8-48     |
| NAS1720KE and<br>NAS1720KE (L)                       | 8.1.3.1.2(i)              | Aluminum                 | Clad 7075-T6            | 8-49     |
| NAS1720C and<br>NAS1720C (L)                         | 8.1.3.1.2(j)              | A-286                    | Clad 2024-T3            | 8-50     |
| AF3243                                               | 8.1.3.1.2(m)              | Aluminum                 | Clad 2024-T3            | 8-53     |
| HC3213                                               | 8.1.3.1.2(n)              | Aluminum                 | Clad 2024-T3            | 8-54     |
| HC6223                                               | 8.1.3.1.2(o)              | Aluminum                 | Clad 2024-T3            | 8-55     |
| HC6253                                               | 8.1.3.1.2(p)              | Aluminum                 | Clad 2024-T3            | 8-56     |
| AF3213                                               | 8.1.3.1.2(q)              | Aluminum                 | Clad 2024-T3            | 8-56a    |
| CR3213                                               | 8.1.3.1.2(r)              | Aluminum                 | Clad 2024-T3            | 8-56b    |
| CR3243                                               | 8.1.3.1.2(s)              | Aluminum                 | Clad 2024-T3            | 8-56c    |
| HC3243                                               | 8.1.3.1.2(t)              | Aluminum                 | Clad 2024-T3            | 8-56d    |
| AF3223                                               | 8.1.3.1.2(u)              | Aluminum                 | Clad 2024-T3            | 8-56e    |
| CR3223                                               | 8.1.3.1.2(v)              | Aluminum                 | Clad 2024-T3            | 8-56f    |



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**Table 8.1.1(b). Fastener Index for Blind Fasteners (Continued)**

| Fastener Identification                                 | Table Number               | Fastener Sleeve Material | Sheet or Plate Material | Page No. |
|---------------------------------------------------------|----------------------------|--------------------------|-------------------------|----------|
| <u>Flush-head, Friction-Lock Blind Rivets</u>           |                            |                          |                         |          |
| CR 6626 (MC) <sup>a</sup>                               | 8.1.3.2.1(a)               | A-286                    | Various                 | 8-57     |
| MS20601M (MC)                                           | 8.1.3.2.1(b)               | Monel                    | 17-7PH (TH1050)         | 8-58     |
| MS20601M (D) <sup>a</sup>                               | 8.1.3.2.1(c)               | Monel                    | AISI 301                | 8-59     |
| MS20601M (MC)                                           | 8.1.3.2.1(d <sub>1</sub> ) | Monel                    | AISI 301-Ann            | 8-60     |
| MS20601M (MC)                                           | 8.1.3.2.1(d <sub>2</sub> ) | Monel                    | AISI 301-¼ Hard         | 8-61     |
| MS20601M (MC)                                           | 8.1.3.2.1(d <sub>3</sub> ) | Monel                    | AISI 301-½ Hard         | 8-62     |
| MS20601M (MC)                                           | 8.1.3.2.1(e)               | Monel                    | 7075-T6                 | 8-63     |
| MS20601AD and MS20603AD (MC)                            | 8.1.3.2.1(f)               | Aluminum                 | Clad 2024-T3            | 8-64     |
| MS20601B (MC)                                           | 8.1.3.2.1(g)               | Aluminum                 | AZ31B-H24               | 8-65     |
| <u>Flush-head, Mechanical-Lock Spindle Blind Rivets</u> |                            |                          |                         |          |
| NAS1399C (MC)                                           | 8.1.3.2.2(a)               | A-286                    | Alloy Steel             | 8-66     |
| CR 2642 (MC)                                            | 8.1.3.2.2(a)               | A-286                    | Alloy Steel             | 8-66     |
| NAS1399 MS or MW (MC)                                   | 8.1.3.2.2(b)               | Monel                    | AISI 301-½ Hard         | 8-67     |
| NAS1291C (MC)                                           | 8.1.3.2.2(c)               | A-286                    | Clad 7075-T6            | 8-68     |
| NAS1399 MS or MW (MC)                                   | 8.1.3.2.2(d)               | Monel                    | Clad 7075-T6            | 8-69     |
| NAS1921M (MC)                                           | 8.1.3.2.2(e)               | Monel                    | Clad 7075-T6            | 8-70     |
| CR 2A62 (MC)                                            | 8.1.3.2.2(f)               | Aluminum                 | Clad 2024-T81           | 8-71     |
| NAS1921B (MC)                                           | 8.1.3.2.2(g)               | Aluminum                 | Clad 7075-T6            | 8-72     |
| NAS1399B (MC)                                           | 8.1.3.2.2(h)               | Aluminum                 | Clad 2024-T3            | 8-73     |
| NAS1399D (MC)                                           | 8.1.3.2.2(h)               | Aluminum                 | Clad 2024-T3            | 8-73     |
| NAS1739B and NAS1379E (MC)                              | 8.1.3.2.2(i)               | Aluminum                 | Clad 2024-T3            | 8-74     |
| NAS1739B and NAS1739E (D)                               | 8.1.3.2.2(i)               | Aluminum                 | Clad 2024-T3            | 8-74     |
| NAS1399B (MC)                                           | 8.1.3.2.2(j)               | Aluminum                 | AZ31B-H24               | 8-75     |
| NAS1739B and NAS1739E (MC)                              | 8.1.3.2.2(j)               | Aluminum                 | AZ31B-H24               | 8-75     |
| CR 4622 (MC)                                            | 8.1.3.2.2(k)               | A-286                    | Clad 7075-T6            | 8-76     |
| CR 4522 (MC)                                            | 8.1.3.2.2(l)               | Monel                    | Clad 7075-T6/T651       | 8-77     |
| NAS1721KE and NAS1721KE (L) (MC)                        | 8.1.3.2.2(m)               | Aluminum                 | Clad 2024-T3            | 8-78     |
| NAS1721C and NAS1721C (L) (MC)                          | 8.1.3.2.2(n)               | A-286                    | Clad 7075-T6            | 8-79     |
| HC3212 (MC)                                             | 8.1.3.2.2(q)               | Aluminum                 | Clad 2024-T3            | 8-82     |
| MBC 4807 and MBC 4907                                   | 8.1.3.2.2(r)               | Aluminum                 | Clad 2024-T3            | 8-83     |
| MBC 4801 and MBC 4901                                   | 8.1.3.2.2(s)               | Aluminum                 | Clad 2024-T3            | 8-84     |
| HC6222                                                  | 8.1.3.2.2(t)               | Aluminum                 | Clad 2024-T3            | 8-85     |
| HC6224                                                  | 8.1.3.2.2(u)               | Aluminum                 | Clad 2024-T3            | 8-86     |
| HC6252 (MC)                                             | 8.1.3.2.2(v)               | Aluminum                 | Clad 2024-T3            | 8-86a    |
| AF3212 (MC)                                             | 8.1.3.2.2(w)               | Aluminum                 | Clad 2024-T3            | 8-86b    |
| CR3212 (MC)                                             | 8.1.3.2.2(x)               | Aluminum                 | Clad 2024-T3            | 8-86c    |
| AF3242 (MC)                                             | 8.1.3.2.2(y)               | Aluminum                 | Clad 2024-T3            | 8-86d    |
| CR3242 (MC)                                             | 8.1.3.2.2(z)               | Aluminum                 | Clad 2024-T3            | 8-86e    |
| HC3242 (MC)                                             | 8.1.3.2.2(aa)              | Aluminum                 | Clad 2024-T3            | 8-86f    |
| AF3222                                                  | 8.1.3.2.2(bb)              | Aluminum                 | Clad 2024-T3            | 8-86g    |
| CR3222                                                  | 8.1.3.2.2(cc)              | Aluminum                 | Clad 2024-T3            | 8-86h    |

<sup>a</sup> MC, machine countersunk holes; D, dimpled holes.

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Table 8.1.1(b). Fastener Index for Blind Fasteners (Continued)

| Fastener Identification        | Table Number               | Fastener<br>Sleeve<br>Material | Sheet or Plate<br>Material      | Page<br>No. |
|--------------------------------|----------------------------|--------------------------------|---------------------------------|-------------|
| <u>Flush-head Blind Bolts</u>  |                            |                                |                                 |             |
| MS21140 (MC)                   | 8.1.3.2.3(a)               | A-286                          | Clad 7075-T6/T651               | 8-87        |
| MS90353 (MC)                   | 8.1.3.2.3(b <sub>1</sub> ) | Alloy Steel                    | Clad 2024-T3/T351               | 8-88        |
| MS90353 (MC)                   | 8.1.3.2.3(b <sub>2</sub> ) | Alloy Steel                    | Clad or Bare 7075-T6<br>or T651 | 8-89        |
| FF-200, FF-260 and FF-312 (MC) | 8.1.3.2.3(c)               | Alloy Steel                    | Clad 2024-T42/<br>7075-T6       | 8-90        |
| NS 100 (MC)                    | 8.1.3.2.3(d)               | Alloy Steel                    | Clad 7075-T6                    | 8-91        |
| SSHFA-200 and SSHFA-260(MC)    | 8.1.3.2.3(e)               | Aluminum                       | Clad 2024-T42/<br>7075-T6       | 8-92        |
| PLT-150 (MC)                   | 8.1.3.2.3(f)               | Alloy Steel                    | Clad 7075-T6/T651               | 8-93        |
| NAS1670L (MC)                  | 8.1.3.2.3(g)               | Alloy Steel                    | Clad 7075-T6/T651               | 8-94        |
| NAS1674L (MC)                  | 8.1.3.2.3(h)               | Aluminum                       | Clad 7075-T6                    | 8-95        |

a MC, machine countersunk holes; D, dimpled holes.

**Table 8.1.1(c). Fastener Index for Swaged-Collar/Upset-Pin Fasteners**

| Fastener Identification                     | Table Number | Fastener Pin Material | Sheet or Plate Material | Page No. |
|---------------------------------------------|--------------|-----------------------|-------------------------|----------|
| Ultimate Single-Shear and Tensile Strengths | 8.1.4        | Alloy Steel and Alum. | ...                     | 8-98     |
| CSR 925                                     | 8.1.4.1(a)   | Titanium              | Clad 7075-T6            | 8-99     |
| CSR 925                                     | 8.1.4.1(b)   | Titanium              | Clad 2024-T3            | 8-100    |
| NAS1436-NAS1442 (MC) <sup>a</sup>           | 8.1.4.2(a)   | Alloy Steel           | Clad 7075-T6/T651       | 8-101    |
| NAS7024-NAS7032 (MC)                        | 8.1.4.2(b)   | Alloy Steel           | Clad 7075-T6/T651       | 8-102    |
| CSR 924 (MC)                                | 8.1.4.2(c)   | Titanium              | Clad 7075-T6            | 8-103    |
| CSR 924 (MC)                                | 8.1.4.2(d)   | Titanium              | Clad 2024-T3            | 8-104    |
| HSR 201 (MC)                                | 8.1.4.2(e)   | A-286                 | Clad 7075-T6            | 8-105    |
| HSR 101 (MC)                                | 8.1.4.2(f)   | Titanium              | Clad 7075-T6            | 8-106    |
| GPL 3SC-V (MC)                              | 8.1.4.2(g)   | Titanium              | Clad 7075-T6            | 8-107    |
| GPL 3SC-V (MC)                              | 8.1.4.2(h)   | Titanium              | Clad 2024-T3            | 8-108    |
| LGPL 2SC-V (MC)                             | 8.1.4.2(i)   | Titanium              | Clad 7075-T6            | 8-109    |
| LGPL 2SC-V (MC)                             | 8.1.4.2(j)   | Titanium              | Clad 2024-T3            | 8-110    |

a MC, machine countersunk holes.

**Table 8.1.1(d). Fastener Index for Threaded Fasteners**

| Fastener Identification <sup>a</sup>       | Table Number             | Fastener Sleeve Material | Sheet        | Page No. |
|--------------------------------------------|--------------------------|--------------------------|--------------|----------|
| Single Shear Strength                      | 8.1.5(a)                 | Steel                    | ...          | 8-113    |
| Tensile Strength                           | 8.1.5(b <sub>1</sub> )   | Steel                    | ...          | 8-114    |
| Tensile Strength                           | 8.1.5(b <sub>2</sub> )   | ...                      | ...          | 8-115    |
| Unit Bearing Strength                      | 8.1.5.1                  | Alloy Steel              | ...          | 8-116    |
| AN 509 Screws (MC) <sup>b</sup>            | 8.1.5.2(a <sub>1</sub> ) | Alloy Steel              | Clad 2024-T3 | 8-117    |
| AN 509 Screws (MC)                         | 8.1.5.2(a <sub>2</sub> ) | CRES                     | Clad 7075-T6 | 8-118    |
| PBF 11 (MC)                                | 8.1.5.2(b)               | Alloy Steel              | Ti-6Al-4V    | 8-119    |
| TL 100 (MC)                                | 8.1.5.2(c)               |                          | Clad 7075-T6 | 8-120    |
| TLV 100 (MC)                               | 8.1.5.2(d)               | Titanium                 | Clad 7075-T6 | 8-121    |
| HPB-V (MC)                                 | 8.1.5.2(e)               | Titanium                 | Clad 7075-T6 | 8-122    |
| KLBHV with KFN 600 (MC)                    | 8.1.5.2(f)               | Titanium                 | Clad 7075-T6 | 8-123    |
| HL-61-70 (MC)                              | 8.1.5.2(g)               | CRES                     | Clad 7075-T6 | 8-124    |
| HL-719-79 (MC)                             | 8.1.5.2(h)               | Alloy Steel              | Clad 7075-T6 | 8-125    |
| HL-11 (MC)                                 | 8.1.5.2(i)               | Titanium                 | Clad 7075-T6 | 8-126    |
| HL-911 (MC)                                | 8.1.5.2(j)               | Titanium                 | Clad 7075-T6 | 8-127    |
| NAS4452S and KS 100-FV with NAS4445DD (MC) | 8.1.5.2(k)               | Alloy Steel or Titanium  | Clad 7075-T6 | 8-128    |
| HPG-V (MC)                                 | 8.1.5.2(l)               | Titanium                 | Clad 7075-T6 | 8-129    |
| NAS4452V with NAS4445 DD (MC)              | 8.1.5.2(m)               | Titanium                 | Clad 7075-T6 | 8-130    |
| HL18Pin, HL70 Collar (MC)                  | 8.1.5.2(n)               | Alloy Steel              | Clad 7075-T6 | 8-131    |
| HL19 Pin, HL70 Collar (MC)                 | 8.1.5.2(o)               | Alloy Steel              | Clad 7075-T6 | 8-132    |

a In some cases entries in this table identify the subject matter in certain tables.

b MC, machine countersunk holes; D, dimpled holes.

Table 8.1.1(e). Fastener Index for Special Fasteners

| Fastener Identification        | Table Number | Fastener Pin Material      | Sheet or Plate Material | Page No. |
|--------------------------------|--------------|----------------------------|-------------------------|----------|
| ACRES Sleeves                  | ...          | A-286                      | Clad 7075-T6            | 8-133    |
| MIL-B-8831/4 (MC) <sup>a</sup> | 8.1.6.2(a)   | Steel Pin, Aluminum Sleeve | Clad 7075-T6            | 8-134    |
| MIL-B-8831/4 (MC)              | 8.1.6.2(b)   | Steel Pin, Aluminum Sleeve | Clad 2024-T3            | 8-135    |

a MC, machine countersunk holes.

Table 8.1.1.1 Fastener Shear Strengths

| F <sub>su</sub> <sup>a</sup> , ksi | Examples of Current Alloys Which Meet Level <sup>a</sup> | Current Usage |                 |                       |
|------------------------------------|----------------------------------------------------------|---------------|-----------------|-----------------------|
|                                    |                                                          | Driven Rivets | Blind Fasteners | Solid Shank Fasteners |
| 28                                 | 5056                                                     | X             | X               |                       |
| 30                                 | 2117                                                     | X             | X               |                       |
| 34                                 | 2017                                                     | X             | X               |                       |
| 36                                 | 2219                                                     | X             | X               |                       |
| 38                                 | 2017                                                     | X             | X               |                       |
| 41                                 | 2024 and 7050-T73                                        | X             |                 |                       |
| 43                                 | 7050-T731                                                | X             | X               | X                     |
| 46                                 | 7075                                                     |               | X               |                       |
| 49                                 | Monel                                                    | Undriven      |                 |                       |
| 50                                 | Ti/Cb                                                    | X             |                 |                       |
| 55                                 | Monel                                                    |               | X               |                       |
| 75                                 | Alloy Steel and CRES                                     |               | X               | X                     |
| 78                                 | A-286                                                    |               |                 | X                     |
| 90                                 | A-286                                                    | Undriven      |                 |                       |
| 95                                 | Alloy Steel, A-286, Ti-6Al-4V                            | X             | X               | X                     |
| 108                                | Alloy Steel and Ti-6Al-2Sn                               |               |                 | X                     |
| 110                                | A-286                                                    |               |                 | X                     |
| 112                                | Alloy Steel                                              |               | X               | X                     |
| 125                                | Alloy Steel and CRES                                     |               |                 | X                     |
| 132                                | Alloy Steel                                              |               |                 | X                     |
| 145                                | MP35N                                                    |               |                 | X                     |
| 156                                | Alloy Steel                                              |               |                 | X                     |
| 180                                | Alloy Steel                                              |               |                 | X                     |

a Different tempers and thermal treatments are used to obtain desired fastener shear strengths.

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**8.1.2 SOLID RIVETS** — The recommended diameter dimensions of the upset tail on solid rivets shall be at least 1.5 times the nominal shank diameter except for 2024-T4 rivets which shall be at least 1.4 times the nominal shank diameter. Tail heights shall be a minimum of 0.3 diameter. Shear strengths for driven rivets may be based on areas corresponding to the nominal hole diameter provided that the nominal hole diameter is not larger than the values listed in Table 8.1.2(a). If the nominal hole diameter is larger than the listed value, the listed value shall be used. Shear strength values for solid rivets of a number of rivet materials are given in Table 8.1.2(b).

**8.1.2.1 Protruding-Head Solid Rivet Joints** — The unit load at which shear or bearing type of failure occurs is calculated separately and the lower of the two governs the design.

The design bearing stress for various materials at both room and elevated temperatures is given in the strength properties stated for each alloy or group of alloys and is applicable to riveted joints wherein cylindrical holes are used and where  $t/D$  is greater than or equal to 0.18; where  $t/D$  is less than 0.18, tests to substantiate yield and ultimate bearing strengths must be performed. These bearing stresses are applicable only for the design of rigid joints where there is no possibility of relative motion of the parts joined without deformation of such parts. Design bearing stresses at low temperatures will be higher than those specified for room temperature; however, no quantitative data are available.

For convenience, “unit” sheet bearing strengths for rivets, based on a bearing stress of 100 ksi and nominal hole diameters, are given in Table 8.1.2.1(a).

In computing protruding-head rivet design shear strengths, the shear strength values obtained from Table 8.1.2(b) should be multiplied by the correction factors given in Table 8.1.2.1(b). This compensates for the reduction in rivet shear strength resulting from high bearing stresses on the rivet at  $t/D$  ratios less than 0.33 for single-shear joints and 0.67 for double-shear joints.

For those rivet material sheet material combinations where test data shows the above to be unconservative or for rivet materials other than those shown in Table 8.1.2(b), joint allowables should be established by test in accordance with Section 9.4. From such tests tabular presentation of ultimate load and yield load allowables are made.

Unless otherwise specified, yield load is defined in Section 9.4.1.3.3 as the load which results in a joint permanent set equal to  $0.04D$ , where  $D$  is the decimal equivalent of the hole diameter defined in Table 9.4.1.2(a).

Table 8.1.2.1(c) provides ultimate and yield strength data on protruding-head A-286 solid rivets in aged A-286 sheet, for a variety of conditions of exposure.

**8.1.2.2 Flush-Head Solid Rivet Joints** — Tables 8.1.2.2(a) through (s) contain joint allowables for various flush-head solid rivet/sheet material combinations. The allowable ultimate loads were established from test data using the average ultimate test load divided by a factor of 1.15. (See Section 9.4 for possible variations.) This factor is not applicable to shear strength cutoff values. Shear strength cutoff values may be either the procurement specification shear strength ( $S$  value) of the fastener, or if no specification exists, a statistical value determined from test results as described in Section 9.4.

Yield load allowables are established from test data. Unless otherwise specified, the yield load is defined in Section 9.4.1.3.3 as the load which results in a joint permanent set equal to  $0.04D$ , where  $D$  is the decimal equivalent of the hole diameter defined in Table 9.4.1.2(a).

For machine countersunk joints, the sheet gage specified in the tables is that of the countersunk sheet. When the noncountersunk sheet is thinner than the countersunk sheet, the bearing allowable for the noncountersunk sheet-fastener combination should be computed, compared to the table value, and the lower of the two values selected. Increased attention should be paid to detail design in cases where  $t/D < 0.25$  because of possibly greater incidence of difficulty in service life.

**Table 8.1.2(a). Standard Rivet-Hole Drill Sizes and Nominal Hole Diameters**

| Rivet Size, in.            | 1/16  | 3/32  | 1/8    | 5/32  | 3/16  | 1/4   | 5/16  | 3/8   |
|----------------------------|-------|-------|--------|-------|-------|-------|-------|-------|
| Drill No. ....             | 51    | 41    | 30     | 21    | 11    | F     | P     | W     |
| Nominal Hole Diameter, in. | 0.067 | 0.096 | 0.1285 | 0.159 | 0.191 | 0.257 | 0.323 | 0.386 |

Table 8.1.2(b). Single Shear Strength of Solid Rivets<sup>a</sup>

| Undriven          |                       |     | Driven                 |                                    | Rivet<br>Designation | Rivet Size                                     |      |      |      |      |      |      |       |
|-------------------|-----------------------|-----|------------------------|------------------------------------|----------------------|------------------------------------------------|------|------|------|------|------|------|-------|
| Rivet<br>Material | F <sub>su</sub> (ksi) |     | Rivet<br>Material      | F <sub>su</sub> <sup>b</sup> (ksi) |                      | 1/16                                           | 3/32 | 1/8  | 5/32 | 3/16 | 1/4  | 5/16 | 3/8   |
|                   | Min                   | Max |                        |                                    |                      | Driven Single Shear Strength, lbs <sup>c</sup> |      |      |      |      |      |      |       |
| 5056-H32          | 24                    | n/a | 5056-H321 <sup>d</sup> | 28 <sup>e</sup>                    | B <sup>f</sup>       | 99                                             | 203  | 363  | 556  | 802  | 1450 | 2290 | 3275  |
| 2117-T4           | 26                    | n/a | 2117-T3                | 30 <sup>e</sup>                    | AD                   | 106                                            | 217  | 389  | 596  | 860  | 1555 | 2455 | 3510  |
| 2017-T4           | 35                    | 42  | 2017-T3                | 38 <sup>e</sup>                    | D                    | 134                                            | 275  | 493  | 755  | 1085 | 1970 | 3115 | 4445  |
| 2024-T4           | 37                    | n/a | 2024-T31               | 41 <sup>g</sup>                    | DD                   | 145                                            | 297  | 532  | 814  | 1175 | 2125 | 3360 | 4795  |
| 7050-T73          | 41                    | 46  | 7050-T731 <sup>d</sup> | 43 <sup>e</sup>                    | E <sup>h</sup>       | 152                                            | 311  | 558  | 854  | 1230 | 2230 | 3520 | 5030  |
| Monel             | 49                    | 59  | Monel                  | 52 <sup>e</sup>                    | M                    | 183                                            | 376  | 674  | 1030 | 1490 | 2695 | 4260 | 6085  |
| Ti-45Cb           | 50                    | 59  | Ti-45Cb                | 53 <sup>e</sup>                    | T                    | 187                                            | 384  | 687  | 1050 | 1515 | 2745 | 4340 | 6200  |
| A-286             | 85                    | 95  | A-286                  | 90 <sup>e</sup>                    | -                    | 317                                            | 651  | 1165 | 1785 | 2575 | 4665 | 7375 | 10500 |

- a All rivets must be sufficiently driven to fill the rivet hole at the shear plane. Driving changes the rivet strength from the undriven to the driven condition and thus provides the above driven shear strengths.
- b Shear stresses are for the as driven condition on B-basis probability.
- c Based on nominal hole diameter specified in Table 8.1.2(a).
- d The temper designations last digit (1), indicates recognition of strengthening derived from driving.
- e The bucktail’s minimum diameter is 1.5 times the nominal hole diameter in Table 8.1.2(a).
- f Should not be exposed to temperatures over 150°F.
- g Driven in the W (fresh or ice box) condition to minimum 1.4D bucktail diameter.
- h E (or KE, as per NAS documents).

Table 8.1.1(a). Unit Bearing Strength of Sheet on Rivets,  $F_{br} = 100$  ksi

| Sheet thickness, in. | Unit Bearing Strength for Indicated Rivet Diameter, lbs |      |      |      |      |      |      |      |
|----------------------|---------------------------------------------------------|------|------|------|------|------|------|------|
|                      | 1/16                                                    | 3/32 | 1/8  | 5/32 | 3/16 | 1/4  | 5/16 | 3/8  |
| 0.012 .....          | 80                                                      | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 0.016 .....          | 107                                                     | ...  | ...  | ...  | ...  | ...  | ...  | ...  |
| 0.018 .....          | 121                                                     | 173  | ...  | ...  | ...  | ...  | ...  | ...  |
| 0.020 .....          | 134                                                     | 192  | ...  | ...  | ...  | ...  | ...  | ...  |
| 0.025 .....          | 168                                                     | 240  | 321  | ...  | ...  | ...  | ...  | ...  |
| 0.032 .....          | 214                                                     | 307  | 411  | 509  | ...  | ...  | ...  | ...  |
| 0.036 .....          | 241                                                     | 346  | 462  | 572  | 688  | ...  | ...  | ...  |
| 0.040 .....          | 268                                                     | 384  | 514  | 636  | 764  | ...  | ...  | ...  |
| 0.045 .....          | 302                                                     | 432  | 578  | 716  | 860  | ...  | ...  | ...  |
| 0.050 .....          | 335                                                     | 480  | 642  | 795  | 955  | 1285 | ...  | ...  |
| 0.063 .....          | 422                                                     | 605  | 810  | 1002 | 1203 | 1619 | 2035 | ...  |
| 0.071 .....          | 476                                                     | 682  | 912  | 1129 | 1356 | 1825 | 2293 | 2741 |
| 0.080 .....          | 536                                                     | 768  | 1028 | 1272 | 1528 | 2056 | 2584 | 3088 |
| 0.090 .....          | 603                                                     | 864  | 1156 | 1431 | 1719 | 2313 | 2907 | 3474 |
| 0.100 .....          | 670                                                     | 960  | 1285 | 1590 | 1910 | 2570 | 3230 | 3860 |
| 0.125 .....          | 838                                                     | 1200 | 1606 | 1988 | 2388 | 3212 | 4038 | 4825 |
| 0.160 .....          | 1072                                                    | 1536 | 2056 | 2544 | 3056 | 4112 | 5168 | 6176 |
| 0.190 .....          | 1273                                                    | 1824 | 2442 | 3021 | 3629 | 4883 | 6137 | 7334 |
| 0.250 .....          | 1670                                                    | 2400 | 3210 | 3975 | 4775 | 6425 | 8075 | 9650 |



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**Table 8.1.2.1(b). Shear Strength Correction Factors for Solid Protruding Head Rivets**

| Rivet Diameter, in.   | 1/16                                | 3/32  | 1/8   | 5/32  | 3/16  | 1/4   | 5/16  | 3/8   |
|-----------------------|-------------------------------------|-------|-------|-------|-------|-------|-------|-------|
|                       | Single-Shear Rivet Strength Factors |       |       |       |       |       |       |       |
| Sheet thickness, in.: |                                     |       |       |       |       |       |       |       |
| 0.016 .....           | 0.964                               | ...   | ...   | ...   | ...   | ...   | ...   | ...   |
| 0.018 .....           | 0.981                               | 0.912 | ...   | ...   | ...   | ...   | ...   | ...   |
| 0.020 .....           | 0.995                               | 0.933 | ...   | ...   | ...   | ...   | ...   | ...   |
| 0.025 .....           | 1.000                               | 0.970 | 0.920 | ...   | ...   | ...   | ...   | ...   |
| 0.032 .....           | ...                                 | 1.000 | 0.964 | 0.925 | ...   | ...   | ...   | ...   |
| 0.036 .....           | ...                                 | ...   | 0.981 | 0.946 | 0.912 | ...   | ...   | ...   |
| 0.040 .....           | ...                                 | ...   | 0.995 | 0.964 | 0.933 | ...   | ...   | ...   |
| 0.045 .....           | ...                                 | ...   | 1.000 | 0.981 | 0.953 | ...   | ...   | ...   |
| 0.050 .....           | ...                                 | ...   | ...   | 0.995 | 0.970 | 0.920 | ...   | ...   |
| 0.063 .....           | ...                                 | ...   | ...   | 1.000 | 1.000 | 0.961 | 0.922 | ...   |
| 0.071 .....           | ...                                 | ...   | ...   | ...   | ...   | 0.979 | 0.944 | 0.909 |
| 0.080 .....           | ...                                 | ...   | ...   | ...   | ...   | 0.995 | 0.964 | 0.933 |
| 0.090 .....           | ...                                 | ...   | ...   | ...   | ...   | 1.000 | 0.981 | 0.953 |
| 0.100 .....           | ...                                 | ...   | ...   | ...   | ...   | ...   | 0.995 | 0.972 |
| 0.125 .....           | ...                                 | ...   | ...   | ...   | ...   | ...   | 1.000 | 1.000 |
|                       | Double-Shear Rivet Strength Factors |       |       |       |       |       |       |       |
| Sheet thickness, in.: |                                     |       |       |       |       |       |       |       |
| 0.016 .....           | 0.687                               | ...   | ...   | ...   | ...   | ...   | ...   | ...   |
| 0.018 .....           | 0.744                               | 0.518 | ...   | ...   | ...   | ...   | ...   | ...   |
| 0.020 .....           | 0.789                               | 0.585 | ...   | ...   | ...   | ...   | ...   | ...   |
| 0.025 .....           | 0.870                               | 0.708 | 0.545 | ...   | ...   | ...   | ...   | ...   |
| 0.032 .....           | 0.941                               | 0.814 | 0.687 | 0.560 | ...   | ...   | ...   | ...   |
| 0.036 .....           | 0.969                               | 0.857 | 0.744 | 0.630 | 0.518 | ...   | ...   | ...   |
| 0.040 .....           | 0.992                               | 0.891 | 0.789 | 0.687 | 0.585 | ...   | ...   | ...   |
| 0.045 .....           | 1.000                               | 0.924 | 0.834 | 0.744 | 0.653 | ...   | ...   | ...   |
| 0.050 .....           | ...                                 | 0.951 | 0.870 | 0.789 | 0.708 | 0.545 | ...   | ...   |
| 0.063 .....           | ...                                 | 1.000 | 0.937 | 0.872 | 0.808 | 0.679 | 0.550 | ...   |
| 0.071 .....           | ...                                 | ...   | 0.966 | 0.909 | 0.852 | 0.737 | 0.622 | 0.508 |
| 0.080 .....           | ...                                 | ...   | 0.992 | 0.941 | 0.891 | 0.789 | 0.687 | 0.585 |
| 0.090 .....           | ...                                 | ...   | 1.000 | 0.969 | 0.924 | 0.834 | 0.744 | 0.653 |
| 0.100 .....           | ...                                 | ...   | ...   | 0.992 | 0.951 | 0.870 | 0.789 | 0.708 |
| 0.125 .....           | ...                                 | ...   | ...   | 1.000 | 1.000 | 0.935 | 0.870 | 0.805 |
| 0.160 .....           | ...                                 | ...   | ...   | ...   | ...   | 0.992 | 0.941 | 0.891 |
| 0.190 .....           | ...                                 | ...   | ...   | ...   | ...   | 1.000 | 0.981 | 0.939 |
| 0.250 .....           | ...                                 | ...   | ...   | ...   | ...   | ...   | 1.000 | 1.000 |

a Sheet thickness is that of the thinnest sheet in single-shear joints and the middle sheet in double-shear joints. Values based on tests of aluminum rivets, Reference 8.1(a).

**Table 8.1.2.1(c). Static Joint Strength of Protruding Head A-286 Solid Rivets in A-286 Alloy Sheet at Various Temperatures**

|                                                          |                                                   |                 |                 |                                |                 |                 |                                                            |                   |                   |
|----------------------------------------------------------|---------------------------------------------------|-----------------|-----------------|--------------------------------|-----------------|-----------------|------------------------------------------------------------|-------------------|-------------------|
| Rivet Type .....                                         | NAS1198 ( $F_{su} = 90$ ksi)                      |                 |                 |                                |                 |                 |                                                            |                   |                   |
| Sheet Material .....                                     | A-286, solution treated and aged, $F_u = 140$ ksi |                 |                 |                                |                 |                 |                                                            |                   |                   |
| Temperature .....                                        | Room Temperature                                  |                 |                 | 1200 °F, Stabilized 15 Minutes |                 |                 | 1200 °F, Rapid Heating in 20 Seconds, Tested in 15 Seconds |                   |                   |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) | 1/8<br>(0.1285)                                   | 5/32<br>(0.159) | 3/16<br>(0.191) | 1/8<br>(0.1285)                | 5/32<br>(0.159) | 3/16<br>(0.191) | 1/8<br>(0.1285)                                            | 5/32<br>(0.159)   | 3/16<br>(0.191)   |
| Sheet thickness, in.:                                    | Ultimate Strength <sup>a</sup> , lbs.             |                 |                 |                                |                 |                 |                                                            |                   |                   |
| 0.020 .....                                              | 478                                               | ...             | ...             | 331                            | ...             | ...             | 470 <sup>b</sup>                                           | ...               | ...               |
| 0.025 .....                                              | 590                                               | 740             | ...             | 426                            | 626             | ...             | 587 <sup>b</sup>                                           | 726 <sup>b</sup>  | ...               |
| 0.032 .....                                              | 745                                               | 932             | 1132            | 560                            | 801             | 962             | 752 <sup>b</sup>                                           | 930 <sup>b</sup>  | 1117 <sup>b</sup> |
| 0.040 .....                                              | 923                                               | 1152            | 1397            | 682                            | 1002            | 1204            | 783                                                        | 1164 <sup>b</sup> | 1397 <sup>b</sup> |
| 0.050 .....                                              | 1023                                              | 1428            | 1677            | ...                            | 1044            | 1505            | ...                                                        | 1198              | 1729 <sup>b</sup> |
| 0.063 .....                                              | 1131                                              | 1578            | 1821            | ...                            | ...             | 1507            | ...                                                        | ...               | ...               |
| 0.071 .....                                              | 1170                                              | 1660            | 1909            | ...                            | ...             | ...             | ...                                                        | ...               | ...               |
| 0.080 .....                                              | ...                                               | 1752            | 2008            | ...                            | ...             | ...             | ...                                                        | ...               | ...               |
| 0.090 .....                                              | ...                                               | 1790            | 2118            | ...                            | ...             | ...             | ...                                                        | ...               | ...               |
| 0.100 .....                                              | ...                                               | ...             | 2229            | ...                            | ...             | ...             | ...                                                        | ...               | ...               |
| 0.125 .....                                              | ...                                               | ...             | 2504            | ...                            | ...             | ...             | ...                                                        | ...               | ...               |
| 0.160 .....                                              | ...                                               | ...             | 2580            | ...                            | ...             | ...             | ...                                                        | ...               | ...               |
| Rivet shear strength <sup>c</sup> .....                  | 1170                                              | 1790            | 2580            | 682                            | 1044            | 1507            | 783                                                        | 1198              | 1729              |
| Sheet thickness, in.:                                    | Yield Strength <sup>a,d</sup> , lbs.              |                 |                 |                                |                 |                 |                                                            |                   |                   |
| 0.020 .....                                              | 447                                               | ...             | ...             | 300                            | ...             | ...             | 300                                                        | ...               | ...               |
| 0.025 .....                                              | 590                                               | 695             | ...             | 374                            | 464             | ...             | 374                                                        | 464               | ...               |
| 0.032 .....                                              | 745                                               | 932             | 974             | 479                            | 593             | 713             | 478                                                        | 593               | 712               |
| 0.040 .....                                              | 867                                               | 1152            | 1167            | 598                            | 741             | 890             | 598                                                        | 740               | 889               |
| 0.050 .....                                              | 938                                               | 1331            | 1407            | ...                            | 925             | 1112            | ...                                                        | 924               | 1110              |
| 0.063 .....                                              | 1031                                              | 1447            | 1649            | ...                            | ...             | 1400            | ...                                                        | ...               | ...               |
| 0.071 .....                                              | 1089                                              | 1518            | 1723            | ...                            | ...             | ...             | ...                                                        | ...               | ...               |
| 0.080 .....                                              | ...                                               | 1597            | 1806            | ...                            | ...             | ...             | ...                                                        | ...               | ...               |
| 0.090 .....                                              | ...                                               | 1686            | 1898            | ...                            | ...             | ...             | ...                                                        | ...               | ...               |
| 0.100 .....                                              | ...                                               | ...             | 1990            | ...                            | ...             | ...             | ...                                                        | ...               | ...               |
| 0.125 .....                                              | ...                                               | ...             | 2221            | ...                            | ...             | ...             | ...                                                        | ...               | ...               |
| 0.160 .....                                              | ...                                               | ...             | 2543            | ...                            | ...             | ...             | ...                                                        | ...               | ...               |

a Test data from which the yield and ultimate strengths were derived can be found in Reference 8.1.2.1.  
b Yield value is less than 2/3 of indicated ultimate.  
c Rivet shear strength is documented in NAS1198 as 90 ksi.  
d Permanent set at yield load: 0.005 inch.  
Note: Because of difficulties encountered upsetting countersunk head rivets in thin A-286 sheet, such conditions should be avoided in design.

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Table 8.1.2.2(a). Static Joint Strength of 100° Flush Head Monel Solid Rivets in Machine-Countersunk Stainless Steel Sheet

|                                                          |                                   |                               |                   |                  |                  |                  |                                       |                 |                  |                  |
|----------------------------------------------------------|-----------------------------------|-------------------------------|-------------------|------------------|------------------|------------------|---------------------------------------|-----------------|------------------|------------------|
| Rivet Type .....                                         | MS20427M ( $F_{su} = 49$ ksi)     |                               |                   |                  |                  |                  |                                       |                 |                  |                  |
| Sheet Material .....                                     | AISI 302-Annealed                 |                               |                   | AISI 301-¼ Hard  |                  |                  | AISI 301-½ Hard<br>AISI 301-Full Hard |                 |                  |                  |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) | 1/8<br>(0.1285)                   | 5/32<br>(0.159)               | 3/16<br>(0.191)   | 1/8<br>(0.1285)  | 5/32<br>(0.159)  | 3/16<br>(0.191)  | 3/32<br>(0.096)                       | 1/8<br>(0.1285) | 5/32<br>(0.159)  | 3/16<br>(0.191)  |
| Sheet thickness, in.:                                    | Ultimate Strength, lbs            |                               |                   |                  |                  |                  |                                       |                 |                  |                  |
| 0.040 .....                                              | 439 <sup>a</sup>                  | ...                           | ...               | 439              | ...              | ...              | 251                                   | 439             | ...              | ...              |
| 0.050 .....                                              | 526 <sup>a</sup>                  | <sup>b</sup> 673 <sup>a</sup> | ...               | 468              | <sup>b</sup> 673 | ...              | 322                                   | 447             | <sup>b</sup> 673 | ...              |
| 0.063 .....                                              | 635 <sup>a</sup>                  | 820 <sup>a</sup>              | <sup>b</sup> ...  | 595              | 732              | <sup>b</sup> ... | 355                                   | 538             | 688              | <sup>b</sup> ... |
| 0.071 .....                                              | ...                               | 915 <sup>a</sup>              | 1110 <sup>a</sup> | 635              | 830              | 990              | ...                                   | 615             | 741              | 984              |
| 0.080 .....                                              | ...                               | 973 <sup>a</sup>              | 1246 <sup>a</sup> | <sup>b</sup> ... | 936              | 1118             | <sup>b</sup> ...                      | 635             | 850              | 995              |
| 0.090 .....                                              | ...                               | ...                           | 1380 <sup>a</sup> | ...              | 973              | 1255             | ...                                   | ...             | 973              | 1132             |
| 0.100 .....                                              | ...                               | ...                           | 1400              | ...              | ...              | 1400             | ...                                   | ...             | ...              | 1280             |
| 0.125 .....                                              | ...                               | ...                           | ...               | ...              | ...              | ...              | ...                                   | ...             | ...              | 1400             |
| Rivet shear strength <sup>c</sup> .....                  | 635                               | 973                           | 1400              | 635              | 973              | 1400             | 355                                   | 635             | 973              | 1400             |
| Sheet thickness, in.:                                    | Yield Strength <sup>d</sup> , lbs |                               |                   |                  |                  |                  |                                       |                 |                  |                  |
| 0.040 .....                                              | 259                               | ...                           | ...               | 368              | ...              | ...              | 212                                   | 324             | ...              | ...              |
| 0.050 .....                                              | 324                               | 402                           | ...               | 442              | 570              | ...              | 293                                   | 360             | 498              | ...              |
| 0.063 .....                                              | 408                               | 506                           | ...               | 492              | 686              | ...              | 355                                   | 480             | 557              | ...              |
| 0.071 .....                                              | ...                               | 570                           | 685               | 561              | 714              | 958              | ...                                   | 561             | 630              | 780              |
| 0.080 .....                                              | ...                               | 643                           | 771               | ...              | 764              | 1012             | ...                                   | 635             | 765              | 848              |
| 0.090 .....                                              | ...                               | ...                           | 865               | ...              | 893              | 1062             | ...                                   | ...             | 893              | 1000             |
| 0.100 .....                                              | ...                               | ...                           | 965               | ...              | ...              | 1160             | ...                                   | ...             | ...              | 1160             |
| 0.125 .....                                              | ...                               | ...                           | ...               | ...              | ...              | ...              | ...                                   | ...             | ...              | 1400             |
| Head height (ref.), in. ....                             | 0.048                             | 0.061                         | 0.077             | 0.048            | 0.061            | 0.077            | 0.042                                 | 0.048           | 0.061            | 0.077            |

a Yield value is less than 2/3 of the indicated ultimate strength value.  
b Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
c Rivet shear strength is documented in MS20427M.  
d Permanent set at yield load: 0.005 inch.

**Table 8.1.2.2(b). Static Joint Strength of 100° Flush Head Monel Solid Rivets in Dimpled Stainless Steel Sheet**

| Rivet Type .....                        | MS20427M ( $F_{su} = 49$ ksi) |         |         |         |                     |         |         |                     |          |         |         |
|-----------------------------------------|-------------------------------|---------|---------|---------|---------------------|---------|---------|---------------------|----------|---------|---------|
| Sheet Material .....                    | AISI 302 - annealed           |         |         |         | AISI 301 - 1/4 hard |         |         | AISI 301 - 1/2 hard |          |         |         |
| Rivet Diameter, in. ....                | 1/8                           | 5/32    | 3/16    | 1/4     | 1/8                 | 5/32    | 3/16    | 3/32                | 1/8      | 5/32    | 3/16    |
| (Nominal Hole Diameter, in.) .....      | (0.1285)                      | (0.159) | (0.191) | (0.257) | (0.1285)            | (0.159) | (0.191) | (0.096)             | (0.1285) | (0.159) | (0.191) |
| Ultimate Strength, lbs.                 |                               |         |         |         |                     |         |         |                     |          |         |         |
| Sheet thickness, in.:                   |                               |         |         |         |                     |         |         |                     |          |         |         |
| 0.020 .....                             | 348                           | ...     | ...     | ...     | 497                 | ...     | ...     | 348                 | 497      | ...     | ...     |
| 0.025 .....                             | 441                           | 536     | ...     | ...     | 595                 | 766     | ...     | 355                 | 595      | 766     | ...     |
| 0.032 .....                             | 568                           | 698     | 846     | ...     | 635                 | 931     | 1163    | ...                 | 635      | 931     | 1163    |
| 0.040 .....                             | 635                           | 884     | 1046    | 1370    | ...                 | 973     | 1382    | ...                 | ...      | 973     | 1382    |
| 0.050 .....                             | ...                           | 973     | 1320    | 1730    | ...                 | ...     | 1405    | ...                 | ...      | ...     | 1405    |
| 0.063 .....                             | ...                           | ...     | 1405    | 2240    | ...                 | ...     | ...     | ...                 | ...      | ...     | ...     |
| 0.071 .....                             | ...                           | ...     | ...     | 2490    | ...                 | ...     | ...     | ...                 | ...      | ...     | ...     |
| 0.080 .....                             | ...                           | ...     | ...     | 2540    | ...                 | ...     | ...     | ...                 | ...      | ...     | ...     |
| Rivet shear strength <sup>a</sup> ..... | 635                           | 973     | 1405    | 2540    | 635                 | 973     | 1405    | 355                 | 635      | 973     | 1405    |
| Yield Strength <sup>b</sup> , lbs.      |                               |         |         |         |                     |         |         |                     |          |         |         |
| Sheet thickness, in.:                   |                               |         |         |         |                     |         |         |                     |          |         |         |
| 0.020 .....                             | 336                           | ...     | ...     | ...     | 449                 | ...     | ...     | 329                 | 449      | ...     | ...     |
| 0.025 .....                             | 427                           | 518     | ...     | ...     | 533                 | 681     | ...     | 355                 | 533      | 681     | ...     |
| 0.032 .....                             | 550                           | 679     | 801     | ...     | 635                 | 842     | 1049    | ...                 | 635      | 842     | 1049    |
| 0.040 .....                             | 635                           | 856     | 1020    | 1326    | ...                 | 973     | 1252    | ...                 | ...      | 973     | 1252    |
| 0.050 .....                             | ...                           | 973     | 1280    | 1678    | ...                 | ...     | 1405    | ...                 | ...      | ...     | 1405    |
| 0.063 .....                             | ...                           | ...     | 1405    | 2140    | ...                 | ...     | ...     | ...                 | ...      | ...     | ...     |
| 0.071 .....                             | ...                           | ...     | ...     | 2420    | ...                 | ...     | ...     | ...                 | ...      | ...     | ...     |
| 0.080 .....                             | ...                           | ...     | ...     | 2540    | ...                 | ...     | ...     | ...                 | ...      | ...     | ...     |
| Head height (max.), in. ....            | 0.048                         | 0.061   | 0.077   | 0.103   | 0.048               | 0.061   | 0.077   | 0.042               | 0.048    | 0.061   | 0.077   |

a Rivet shear strength from Table 8.1.2(b).

b Permanent set at yield load: 0.005 inch.

**Table 8.1.2.2(c). Static Joint Strength of 100° Flush Head Aluminum Alloy (2117-T3) Solid Rivets in Dimpled Aluminum Alloy Sheet<sup>a,b</sup>**

| Rivet Type .....                                               | MS20426AD ( $F_{su} = 30$ ksi)              |                 |                     |                 |                      |                 |                     |                 |                 |
|----------------------------------------------------------------|---------------------------------------------|-----------------|---------------------|-----------------|----------------------|-----------------|---------------------|-----------------|-----------------|
|                                                                | 2024-T3<br>2024-T42<br>2024-T62<br>2024-T81 |                 | 2024-T3<br>2024-T42 |                 | 2024-T62<br>2024-T81 |                 | 2024-T86<br>7075-T6 |                 |                 |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) ..... | 3/32<br>(0.096)                             | 1/8<br>(0.1285) | 5/32<br>(0.159)     | 3/16<br>(0.191) | 5/32<br>(0.159)      | 3/16<br>(0.191) | 1/8<br>(0.1285)     | 5/32<br>(0.159) | 3/16<br>(0.191) |
| Sheet thickness, in.:                                          | Ultimate Strength, lbs.                     |                 |                     |                 |                      |                 |                     |                 |                 |
|                                                                |                                             |                 |                     |                 |                      |                 |                     |                 |                 |
| 0.016 .....                                                    | 177                                         | ...             | ...                 | ...             | ...                  | ...             | ...                 | ...             | ...             |
| 0.020 .....                                                    | 209                                         | 299             | ...                 | ...             | ...                  | ...             | 302                 | ...             | ...             |
| 0.025 .....                                                    | 217                                         | 360             | 474                 | ...             | 462                  | ...             | 383                 | 462             | ...             |
| 0.032 .....                                                    | ...                                         | 388             | 568                 | 722             | 596                  | 725             | 388                 | 596             | 725             |
| 0.040 .....                                                    | ...                                         | ...             | 596                 | 839             | ...                  | 862             | ...                 | ...             | 862             |
| 0.050 .....                                                    | ...                                         | ...             | ...                 | 862             | ...                  | ...             | ...                 | ...             | ...             |
| Rivet shear strength <sup>c</sup> .....                        | 217                                         | 388             | 596                 | 862             | 596                  | 862             | 388                 | 596             | 862             |
| Sheet thickness, in.:                                          | Yield Strength <sup>d</sup> , lbs.          |                 |                     |                 |                      |                 |                     |                 |                 |
|                                                                |                                             |                 |                     |                 |                      |                 |                     |                 |                 |
| 0.016 .....                                                    | 154                                         | ...             | ...                 | ...             | ...                  | ...             | ...                 | ...             | ...             |
| 0.020 .....                                                    | 184                                         | 257             | ...                 | ...             | ...                  | ...             | 257                 | ...             | ...             |
| 0.025 .....                                                    | 209                                         | 315             | 324                 | ...             | 324                  | ...             | 315                 | 410             | ...             |
| 0.032 .....                                                    | ...                                         | 367             | 430                 | 512             | 430                  | 512             | 367                 | 525             | 640             |
| 0.040 .....                                                    | ...                                         | ...             | 506                 | 644             | ...                  | 644             | ...                 | ...             | 782             |
| 0.050 .....                                                    | ...                                         | ...             | ...                 | 757             | ...                  | ...             | ...                 | ...             | ...             |
| Head height (max.), in. ....                                   | 0.036                                       | 0.042           | 0.055               | 0.070           | 0.055                | 0.070           | 0.042               | 0.055           | 0.070           |

a These allowables apply to double dimpled sheets and to the upper sheet dimpled into a machine-countersunk lower sheet. Sheet gage is that of the thinnest sheet for double dimpled joints and of the upper dimpled sheet for dimpled, machine-countersunk joints. The thickness of machine-countersunk sheet must be at least one tabulated gage thicker than the upper sheet. In no case shall allowables be obtained by extrapolation for gages other than those shown.

b Test data from which the yield strengths listed were derived and can be found in Reference 8.1.2.2.

c Rivet shear strength from Table 8.1.2(b).

d Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.

**Table 8.1.2.2(d). Static Joint Strength of 100° Flush Head Aluminum Alloy (2017-T3) Solid Rivets in Dimpled Aluminum Alloy Sheet<sup>a,b</sup>**

| Rivet Type .....                        | MS20426D ( $F_{su} = 38$ ksi) |         |         |                      |         |         |                       |         |         |
|-----------------------------------------|-------------------------------|---------|---------|----------------------|---------|---------|-----------------------|---------|---------|
| Sheet Material .....                    | 2024-T3 and 2024-T42          |         |         | 2024-T86 and 7075-T6 |         |         | 2024-T62 and 2024-T81 |         |         |
| Rivet Diameter, in. ....                | 5/32                          | 3/16    | 1/4     | 5/32                 | 3/16    | 1/4     | 5/32                  | 3/16    | 1/4     |
| (Nominal Hole Diameter, in.) ....       | (0.159)                       | (0.191) | (0.257) | (0.159)              | (0.191) | (0.257) | (0.159)               | (0.191) | (0.257) |
| Ultimate Strength, lbs.                 |                               |         |         |                      |         |         |                       |         |         |
| Sheet thickness, in.:                   |                               |         |         |                      |         |         |                       |         |         |
| 0.025 .....                             | 419                           | ...     | ...     | 530                  | ...     | ...     | 419                   | ...     | ...     |
| 0.032 .....                             | 600                           | 681     | ...     | 672                  | 822     | ...     | 600                   | 681     | ...     |
| 0.040 .....                             | 738                           | 905     | 845     | 755                  | 1000    | 1108    | 738                   | 905     | 1108    |
| 0.050 .....                             | 755                           | 1090    | 1332    | ...                  | 1090    | 1508    | 755                   | 1090    | 1508    |
| 0.063 .....                             | ...                           | ...     | 1695    | ...                  | ...     | 1803    | ...                   | ...     | 1803    |
| 0.071 .....                             | ...                           | ...     | 1853    | ...                  | ...     | 1930    | ...                   | ...     | 1930    |
| 0.080 .....                             | ...                           | ...     | 1970    | ...                  | ...     | 1970    | ...                   | ...     | 1970    |
| Rivet shear strength <sup>c</sup> ..... | 755                           | 1090    | 1970    | 755                  | 1090    | 1970    | 755                   | 1090    | 1970    |
| Yield Strength <sup>d</sup> , lbs.      |                               |         |         |                      |         |         |                       |         |         |
| Sheet thickness, in.:                   |                               |         |         |                      |         |         |                       |         |         |
| 0.025 .....                             | 336                           | ...     | ...     | 450                  | ...     | ...     | 336                   | ...     | ...     |
| 0.032 .....                             | 483                           | 546     | ...     | 581                  | ...     | ...     | 483                   | 546     | ...     |
| 0.040 .....                             | 589                           | 730     | 845     | 675                  | 705     | 978     | 589                   | 730     | 845     |
| 0.050 .....                             | 681                           | 888     | 1187    | ...                  | 867     | 1508    | 681                   | 888     | 1187    |
| 0.063 .....                             | ...                           | ...     | 1415    | ...                  | 1007    | 1803    | ...                   | ...     | 1415    |
| 0.071 .....                             | ...                           | ...     | 1656    | ...                  | ...     | 1930    | ...                   | ...     | 1656    |
| 0.080 .....                             | ...                           | ...     | 1870    | ...                  | ...     | 1970    | ...                   | ...     | 1870    |
| Head height (max.), in. ....            | 0.055                         | 0.070   | 0.095   | 0.055                | 0.070   | 0.095   | 0.055                 | 0.070   | 0.095   |

a These allowables apply to double dimpled sheets and to the upper sheet dimpled into a machine-countersunk lower sheet. Sheet gage is that of the thinnest sheet for double dimpled joints and of the upper dimpled sheet for dimpled, machine-countersunk joints. The thickness of machine-countersunk sheet must be at least one tabulated gage thicker than the upper sheet. In no case shall allowables be obtained by extrapolation for gages other than those shown.

b Test data from which the yield strengths listed were derived and can be found in Reference 8.1.2.2.

c Rivet shear strength from Table 8.1.2(b).

d Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.

Table 8.1.2.2(e). Static Joint Strength of 100° Flush Head Aluminum Alloy (2024-T31) Solid Rivets in Dimpled Aluminum Alloy Sheet<sup>a,b</sup>

| Rivet Type . . . . .                        | MS20426DD ( $F_{su}$ = 41 ksi)     |                |                      |                |                     |                |
|---------------------------------------------|------------------------------------|----------------|----------------------|----------------|---------------------|----------------|
|                                             | 2024-T3<br>2024-T42                |                | 2024-T62<br>2024-T81 |                | 2024-T86<br>7075-T6 |                |
|                                             | 3/16<br>(0.191)                    | 1/4<br>(0.257) | 3/16<br>(0.191)      | 1/4<br>(0.257) | 3/16<br>(0.191)     | 1/4<br>(0.257) |
| Rivet Diameter, in. . . . .                 |                                    |                |                      |                |                     |                |
| (Nominal Hole Diameter, in.) . .            |                                    |                |                      |                |                     |                |
|                                             | Ultimate Strength, lbs.            |                |                      |                |                     |                |
| Sheet thickness, in.:                       |                                    |                |                      |                |                     |                |
| 0.032 . . . . .                             | 744                                | ...            | 786                  | ...            | 786                 | ...            |
| 0.040 . . . . .                             | 941                                | 879            | 982                  | 1300           | 982                 | 1300           |
| 0.050 . . . . .                             | 1110                               | 1359           | 1152                 | 1705           | 1152                | 1705           |
| 0.063 . . . . .                             | 1175                               | 1727           | 1175                 | 2010           | 1175                | 2010           |
| 0.071 . . . . .                             | ...                                | 1883           | ...                  | 2125           | ...                 | 2125           |
| 0.080 . . . . .                             | ...                                | 2025           | ...                  | ...            | ...                 | ...            |
| 0.090 . . . . .                             | ...                                | 2125           | ...                  | ...            | ...                 | ...            |
| Rivet shear strength <sup>c</sup> . . . . . | 1175                               | 2125           | 1175                 | 2125           | 1175                | 2125           |
|                                             | Yield Strength <sup>d</sup> , lbs. |                |                      |                |                     |                |
| Sheet thickness, in.:                       |                                    |                |                      |                |                     |                |
| 0.032 . . . . .                             | 582                                | ...            | 649                  | ...            | 786                 | ...            |
| 0.040 . . . . .                             | 666                                | 879            | 816                  | 962            | 982                 | 978            |
| 0.050 . . . . .                             | 738                                | 1308           | 961                  | 1308           | 1152                | 1543           |
| 0.063 . . . . .                             | 925                                | 1564           | 1068                 | 1564           | 1175                | 1958           |
| 0.071 . . . . .                             | ...                                | 1711           | ...                  | 1711           | ...                 | 2125           |
| 0.080 . . . . .                             | ...                                | 1928           | ...                  | ...            | ...                 | ...            |
| 0.090 . . . . .                             | ...                                | 2121           | ...                  | ...            | ...                 | ...            |
| Head height (max.), in. . . . .             | 0.070                              | 0.095          | 0.070                | 0.095          | 0.070               | 0.095          |

a These allowables apply to double dimpled sheets and to the upper sheet dimpled into a machine-countersunk lower sheet. Sheet gage is that of the thinnest sheet for double dimpled joints and of the upper dimpled sheet for dimpled, machine-countersunk joints. The thickness of machine-countersunk sheet must be at least one tabulated gage thicker than the upper sheet. In no case shall allowables be obtained by extrapolation for gages other than those shown.

b Test data from which the yield strengths listed were derived and can be found in Reference 8.1.2.2.

c Rivet shear strength from Table 8.1.2(b).

d Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.

Table 8.1.2.2(f). Static Joint Strength of 100° Flush Head Aluminum Alloy Solid Rivets in Machine-Countersunk Aluminum Alloy Sheet

| Rivet Type .....                                         | MS20426AD (2117-T3)<br>(F <sub>su</sub> = 30 ksi) |                  |                  |                  | MS20426D (2017-T3)<br>(F <sub>su</sub> = 38 ksi) |                               |                   | MS20426DD<br>(2024-T31)<br>(F <sub>su</sub> = 41 ksi) |                   |
|----------------------------------------------------------|---------------------------------------------------|------------------|------------------|------------------|--------------------------------------------------|-------------------------------|-------------------|-------------------------------------------------------|-------------------|
| Sheet Material .....                                     | Clad 2024-T42                                     |                  |                  |                  |                                                  |                               |                   |                                                       |                   |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) | 3/32<br>(0.096)                                   | 1/8<br>(0.1285)  | 5/32<br>(0.159)  | 3/16<br>(0.191)  | 5/32<br>(0.159)                                  | 3/16<br>(0.191)               | 1/4<br>(0.257)    | 3/16<br>(0.191)                                       | 1/4<br>(0.257)    |
| Sheet thickness, in.:                                    | Ultimate Strength <sup>a</sup> , lbs              |                  |                  |                  |                                                  |                               |                   |                                                       |                   |
|                                                          | 178                                               | ...              | ...              | ...              | ...                                              | ...                           | ...               | ...                                                   | ...               |
|                                                          | 193                                               | <sup>c</sup> 309 | ...              | ...              | ...                                              | ...                           | ...               | ...                                                   | ...               |
|                                                          | 206                                               | 340              | <sup>c</sup> 479 | ...              | 580 <sup>b</sup>                                 | ...                           | ...               | ...                                                   | ...               |
|                                                          | 216                                               | 363              | 523              | <sup>c</sup> 705 | 657 <sup>b</sup>                                 | <sup>c</sup> 859 <sup>b</sup> | ...               | 886                                                   | ...               |
|                                                          | ...                                               | 373              | 542              | 739              | <sup>c</sup> 690                                 | 917 <sup>b</sup>              | <sup>c</sup> ...  | 942                                                   | <sup>c</sup> ...  |
|                                                          | ...                                               | ...              | 560              | 769              | 720                                              | 969 <sup>b</sup>              | ...               | 992                                                   | ...               |
|                                                          | ...                                               | ...              | 575              | 795              | 746                                              | 1015                          | 1552 <sup>b</sup> | 1035                                                  | 1647 <sup>b</sup> |
|                                                          | ...                                               | ...              | ...              | 818              | ...                                              | 1054                          | 1640 <sup>b</sup> | <sup>c</sup> 1073                                     | 1738 <sup>b</sup> |
|                                                          | ...                                               | ...              | ...              | 853              | ...                                              | 1090                          | 1773              | 1131                                                  | 1877              |
|                                                          | ...                                               | ...              | ...              | ...              | ...                                              | ...                           | 1891              | ...                                                   | 2000              |
|                                                          | ...                                               | ...              | ...              | ...              | ...                                              | ...                           | 1970              | ...                                                   | 2084              |
| Rivet shear strength <sup>d</sup> .....                  | 217                                               | 388              | 596              | 862              | 755                                              | 1090                          | 1970              | 1175                                                  | 2125              |
| Sheet thickness, in.:                                    | Yield Strength <sup>a,e</sup> , lbs               |                  |                  |                  |                                                  |                               |                   |                                                       |                   |
|                                                          | 132                                               | ...              | ...              | ...              | ...                                              | ...                           | ...               | ...                                                   | ...               |
|                                                          | 153                                               | 231              | ...              | ...              | ...                                              | ...                           | ...               | ...                                                   | ...               |
|                                                          | 188                                               | 261              | 321              | ...              | 345                                              | ...                           | ...               | ...                                                   | ...               |
|                                                          | 213                                               | 321              | 402              | 471              | 401                                              | 515                           | ...               | 614                                                   | ...               |
|                                                          | ...                                               | 348              | 453              | 538              | 481                                              | 557                           | ...               | 669                                                   | ...               |
|                                                          | ...                                               | ...              | 498              | 616              | 562                                              | 623                           | ...               | 761                                                   | ...               |
|                                                          | ...                                               | ...              | 537              | 685              | 633                                              | 746                           | 861               | 842                                                   | 1053              |
|                                                          | ...                                               | ...              | ...              | 745              | ...                                              | 854                           | 1017              | 913                                                   | 1115              |
|                                                          | ...                                               | ...              | ...              | 836              | ...                                              | 1018                          | 1313              | 1021                                                  | 1357              |
|                                                          | ...                                               | ...              | ...              | ...              | ...                                              | ...                           | 1574              | ...                                                   | 1694              |
|                                                          | ...                                               | ...              | ...              | ...              | ...                                              | ...                           | 1753              | ...                                                   | 1925              |
| Head height (ref.), in. ....                             | 0.036                                             | 0.042            | 0.055            | 0.070            | 0.055                                            | 0.070                         | 0.095             | 0.070                                                 | 0.095             |

a Test data from which the yield and ultimate strength listed were derived can be found in Reference 8.1.2.2.  
b Yield value is less than 2/3 of the indicated ultimate strength value.  
c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
d Rivet shear strength is documented in MS20426.  
e Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.



**Table 8.1.2.2(g). Static Joint Strength of 100° Flush Head Aluminum Alloy (5056-H321) Solid Rivets in Machine-Countersunk Magnesium Alloy Sheet**

|                                                            |                                   |                               |                               |                               |                   |
|------------------------------------------------------------|-----------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------|
| Rivet Type .....                                           | MS20426B ( $F_{su} = 28$ ksi)     |                               |                               |                               |                   |
| Sheet Material .....                                       | AZ31B-H24                         |                               |                               |                               |                   |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) . | 3/32<br>(0.096)                   | 1/8<br>(0.1285)               | 5/32<br>(0.159)               | 3/16<br>(0.191)               | 1/4<br>(0.257)    |
| Sheet thickness, in.:                                      | Ultimate Strength, lbs            |                               |                               |                               |                   |
|                                                            | 172 <sup>a</sup>                  | ...                           | ...                           | ...                           | ...               |
|                                                            | 180                               | <sup>b</sup> 304 <sup>a</sup> | ...                           | ...                           | ...               |
|                                                            | 190                               | 318                           | <sup>b</sup> 467 <sup>a</sup> | ...                           | ...               |
|                                                            | 203                               | 337                           | 490                           | <sup>b</sup> 679 <sup>a</sup> | ...               |
|                                                            | ...                               | 348                           | 503                           | 697 <sup>a</sup>              | <sup>b</sup> ...  |
|                                                            | ...                               | 360                           | 519                           | 715                           | ...               |
|                                                            | ...                               | 363                           | 536                           | 737                           | 1244              |
|                                                            | ...                               | ...                           | 554                           | 757                           | 1271 <sup>b</sup> |
|                                                            | ...                               | ...                           | 556                           | 802                           | 1343              |
|                                                            | ...                               | ...                           | ...                           | ...                           | 1440              |
|                                                            | ...                               | ...                           | ...                           | ...                           | 1450              |
| Rivet shear strength <sup>c</sup> .....                    | 203                               | 363                           | 556                           | 802                           | 1450              |
| Sheet thickness, in.:                                      | Yield Strength <sup>d</sup> , lbs |                               |                               |                               |                   |
|                                                            | 104                               | ...                           | ...                           | ...                           | ...               |
|                                                            | 127                               | 172                           | ...                           | ...                           | ...               |
|                                                            | 152                               | 214                           | 268                           | ...                           | ...               |
|                                                            | 186                               | 259                           | 334                           | 409                           | ...               |
|                                                            | ...                               | 287                           | 369                           | 459                           | ...               |
|                                                            | ...                               | 318                           | 406                           | 504                           | ...               |
|                                                            | ...                               | 353                           | 450                           | 555                           | 792               |
|                                                            | ...                               | ...                           | 491                           | 606                           | 856               |
|                                                            | ...                               | ...                           | 556                           | 735                           | 1030              |
|                                                            | ...                               | ...                           | ...                           | ...                           | 1273              |
|                                                            | ...                               | ...                           | ...                           | ...                           | 1450              |
| Head height (ref.), in. ....                               | 0.036                             | 0.042                         | 0.055                         | 0.070                         | 0.095             |

a Yield value is less than 2/3 of the indicated ultimate strength value.  
b Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
c Rivet shear strength is documented in MS20426.  
d Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.

**Table 8.1.2.2(h). Static Joint Strength of 100° Flush Head Monel Solid Rivets in Machine-Countersunk Titanium Alloy Sheet**

|                                                                                                                                                              |                                               |                  |                  |                   |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|------------------|------------------|-------------------|
| Rivet Type .....                                                                                                                                             | MS20427M ( $F_{su} = 49$ ksi)                 |                  |                  |                   |
| Sheet Material .....                                                                                                                                         | Commercially Pure Titanium, $F_{tu} = 80$ ksi |                  |                  |                   |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) .....                                                                                               | 1/8<br>(0.1285)                               | 5/32<br>(0.159)  | 3/16<br>(0.191)  | 1/4<br>(0.257)    |
| Sheet thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 ..... | Ultimate Strength, lbs                        |                  |                  |                   |
|                                                                                                                                                              | 531                                           | ...              | ...              | ...               |
|                                                                                                                                                              | 573                                           | <sup>a</sup> 818 | ...              | ...               |
|                                                                                                                                                              | 626                                           | 885              | <sup>a</sup> ... | ...               |
|                                                                                                                                                              | 635                                           | 926              | 1242             | ...               |
|                                                                                                                                                              | ...                                           | 973              | 1302             | <sup>a</sup> ...  |
|                                                                                                                                                              | ...                                           | ...              | 1360             | ...               |
|                                                                                                                                                              | ...                                           | ...              | 1400             | 2260              |
|                                                                                                                                                              | ...                                           | ...              | ...              | 2460 <sup>a</sup> |
|                                                                                                                                                              | ...                                           | ...              | ...              | 2540              |
|                                                                                                                                                              | 635                                           | 973              | 1400             | 2540              |
| Sheet thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 ..... | Yield Strength <sup>c</sup> , lbs             |                  |                  |                   |
|                                                                                                                                                              | 376                                           | ...              | ...              | ...               |
|                                                                                                                                                              | 472                                           | 582              | ...              | ...               |
|                                                                                                                                                              | 598                                           | 736              | ...              | ...               |
|                                                                                                                                                              | 635                                           | 835              | 933              | ...               |
|                                                                                                                                                              | ...                                           | 945              | 1130             | ...               |
|                                                                                                                                                              | ...                                           | ...              | 1268             | ...               |
|                                                                                                                                                              | ...                                           | ...              | 1400             | 1860              |
|                                                                                                                                                              | ...                                           | ...              | ...              | 2340              |
|                                                                                                                                                              | ...                                           | ...              | ...              | 2540              |
| Head height (max.), in. ....                                                                                                                                 | 0.048                                         | 0.061            | 0.077            | 0.103             |

a Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.

b Rivet shear strength is documented in MS20427.

c Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.

Table 8.1.2.2(i). Static Joint Strength of 120° Flush Shear Head Aluminum Alloy (2017-T3) Solid Rivets in Machine-Countersunk Aluminum Alloy Sheet

|                                                                                                                                                                                                                                       |                                          |                 |                 |                 |                |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------|-----------------|-----------------|-----------------|----------------|
| Rivet Type .....                                                                                                                                                                                                                      | BRFS-D <sup>a</sup> ( $F_{su}$ = 38 ksi) |                 |                 |                 |                |
| Sheet Material .....                                                                                                                                                                                                                  | Clad 2024-T3                             |                 |                 |                 |                |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) <sup>b</sup> .                                                                                                                                                               | 3/32<br>(0.096)                          | 1/8<br>(0.1285) | 5/32<br>(0.159) | 3/16<br>(0.191) | 1/4<br>(0.257) |
| Sheet thickness, in.:<br>0.020 .....<br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>Rivet shear strength <sup>c</sup> ..... | Ultimate Strength, lbs                   |                 |                 |                 |                |
|                                                                                                                                                                                                                                       | 139                                      | ...             | ...             | ...             | ...            |
|                                                                                                                                                                                                                                       | 176                                      | 233             | ...             | ...             | ...            |
|                                                                                                                                                                                                                                       | 226                                      | 300             | 367             | ...             | ...            |
|                                                                                                                                                                                                                                       | 275                                      | 378             | 465             | 552             | ...            |
|                                                                                                                                                                                                                                       | ...                                      | 477             | 585             | 697             | 930            |
|                                                                                                                                                                                                                                       | ...                                      | 494             | 741             | 886             | 1182           |
|                                                                                                                                                                                                                                       | ...                                      | ...             | 755             | 1005            | 1338           |
|                                                                                                                                                                                                                                       | ...                                      | ...             | ...             | 1090            | 1513           |
|                                                                                                                                                                                                                                       | ...                                      | ...             | ...             | ...             | 1711           |
|                                                                                                                                                                                                                                       | ...                                      | ...             | ...             | ...             | 1902           |
|                                                                                                                                                                                                                                       | ...                                      | ...             | ...             | ...             | 1970           |
|                                                                                                                                                                                                                                       | 275                                      | 494             | 755             | 1090            | 1970           |
| Sheet thickness, in.:<br>0.020 .....<br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....                                            | Yield Strength <sup>d</sup> , lbs        |                 |                 |                 |                |
|                                                                                                                                                                                                                                       | 137                                      | ...             | ...             | ...             | ...            |
|                                                                                                                                                                                                                                       | 171                                      | 229             | ...             | ...             | ...            |
|                                                                                                                                                                                                                                       | 207                                      | 294             | 359             | ...             | ...            |
|                                                                                                                                                                                                                                       | 231                                      | 357             | 453             | 547             | ...            |
|                                                                                                                                                                                                                                       | ...                                      | 398             | 550             | 680             | 918            |
|                                                                                                                                                                                                                                       | ...                                      | 451             | 614             | 814             | 1149           |
|                                                                                                                                                                                                                                       | ...                                      | ...             | 655             | 857             | 1295           |
|                                                                                                                                                                                                                                       | ...                                      | ...             | ...             | 914             | 1430           |
|                                                                                                                                                                                                                                       | ...                                      | ...             | ...             | ...             | 1513           |
|                                                                                                                                                                                                                                       | ...                                      | ...             | ...             | ...             | 1592           |
|                                                                                                                                                                                                                                       | ...                                      | ...             | ...             | ...             | 1790           |
| Head height (ref.), in. ....                                                                                                                                                                                                          | 0.018                                    | 0.023           | 0.030           | 0.039           | 0.049          |

a Data supplied by Briles Rivet Corp.  
b Fasteners installed in hole diameters of 0.0975, 0.1285, 0.1615, 0.1945, 0.257, +0.0005, -0.001, respectively.  
c Shear strength based on Table 8.1.2(b) and  $F_{su}$  = 38 ksi.  
d Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

Table 8.1.2.2(j). Static Joint Strength of 120° Flush Shear Head Aluminum Alloy (2117-T3) Solid Rivets in Machine-Countersunk Aluminum Alloy Sheet

|                                                                                                                                                                                                                                       |                                           |                 |                 |                 |                |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|-----------------|-----------------|-----------------|----------------|
| Rivet Type .....                                                                                                                                                                                                                      | BRFS-AD <sup>a</sup> ( $F_{su} = 30$ ksi) |                 |                 |                 |                |
| Sheet Material .....                                                                                                                                                                                                                  | Clad 2024-T3                              |                 |                 |                 |                |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) <sup>b</sup> .                                                                                                                                                               | 3/32<br>(0.096)                           | 1/8<br>(0.1285) | 5/32<br>(0.159) | 3/16<br>(0.191) | 1/4<br>(0.257) |
| Sheet thickness, in.:<br>0.020 .....<br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>Rivet shear strength <sup>c</sup> ..... | Ultimate Strength, lbs                    |                 |                 |                 |                |
|                                                                                                                                                                                                                                       | 119                                       | ...             | ...             | ...             | ...            |
|                                                                                                                                                                                                                                       | 144                                       | 201             | ...             | ...             | ...            |
|                                                                                                                                                                                                                                       | 171                                       | 250             | 316             | ...             | ...            |
|                                                                                                                                                                                                                                       | 204                                       | 292             | 386             | 474             | ...            |
|                                                                                                                                                                                                                                       | 217                                       | 343             | 451             | 571             | 806            |
|                                                                                                                                                                                                                                       | ...                                       | 388             | 536             | 675             | 987            |
|                                                                                                                                                                                                                                       | ...                                       | ...             | 596             | 737             | 1073           |
|                                                                                                                                                                                                                                       | ...                                       | ...             | ...             | 812             | 1169           |
|                                                                                                                                                                                                                                       | ...                                       | ...             | ...             | 862             | 1278           |
|                                                                                                                                                                                                                                       | ...                                       | ...             | ...             | ...             | 1371           |
|                                                                                                                                                                                                                                       | ...                                       | ...             | ...             | ...             | 1550           |
|                                                                                                                                                                                                                                       | 217                                       | 388             | 596             | 862             | 1550           |
| Sheet thickness, in.:<br>0.020 .....<br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....                                            | Yield Strength <sup>d</sup> , lbs         |                 |                 |                 |                |
|                                                                                                                                                                                                                                       | 119                                       | ...             | ...             | ...             | ...            |
|                                                                                                                                                                                                                                       | 144                                       | 201             | ...             | ...             | ...            |
|                                                                                                                                                                                                                                       | 171                                       | 250             | 316             | ...             | ...            |
|                                                                                                                                                                                                                                       | 204                                       | 292             | 386             | 474             | ...            |
|                                                                                                                                                                                                                                       | 217                                       | 343             | 451             | 571             | 806            |
|                                                                                                                                                                                                                                       | ...                                       | 388             | 536             | 675             | 987            |
|                                                                                                                                                                                                                                       | ...                                       | ...             | 596             | 737             | 1073           |
|                                                                                                                                                                                                                                       | ...                                       | ...             | ...             | 812             | 1169           |
|                                                                                                                                                                                                                                       | ...                                       | ...             | ...             | 862             | 1278           |
|                                                                                                                                                                                                                                       | ...                                       | ...             | ...             | ...             | 1371           |
|                                                                                                                                                                                                                                       | ...                                       | ...             | ...             | ...             | 1550           |
| Head height (ref.), in. ....                                                                                                                                                                                                          | 0.018                                     | 0.023           | 0.030           | 0.039           | 0.049          |

a Data supplied by Briles Rivet Corp.  
b Fasteners installed in hole diameters of 0.0975, 0.1285, 0.1615, 0.1945, 0.257, +0.0005, -0.001, respectively.  
c Shear strength based on Table 8.1.2(b) and  $F_{su} = 38$  ksi.  
d Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

Table 8.1.2.2(k). Static Joint Strength of 120° Flush Shear Head Aluminum Alloy (2024-T31) Solid Rivets in Machine-Countersunk Aluminum Alloy Sheet

|                                                                                                                                                                           |                                           |                |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|----------------|
| Rivet Type .....                                                                                                                                                          | BRFS-DD <sup>a</sup> ( $F_{su} = 41$ ksi) |                |
| Sheet Material .....                                                                                                                                                      | Clad 2024-T3                              |                |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) <sup>b</sup> ....                                                                                                | 3/16<br>(0.191)                           | 1/4<br>(0.257) |
| Sheet thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>Rivet shear strength <sup>c</sup> ..... | Ultimate Strength, lbs                    |                |
|                                                                                                                                                                           | 598                                       | ...            |
|                                                                                                                                                                           | 772                                       | 1000           |
|                                                                                                                                                                           | 994                                       | 1300           |
|                                                                                                                                                                           | 1130                                      | 1480           |
|                                                                                                                                                                           | 1180                                      | 1690           |
|                                                                                                                                                                           | ...                                       | 1920           |
|                                                                                                                                                                           | ...                                       | 2120           |
|                                                                                                                                                                           | 1180                                      | 2120           |
| Sheet thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....                                            | Yield Strength <sup>d</sup> , lbs         |                |
|                                                                                                                                                                           | 598                                       | ...            |
|                                                                                                                                                                           | 772                                       | 1000           |
|                                                                                                                                                                           | 949                                       | 1300           |
|                                                                                                                                                                           | 1000                                      | 1480           |
|                                                                                                                                                                           | 1060                                      | 1680           |
|                                                                                                                                                                           | ...                                       | 1760           |
|                                                                                                                                                                           | ...                                       | 1850           |
| Head height (ref.), in. ....                                                                                                                                              | 0.039                                     | 0.049          |

a Data supplied by Briles Rivet Corp.  
b Fasteners installed in hole diameters of 0.1935 and 0.257, ±0.0005.  
c Shear strength based on Table 8.1.2(b) and  $F_{su} = 41$  ksi.  
d Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

**Table 8.1.2.2(I). Static Joint Strength of 120° Flush Shear Head Ti-45 Cb Solid Rivets in Machine-Countersunk Aluminum Alloy and Titanium Sheet**

| Rivet Type .....                                                      | BRFS-T <sup>a</sup> ( $F_{su}$ = 53 ksi) |                 |                 |                    |                 |                 |
|-----------------------------------------------------------------------|------------------------------------------|-----------------|-----------------|--------------------|-----------------|-----------------|
| Sheet Material .....                                                  | Clad 7075-T6                             |                 |                 | Annealed Ti-6Al-4V |                 |                 |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) <sup>b</sup> | 1/8<br>(0.1285)                          | 5/32<br>(0.159) | 3/16<br>(0.191) | 1/8<br>(0.1285)    | 5/32<br>(0.159) | 3/16<br>(0.191) |
| Ultimate Strength, lbs                                                |                                          |                 |                 |                    |                 |                 |
| Sheet thickness, in.:                                                 |                                          |                 |                 |                    |                 |                 |
| 0.025 .....                                                           | 288                                      | ...             | ...             | 400                | ...             | ...             |
| 0.032 .....                                                           | 369                                      | 456             | ...             | 513                | 635             | ...             |
| 0.040 .....                                                           | 461                                      | 572             | 685             | 564                | 796             | 952             |
| 0.050 .....                                                           | 577                                      | 713             | 858             | 602                | 867             | 1190            |
| 0.063 .....                                                           | 610                                      | 891             | 1080            | 650                | 927             | 1270            |
| 0.071 .....                                                           | 628                                      | 914             | 1220            | 680                | 964             | 1310            |
| 0.080 .....                                                           | 649                                      | 939             | 1300            | 687                | 1005            | 1360            |
| 0.090 .....                                                           | 671                                      | 967             | 1330            | ...                | 1050            | 1420            |
| 0.100 .....                                                           | 687                                      | 996             | 1370            | ...                | ...             | 1470            |
| 0.125 .....                                                           | ...                                      | 1050            | 1450            | ...                | ...             | 1520            |
| 0.160 .....                                                           | ...                                      | ...             | 1520            | ...                | ...             | ...             |
| Rivet shear strength <sup>c</sup> .....                               | 687                                      | 1050            | 1520            | 687                | 1050            | 1520            |
| Yield Strength <sup>d</sup> , lbs                                     |                                          |                 |                 |                    |                 |                 |
| Sheet thickness, in.:                                                 |                                          |                 |                 |                    |                 |                 |
| 0.025 .....                                                           | 288                                      | ...             | ...             | 400                | ...             | ...             |
| 0.032 .....                                                           | 369                                      | 456             | ...             | 513                | 635             | ...             |
| 0.040 .....                                                           | 461                                      | 572             | 685             | 564                | 796             | 952             |
| 0.050 .....                                                           | 577                                      | 713             | 858             | 602                | 867             | 1190            |
| 0.063 .....                                                           | 610                                      | 891             | 1080            | 650                | 927             | 1270            |
| 0.071 .....                                                           | 628                                      | 914             | 1220            | 680                | 964             | 1310            |
| 0.080 .....                                                           | 649                                      | 939             | 1300            | 687                | 1005            | 1360            |
| 0.090 .....                                                           | 671                                      | 967             | 1330            | ...                | 1050            | 1420            |
| 0.100 .....                                                           | 687                                      | 996             | 1370            | ...                | ...             | 1470            |
| 0.125 .....                                                           | ...                                      | 1050            | 1450            | ...                | ...             | 1520            |
| 0.160 .....                                                           | ...                                      | ...             | 1520            | ...                | ...             | ...             |
| Head height (ref.), in. ....                                          | 0.023                                    | 0.030           | 0.039           | 0.023              | 0.030           | 0.039           |

a Data supplied by Briles Rivet Corp.  
b Allowables developed from tests with hole diameters noted, except 5/32 and 3/16 diameters were 0.161 and 0.1935 ±0.0005, respectively.  
c Rivet shear strength based on Table 8.1.2(b) and  $F_{su}$  = 53 ksi.  
d Permanent set at yield load: 4% of nominal hole diameter (Ref. 9.4.1.3.3).

**Table 8.1.2.2(m). Static Joint Strength of 120° Flush Shear Head Aluminum Alloy (7050-T731) Solid Rivets in Machine-Countersunk Aluminum Alloy Sheet**

|                                                                          |                                             |                  |                  |                  |                   |                 |                   |
|--------------------------------------------------------------------------|---------------------------------------------|------------------|------------------|------------------|-------------------|-----------------|-------------------|
| Rivet Type . . . . .                                                     | MS14218E <sup>a</sup> ( $F_{su} = 43$ ksi)  |                  |                  |                  |                   |                 |                   |
| Sheet Material . . . . .                                                 | Clad 2024-T3                                |                  |                  |                  |                   |                 |                   |
| Rivet Diameter, in. . . . .<br>(Nominal Hole Diameter, in.) <sup>b</sup> | 1/8<br>(0.1285)                             | 5/32<br>(0.159)  | 3/16<br>(0.191)  | 7/32<br>(0.228)  | 1/4<br>(0.257)    | 9/32<br>(0.290) | 5/16<br>(0.323)   |
| Sheet thickness, in.:                                                    | Ultimate Strength, lbs                      |                  |                  |                  |                   |                 |                   |
|                                                                          | 215                                         | ...              | ...              | ...              | ...               | ...             | ...               |
|                                                                          | 307                                         | <sup>c</sup> 346 | ...              | ...              | ...               | ...             | ...               |
|                                                                          | 434                                         | 478              | <sup>c</sup> 529 | ...              | ...               | ...             | ...               |
|                                                                          | 508                                         | 673              | 732              | <sup>c</sup> 806 | ...               | ...             | ...               |
|                                                                          | 536                                         | 781              | 1045             | 1135             | <sup>c</sup> 1200 | 1285            | ...               |
|                                                                          | 554                                         | 803              | 1110             | 1365             | 1445              | 1530            | <sup>c</sup> 1630 |
|                                                                          | 558                                         | 827              | 1140             | 1565             | 1735              | 1835            | 1930 <sup>c</sup> |
|                                                                          | ...                                         | 854              | 1175             | 1605             | 1990              | 2200            | 2320              |
|                                                                          | ...                                         | ...              | 1205             | 1645             | 2030              | 2525            | 2725              |
|                                                                          | ...                                         | ...              | 1230             | 1740             | 2140              | 2650            | 3205              |
|                                                                          | ...                                         | ...              | ...              | 1755             | 2230              | 2820            | 3400              |
|                                                                          | ...                                         | ...              | ...              | ...              | ...               | 2840            | 3525              |
|                                                                          | Rivet shear strength <sup>d</sup> . . . . . | 558              | 854              | 1230             | 1755              | 2230            | 2840              |
|                                                                          | Yield Strength <sup>e</sup> , lbs           |                  |                  |                  |                   |                 |                   |
|                                                                          | 215                                         | ...              | ...              | ...              | ...               | ...             | ...               |
|                                                                          | 307                                         | 346              | ...              | ...              | ...               | ...             | ...               |
|                                                                          | 388                                         | 478              | 529              | ...              | ...               | ...             | ...               |
|                                                                          | 487                                         | 601              | 721              | 806              | ...               | ...             | ...               |
|                                                                          | 536                                         | 760              | 912              | 1085             | 1200              | 1285            | ...               |
|                                                                          | 552                                         | 803              | 1030             | 1225             | 1377              | 1530            | 1630              |
|                                                                          | 558                                         | 827              | 1140             | 1385             | 1554              | 1755            | 1930              |
|                                                                          | ...                                         | 854              | 1175             | 1560             | 1750              | 1970            | 2200              |
|                                                                          | ...                                         | ...              | 1205             | 1645             | 1950              | 2200            | 2445              |
|                                                                          | ...                                         | ...              | 1230             | 1735             | 2140              | 2650            | 3060              |
|                                                                          | ...                                         | ...              | ...              | 1755             | 2230              | 2810            | 3400              |
|                                                                          | ...                                         | ...              | ...              | ...              | ...               | 2840            | 3525              |
| Head height (ref.), in. . . . .                                          | 0.027                                       | 0.035            | 0.044            | 0.053            | 0.061             | 0.069           | 0.077             |

a Data supplied by Briles Rivet Corp.

b Allowables developed from tests with hole diameters noted, except 5/32, 3/16, and 5/16 diameters were 0.161, 0.1935, and 0.316, respectively. Hole tolerances were +0.0005-0.001 inch.

c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.

d Shear strength based on Table 8.1.2(b) and  $F_{su} = 43$  ksi.

e Permanent set at yield load: 4% of nominal hole diameter (Ref. 9.4.1.3.3).

Table 8.1.2.2(n). Static Joint Strength of 100° Flush Shear Head Aluminum Alloy (7050-T73) Solid Rivets in Machine-Countersunk Aluminum Alloy Sheet

|                                                                              |                                             |                  |                  |                  |                 |                  |                  |                   |
|------------------------------------------------------------------------------|---------------------------------------------|------------------|------------------|------------------|-----------------|------------------|------------------|-------------------|
| Rivet Type .....                                                             | NAS1097-E <sup>a</sup> ( $F_{su} = 41$ ksi) |                  |                  |                  |                 |                  |                  |                   |
| Sheet Material .....                                                         | Clad 2024-T3                                |                  |                  |                  | Clad 7075-T6    |                  |                  |                   |
| Nominal Rivet Diameter, in. ...<br>(Nominal Hole Diameter, in.) <sup>b</sup> | 1/8<br>(0.1285)                             | 5/32<br>(0.159)  | 3/16<br>(0.191)  | 1/4<br>(0.257)   | 1/8<br>(0.1285) | 5/32<br>(0.159)  | 3/16<br>(0.191)  | 1/4<br>(0.257)    |
| Sheet thickness, in.:                                                        | Ultimate Strength, lbs                      |                  |                  |                  |                 |                  |                  |                   |
|                                                                              |                                             |                  |                  |                  |                 |                  |                  |                   |
| 0.025 .....                                                                  | 227                                         | ...              | ...              | ...              | 278             | ...              | ...              | ...               |
| 0.032 .....                                                                  | 326                                         | <sup>c</sup> 367 | ...              | ...              | 354             | <sup>c</sup> 441 | ...              | ...               |
| 0.040 .....                                                                  | 437                                         | 505              | <sup>c</sup> 561 | ...              | 439             | 547              | <sup>c</sup> 661 | ...               |
| 0.050 .....                                                                  | 466                                         | 679              | 773              | <sup>c</sup> 908 | 456             | 674              | 823              | <sup>c</sup> 1120 |
| 0.063 .....                                                                  | 485                                         | 717              | 1005             | 1275             | 477             | 700              | 980              | 1330 <sup>c</sup> |
| 0.071 .....                                                                  | 497                                         | 731              | 1025             | 1500             | 490             | 716              | 999              | 1570              |
| 0.080 .....                                                                  | 507                                         | 747              | 1045             | 1750             | 505             | 734              | 1020             | 1760              |
| 0.090 .....                                                                  | 521                                         | 765              | 1065             | 1840             | 520             | 754              | 1045             | 1790              |
| 0.100 .....                                                                  | 531                                         | 781              | 1085             | 1870             | 531             | 774              | 1070             | 1825              |
| 0.125 .....                                                                  | ...                                         | 814              | 1135             | 1935             | ...             | 814              | 1130             | 1905              |
| 0.160 .....                                                                  | ...                                         | ...              | 1175             | 2030             | ...             | ...              | 1175             | 2020              |
| 0.190 .....                                                                  | ...                                         | ...              | ...              | 2110             | ...             | ...              | ...              | 2115              |
| 0.250 .....                                                                  | ...                                         | ...              | ...              | 2125             | ...             | ...              | ...              | 2125              |
| Rivet shear strength <sup>d</sup> .....                                      | 531                                         | 814              | 1175             | 2125             | 531             | 814              | 1175             | 2125              |
| Sheet thickness, in.:                                                        | Yield Strength <sup>e</sup> , lbs           |                  |                  |                  |                 |                  |                  |                   |
|                                                                              |                                             |                  |                  |                  |                 |                  |                  |                   |
| 0.025 .....                                                                  | 192                                         | ...              | ...              | ...              | 222             | ...              | ...              | ...               |
| 0.032 .....                                                                  | 283                                         | 311              | ...              | ...              | 307             | 356              | ...              | ...               |
| 0.040 .....                                                                  | 349                                         | 439              | 479              | ...              | 372             | 475              | 542              | ...               |
| 0.050 .....                                                                  | 398                                         | 538              | 674              | 767              | 398             | 572              | 724              | 894               |
| 0.063 .....                                                                  | 462                                         | 617              | 799              | 1105             | 431             | 612              | 836              | 1205              |
| 0.071 .....                                                                  | 497                                         | 665              | 857              | 1310             | 451             | 638              | 867              | 1400              |
| 0.080 .....                                                                  | 507                                         | 720              | 921              | 1400             | 474             | 666              | 900              | 1490              |
| 0.090 .....                                                                  | 521                                         | 765              | 995              | 1500             | 499             | 698              | 938              | 1540              |
| 0.100 .....                                                                  | 531                                         | 781              | 1065             | 1595             | 525             | 729              | 976              | 1595              |
| 0.125 .....                                                                  | ...                                         | 814              | 1135             | 1835             | ...             | 808              | 1070             | 1720              |
| 0.160 .....                                                                  | ...                                         | ...              | 1175             | 2030             | ...             | ...              | 1175             | 1895              |
| 0.190 .....                                                                  | ...                                         | ...              | ...              | 2110             | ...             | ...              | ...              | 2050              |
| 0.250 .....                                                                  | ...                                         | ...              | ...              | 2125             | ...             | ...              | ...              | 2125              |
| Head height (ref.), in. ....                                                 | 0.029                                       | 0.037            | 0.046            | 0.060            | 0.029           | 0.037            | 0.046            | 0.060             |

a Data supplied by Lockheed-Georgia Company.  
b Fasteners installed in hole diameters of 0.130, 0.158, 0.191, and 0.254 ± 0.003 inch, respectively.  
c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
d Shear strength based on Table 8.1.2(b) and  $F_{su} = 41$  ksi.  
e Permanent set at yield load: 4% of nominal hole diameter (Ref. 9.4.1.3.3).



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Table 8.1.2.2(o). Static Joint Strength of 120° Flush Shear Head Aluminum Alloy (2117-T3) Solid Rivets in Machine-Countersunk Aluminum Alloy Sheet

|                                                                                                                                                                                            |                                             |                  |                  |                  |                  |                  |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------|------------------|------------------|------------------|------------------|------------------|
| Rivet Type .....                                                                                                                                                                           | MS14218AD <sup>a</sup> ( $F_{su} = 30$ ksi) |                  |                  |                  |                  |                  |
| Sheet Material .....                                                                                                                                                                       | Clad 2024-T3                                |                  |                  |                  |                  |                  |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) <sup>b</sup>                                                                                                                      | 3/32<br>(0.096)                             | 1/8<br>(0.1285)  | 5/32<br>(0.159)  | 3/16<br>(0.191)  | 7/32<br>(0.228)  | 1/4<br>(0.257)   |
| Sheet thickness, in.:<br>0.020 .....<br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 ..... | Ultimate Strength, lbs                      |                  |                  |                  |                  |                  |
|                                                                                                                                                                                            | 125 <sup>c</sup>                            | ...              | ...              | ...              | ...              | ...              |
|                                                                                                                                                                                            | 153                                         | 212 <sup>c</sup> | ...              | ...              | ...              | ...              |
|                                                                                                                                                                                            | 188                                         | 263              | 334 <sup>c</sup> | ...              | ...              | ...              |
|                                                                                                                                                                                            | 216                                         | 322              | 408              | 498 <sup>c</sup> | ...              | ...              |
|                                                                                                                                                                                            | 217                                         | 380              | 498              | 609              | 740 <sup>c</sup> | 849 <sup>c</sup> |
|                                                                                                                                                                                            | ...                                         | 388              | 588              | 751              | 910              | 1040             |
|                                                                                                                                                                                            | ...                                         | ...              | 596              | 817              | 1015             | 1155             |
|                                                                                                                                                                                            | ...                                         | ...              | ...              | 842              | 1125             | 1290             |
|                                                                                                                                                                                            | ...                                         | ...              | ...              | 862              | 1205             | 1425             |
|                                                                                                                                                                                            | ...                                         | ...              | ...              | ...              | 1225             | 1520             |
|                                                                                                                                                                                            | ...                                         | ...              | ...              | ...              | ...              | 1555             |
|                                                                                                                                                                                            | 217                                         | 388              | 596              | 862              | 1225             | 1555             |
|                                                                                                                                                                                            | Yield Strength <sup>e</sup> , lbs           |                  |                  |                  |                  |                  |
|                                                                                                                                                                                            | 125                                         | ...              | ...              | ...              | ...              | ...              |
|                                                                                                                                                                                            | 153                                         | 212              | ...              | ...              | ...              | ...              |
|                                                                                                                                                                                            | 188                                         | 263              | 334              | ...              | ...              | ...              |
|                                                                                                                                                                                            | 216                                         | 319              | 408              | 498              | ...              | ...              |
|                                                                                                                                                                                            | 217                                         | 370              | 492              | 609              | 740              | 849              |
|                                                                                                                                                                                            | ...                                         | 388              | 574              | 733              | 910              | 1040             |
|                                                                                                                                                                                            | ...                                         | ...              | 596              | 794              | 1005             | 1155             |
|                                                                                                                                                                                            | ...                                         | ...              | ...              | 842              | 1090             | 1275             |
|                                                                                                                                                                                            | ...                                         | ...              | ...              | 862              | 1180             | 1380             |
|                                                                                                                                                                                            | ...                                         | ...              | ...              | ...              | 1225             | 1480             |
|                                                                                                                                                                                            | ...                                         | ...              | ...              | ...              | ...              | 1555             |
| Head height (ref.), in. ....                                                                                                                                                               | 0.022                                       | 0.027            | 0.035            | 0.044            | 0.053            | 0.061            |

a Data supplied by Briles Rivet Corp.  
b Load allowables developed from tests with hole diameters noted, except 3/32, 5/32, and 3/16 diameters were 0.098, 0.161, and 0.1935, respectively. Hole tolerance was +0.0005-0.001 inch.  
c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
d Shear strength based on Table 8.1.2(b) and  $F_{su} = 30$  ksi.  
e Permanent set at yield load: 4% of nominal hole diameter (Ref. 9.4.1.3.3).

Table 8.1.2.2(p). Static Joint Strength of 120° Flush Tension Type Head Aluminum Alloy (7050-T731) Solid Rivets in Machine-Countersunk Aluminum Alloy Sheet

|                                                                                                                                                                                            |                                             |                  |                  |                  |                   |                  |                   |                   |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------|------------------|------------------|------------------|-------------------|------------------|-------------------|-------------------|
| Rivet Type .....                                                                                                                                                                           | MS14219 E <sup>a</sup> ( $F_{su} = 43$ ksi) |                  |                  |                  |                   |                  |                   |                   |
| Sheet Material .....                                                                                                                                                                       | Clad 2024-T3                                |                  |                  |                  |                   |                  |                   |                   |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) <sup>b</sup>                                                                                                                      | 3/32<br>(0.096)                             | 1/8<br>(0.1285)  | 5/32<br>(0.159)  | 3/16<br>(0.191)  | 7/32<br>(0.228)   | 1/4<br>(0.257)   | 9/32<br>(0.290)   | 5/16<br>(0.523)   |
| Sheet thickness, in.:<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 ..... | Ultimate Strength, lbs                      |                  |                  |                  |                   |                  |                   |                   |
|                                                                                                                                                                                            | 210                                         | ...              | ...              | ...              | ...               | ...              | ...               | ...               |
|                                                                                                                                                                                            | 279                                         | <sup>c</sup> 339 | ...              | ...              | ...               | ...              | ...               | ...               |
|                                                                                                                                                                                            | 310                                         | 473              | <sup>c</sup> 527 | ...              | ...               | ...              | ...               | ...               |
|                                                                                                                                                                                            | 311                                         | 538              | 743              | <sup>c</sup> 819 | ...               | ...              | ...               | ...               |
|                                                                                                                                                                                            | ...                                         | 558              | 788              | 979              | <sup>c</sup> 1065 | ...              | ...               | ...               |
|                                                                                                                                                                                            | ...                                         | ...              | 834              | 1105             | 1280              | <sup>c</sup> ... | ...               | ...               |
|                                                                                                                                                                                            | ...                                         | ...              | 854              | 1165             | 1520              | 1625             | ...               | ...               |
|                                                                                                                                                                                            | ...                                         | ...              | ...              | 1230             | 1605              | 1890             | <sup>c</sup> 2020 | 2120              |
|                                                                                                                                                                                            | ...                                         | ...              | ...              | ...              | 1755              | 2145             | 2580              | 2965 <sup>c</sup> |
|                                                                                                                                                                                            | ...                                         | ...              | ...              | ...              | ...               | 2230             | 2840              | 3415              |
|                                                                                                                                                                                            | ...                                         | ...              | ...              | ...              | ...               | ...              | ...               | 3525              |
| Rivet shear strength <sup>d</sup> .....                                                                                                                                                    | 311                                         | 588              | 854              | 1230             | 1755              | 2230             | 2840              | 3525              |
| Sheet thickness, in.:<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 ..... | Yield Strength <sup>e</sup> , lbs           |                  |                  |                  |                   |                  |                   |                   |
|                                                                                                                                                                                            | 210                                         | ...              | ...              | ...              | ...               | ...              | ...               | ...               |
|                                                                                                                                                                                            | 277                                         | 339              | ...              | ...              | ...               | ...              | ...               | ...               |
|                                                                                                                                                                                            | 301                                         | 468              | 527              | ...              | ...               | ...              | ...               | ...               |
|                                                                                                                                                                                            | 309                                         | 538              | 728              | 819              | ...               | ...              | ...               | ...               |
|                                                                                                                                                                                            | ...                                         | 543              | 788              | 979              | 1065              | ...              | ...               | ...               |
|                                                                                                                                                                                            | ...                                         | ...              | 823              | 1100             | 1280              | ...              | ...               | ...               |
|                                                                                                                                                                                            | ...                                         | ...              | 833              | 1165             | 1490              | 1625             | ...               | ...               |
|                                                                                                                                                                                            | ...                                         | ...              | ...              | 1190             | 1605              | 1875             | 2020              | 2120              |
|                                                                                                                                                                                            | ...                                         | ...              | ...              | ...              | 1705              | 2145             | 2580              | 2945              |
|                                                                                                                                                                                            | ...                                         | ...              | ...              | ...              | ...               | 2200             | 2765              | 3390              |
|                                                                                                                                                                                            | ...                                         | ...              | ...              | ...              | ...               | ...              | ...               | 3455              |
| Head height (ref.), in. ....                                                                                                                                                               | 0.034                                       | 0.041            | 0.053            | 0.068            | 0.077             | 0.090            | 0.100             | 0.104             |

a Data supplied by Briles Rivet Corp.  
b Load allowables developed from tests with hole diameters noted, except 5/32, 3/16, and 5/16 diameter were 0.161, 0.1935, and 0.316, respectively. Hole tolerances were + 0.0005, -0.001 inch.  
c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
d Rivet shear strength based on Table 8.1.2(b) and  $F_{su} = 43$  ksi.  
e Permanent set at yield load: 4% of nominal hole diameter (Ref. 9.4.1.3.3).

**Table 8.1.2.2(q). Static Joint Strength of 120° Flush Tension Type Head Aluminum Alloy (7050-T731) Solid Rivets in Machine-Countersunk Aluminum Alloy Sheet**

|                                                                                                                                                                             |                                             |                  |                  |                   |                   |                  |                   |                   |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------|------------------|------------------|-------------------|-------------------|------------------|-------------------|-------------------|
| Rivet Type .....                                                                                                                                                            | MS14219 E <sup>a</sup> ( $F_{su}$ = 43 ksi) |                  |                  |                   |                   |                  |                   |                   |
| Sheet Material .....                                                                                                                                                        | Clad 7075-T6                                |                  |                  |                   |                   |                  |                   |                   |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) <sup>b</sup>                                                                                                       | 3/32<br>(0.096)                             | 1/8<br>(0.1285)  | 5/32<br>(0.159)  | 3/16<br>(0.191)   | 7/32<br>(0.228)   | 1/4<br>(0.257)   | 9/32<br>(0.290)   | 5/16<br>(0.523)   |
| Sheet thickness, in.:<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 ..... | Ultimate Strength, lbs                      |                  |                  |                   |                   |                  |                   |                   |
|                                                                                                                                                                             | 272                                         | ...              | ...              | ...               | ...               | ...              | ...               | ...               |
|                                                                                                                                                                             | 297                                         | <sup>c</sup> 455 | ...              | ...               | ...               | ...              | ...               | ...               |
|                                                                                                                                                                             | 311                                         | 522              | <sup>c</sup> 704 | ...               | ...               | ...              | ...               | ...               |
|                                                                                                                                                                             | ...                                         | 558              | 803              | <sup>c</sup> 1065 | ...               | ...              | ...               | ...               |
|                                                                                                                                                                             | ...                                         | ...              | 832              | 1140              | <sup>c</sup> 1435 | ...              | ...               | ...               |
|                                                                                                                                                                             | ...                                         | ...              | 854              | 1180              | 1600              | <sup>c</sup> ... | ...               | ...               |
|                                                                                                                                                                             | ...                                         | ...              | ...              | 1220              | 1650              | 2030             | ...               | ...               |
|                                                                                                                                                                             | ...                                         | ...              | ...              | 1230              | 1700              | 2090             | <sup>c</sup> 2565 | 2860              |
|                                                                                                                                                                             | ...                                         | ...              | ...              | ...               | 1755              | 2230             | 2740              | 3295 <sup>c</sup> |
|                                                                                                                                                                             | ...                                         | ...              | ...              | ...               | ...               | ...              | 2840              | 3525              |
| Rivet shear strength <sup>d</sup> .....                                                                                                                                     | 311                                         | 558              | 854              | 1230              | 1755              | 2230             | 2840              | 3525              |
| Sheet thickness, in.:<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 ..... | Yield Strength <sup>e</sup> , lbs           |                  |                  |                   |                   |                  |                   |                   |
|                                                                                                                                                                             | 272                                         | ...              | ...              | ...               | ...               | ...              | ...               | ...               |
|                                                                                                                                                                             | 296                                         | 455              | ...              | ...               | ...               | ...              | ...               | ...               |
|                                                                                                                                                                             | 308                                         | 522              | 704              | ...               | ...               | ...              | ...               | ...               |
|                                                                                                                                                                             | ...                                         | 550              | 802              | 1065              | ...               | ...              | ...               | ...               |
|                                                                                                                                                                             | ...                                         | ...              | 823              | 1140              | 1435              | ...              | ...               | ...               |
|                                                                                                                                                                             | ...                                         | ...              | 845              | 1170              | 1600              | ...              | ...               | ...               |
|                                                                                                                                                                             | ...                                         | ...              | ...              | 1205              | 1650              | 2030             | ...               | ...               |
|                                                                                                                                                                             | ...                                         | ...              | ...              | 1220              | 1685              | 2090             | 2565              | 2860              |
|                                                                                                                                                                             | ...                                         | ...              | ...              | ...               | 1740              | 2195             | 2715              | 3295              |
|                                                                                                                                                                             | ...                                         | ...              | ...              | ...               | ...               | ...              | 2815              | 3480              |
| Head height (ref.), in. ....                                                                                                                                                | 0.034                                       | 0.041            | 0.053            | 0.068             | 0.077             | 0.090            | 0.100             | 0.104             |

a Data supplied by Briles Rivet Corp.  
b Allowables developed from tests with hole diameters noted, except 3/32, 5/32, 3/16, and 5/16 diameters were 0.098, 0.161, 0.1935, and 0.316, respectively. Hole tolerances were +0.0005, -0.001 inch.  
c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
d Rivet shear strength based on Table 8.1.2(b) and  $F_{su}$  = 43 ksi.  
e Permanent set at yield load: 4% of nominal hole diameter (Ref. 9.4.1.3.3).

Table 8.1.2.2(r). Static Joint Strength of Solid 100° Flush Head Aluminum Alloy (7050-T73) Solid Rivets in Machine-Countersunk Aluminum Alloy Sheet

|                                                |                                            |         |         |             |
|------------------------------------------------|--------------------------------------------|---------|---------|-------------|
| Rivet Type .....                               | MS20426E ( $F_{su} = 41$ ksi) <sup>a</sup> |         |         |             |
| Sheet Material .....                           | Clad 2024-T3                               |         |         |             |
| Rivet Diameter, in. ....                       | 1/8                                        | 5/32    | 3/16    | 1/4         |
| (Nominal Hole Diameter, in.) <sup>b</sup> .... | (0.1285)                                   | (0.159) | (0.191) | (0.257)     |
| Sheet thickness, in.:                          | Ultimate Strength, lbs                     |         |         |             |
|                                                |                                            |         |         |             |
|                                                | 0.040 .....                                | 386     | c ...   | ...         |
|                                                | 0.050 .....                                | 419     | 592     | c ...       |
|                                                | 0.063 .....                                | 463     | 647     | 870 c ...   |
|                                                | 0.071 .....                                | 491     | 680     | 910 ...     |
|                                                | 0.080 .....                                | 521     | 718     | 955 ...     |
|                                                | 0.090 .....                                | 531     | 760     | 1005 1610 c |
|                                                | 0.100 .....                                | ...     | 802     | 1055 1680   |
|                                                | 0.125 .....                                | ...     | 814     | 1175 1845   |
|                                                | 0.160 .....                                | ...     | ...     | ...         |
|                                                | 0.190 .....                                | ...     | ...     | ...         |
| Rivet shear strength <sup>d</sup>              | 531                                        | 814     | 1175    | 2125        |
| Sheet thickness, in.:                          | Yield Strength <sup>e</sup> , lbs          |         |         |             |
|                                                |                                            |         |         |             |
|                                                | 0.040 .....                                | 262     | ...     | ...         |
|                                                | 0.050 .....                                | 327     | 404     | ...         |
|                                                | 0.063 .....                                | 412     | 510     | 612 ...     |
|                                                | 0.071 .....                                | 464     | 574     | 690 ...     |
|                                                | 0.080 .....                                | 517     | 647     | 777 ...     |
|                                                | 0.090 .....                                | 531     | 728     | 875 1175    |
|                                                | 0.100 .....                                | ...     | 794     | 972 1310    |
|                                                | 0.125 .....                                | ...     | 814     | 1160 1635   |
|                                                | 0.160 .....                                | ...     | ...     | ...         |
|                                                | 0.190 .....                                | ...     | ...     | ...         |
| Head Height (ref.), in.                        | 0.042                                      | 0.055   | 0.070   | 0.095       |

a Data supplied by Lockheed Ga. Co. and Air Force Materials Laboratory.  
b Load allowables developed from tests with hole diameters of 0.130, 0.158, 0.191, and 0.256 ± 0.003 inch.  
c The values in the table above the horizontal line in each column are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires the specific approval of the procuring agency.  
d Shear strength based on area computed from nominal hole diameters in Table 8.1.2(b) and  $F_{su} = 41$  ksi.  
e Permanent set at yield load: 4% of the nominal hole diameter.

**Table 8.1.2.2(s). Static Joint Strength of Solid 100° Flush Head Aluminum Alloy (7050-T73) Solid Rivets in Machine-Countersunk Aluminum Alloy Sheet**

|                                               |                                            |                  |                  |                   |
|-----------------------------------------------|--------------------------------------------|------------------|------------------|-------------------|
| Rivet Type . . . . .                          | MS20426E ( $F_{su} = 41$ ksi) <sup>a</sup> |                  |                  |                   |
| Sheet Material . . . . .                      | Clad 7075-T6                               |                  |                  |                   |
| Rivet Diameter, in. . . . .                   | 1/8                                        | 5/32             | 3/16             | 1/4               |
| (Nominal Hole Diameter, in.) <sup>b</sup> . . | (0.1285)                                   | (0.159)          | (0.191)          | (0.257)           |
| Ultimate Strength, lbs                        |                                            |                  |                  |                   |
| Sheet thickness, in.:                         |                                            |                  |                  |                   |
| 0.040 . . . . .                               | 318                                        | ...              | ...              | ...               |
| 0.050 . . . . .                               | 393                                        | <sup>c</sup> 492 | ...              | ...               |
| 0.063 . . . . .                               | 440                                        | 606              | <sup>c</sup> 745 | ...               |
| 0.071 . . . . .                               | 469                                        | 642              | 840              | <sup>c</sup> ...  |
| 0.080 . . . . .                               | 502                                        | 683              | 898              | ...               |
| 0.090 . . . . .                               | 531                                        | 728              | 952              | 1430              |
| 0.100 . . . . .                               | ...                                        | 773              | 1005             | 1570 <sup>c</sup> |
| 0.125 . . . . .                               | ...                                        | 814              | 1140             | 1755              |
| 0.160 . . . . .                               | ...                                        | ...              | 1175             | 2010              |
| 0.190 . . . . .                               | ...                                        | ...              | ...              | 2125              |
| Rivet shear strength <sup>d</sup>             | 531                                        | 814              | 1175             | 2125              |
| Yield Strength <sup>e</sup> , lbs             |                                            |                  |                  |                   |
| Sheet thickness, in.:                         |                                            |                  |                  |                   |
| 0.040 . . . . .                               | 257                                        | ...              | ...              | ...               |
| 0.050 . . . . .                               | 330                                        | 399              | ...              | ...               |
| 0.063 . . . . .                               | 423                                        | 515              | 607              | ...               |
| 0.071 . . . . .                               | 469                                        | 586              | 693              | ...               |
| 0.080 . . . . .                               | 502                                        | 666              | 789              | ...               |
| 0.090 . . . . .                               | 531                                        | 728              | 896              | 1175              |
| 0.100 . . . . .                               | ...                                        | 773              | 1005             | 1320              |
| 0.125 . . . . .                               | ...                                        | 814              | 1140             | 1680              |
| 0.160 . . . . .                               | ...                                        | ...              | 1175             | 2010              |
| 0.190 . . . . .                               | ...                                        | ...              | ...              | 2125              |
| Head Height (ref.), in.                       | 0.042                                      | 0.055            | 0.070            | 0.095             |

a Data supplied by Lockheed Ga. Co., Air Force Materials Laboratory, Allfast, Cherry Fasteners, Douglas Aircraft Co., and Huck Mfg. Co.  
b Load allowables developed from tests with hole diameters of 0.130, 0.158, 0.191, and 0.256 ± 0.003 inch.  
c The values in the table above the horizontal line in each column are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires the specific approval of the procuring agency.  
d Shear strength based on area computed from nominal hole diameters in Table 8.1.2(b) and  $F_{su} = 41$  ksi.  
e Permanent set at yield load: 4% of the nominal hole diameter.

Table 8.1.2.2(t). Static Joint Strength of 105 degree Flush Shear Head Aluminum Alloy (7050) Solid Rivet in 100 degree Machine-Countersunk Alloy Sheet

|                                                                                                                                                                                                      |                                                   |                  |                  |                   |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|------------------|------------------|-------------------|
| Rivet Type . . . . .                                                                                                                                                                                 | AL 905 KE <sup>a</sup> (F <sub>su</sub> = 41 ksi) |                  |                  |                   |
| Sheet Material . . . . .                                                                                                                                                                             | Clad 2024-T3                                      |                  |                  |                   |
| Rivet Diameter, in.<br>(Nominal Hole Diameter, in.) <sup>b</sup> . . . . .                                                                                                                           | 1/8<br>(0.1285)                                   | 5/32<br>(0.159)  | 3/16<br>(0.191)  | 1/4<br>(0.257)    |
| Sheet Thickness, in.:<br><br>0.032 . . . . .<br>0.040 . . . . .<br>0.050 . . . . .<br>0.063 . . . . .<br>0.071 . . . . .<br>0.080 . . . . .<br>0.090 . . . . .<br>0.125 . . . . .<br>0.160 . . . . . | Ultimate Strength, lbs.                           |                  |                  |                   |
|                                                                                                                                                                                                      | 325 <sup>c</sup>                                  | ---              | ---              | ---               |
|                                                                                                                                                                                                      | 396                                               | 502 <sup>c</sup> | ---              | ---               |
|                                                                                                                                                                                                      | 452                                               | 612              | 750 <sup>c</sup> | ---               |
|                                                                                                                                                                                                      | 498                                               | 696              | 923              | 1280 <sup>c</sup> |
|                                                                                                                                                                                                      | 526                                               | 731              | 980              | 1425              |
|                                                                                                                                                                                                      | 531                                               | 771              | 1030             | 1585              |
|                                                                                                                                                                                                      | ---                                               | 814              | 1080             | 1735              |
|                                                                                                                                                                                                      | ---                                               | ---              | 1175             | 1985              |
|                                                                                                                                                                                                      | ---                                               | ---              | ---              | 2125              |
| Rivet Shear Strength <sup>d</sup> . . . . .                                                                                                                                                          | 531                                               | 814              | 1175             | 2125              |
| Sheet Thickness, in.:<br><br>0.032 . . .<br>0.040 . . .<br>0.050 . . .<br>0.063 . . .<br>0.071 . . .<br>0.080 . . .<br>0.090 . . .<br>0.125 . . .<br>0.160 . . .                                     | Yield Strength, lbs <sup>e</sup>                  |                  |                  |                   |
|                                                                                                                                                                                                      | 268                                               | ---              | ---              | ---               |
|                                                                                                                                                                                                      | 326                                               | 415              | ---              | ---               |
|                                                                                                                                                                                                      | 399                                               | 504              | 619              | ---               |
|                                                                                                                                                                                                      | 493                                               | 620              | 759              | 1060              |
|                                                                                                                                                                                                      | 526                                               | 692              | 845              | 1175              |
|                                                                                                                                                                                                      | 531                                               | 771              | 942              | 1305              |
|                                                                                                                                                                                                      | ---                                               | 814              | 1050             | 1450              |
|                                                                                                                                                                                                      | ---                                               | ---              | 1175             | 1955              |
|                                                                                                                                                                                                      | ---                                               | ---              | ---              | 2125              |
| Head Height [ref.], <sup>f</sup> in. . . . .                                                                                                                                                         | 0.029                                             | 0.037            | 0.046            | 0.060             |

a Data supplied by Ateliers De La Haute Garonne SARL.  
b Loads developed from tests with hole diameters of 0.1285, 0.161, 0.193, and 0.257, +/- 0.001 inch.  
c The values above the horizontal line in each column are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring activity.  
d Rivet shear strength is based upon Table 8.1.2(b) and F<sub>su</sub> = 41 ksi.  
e Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).  
f Head height values reflect driven rivet configuration.

**8.1.3 Blind Fasteners** — The strengths shown in the following tables are applicable only for the grip lengths and hole tolerances recommended by the respective fastener manufacturers. For some fastener systems, permanent set at yield load may be increased if hole sizes greater than those listed in the applicable table are used. This condition may exist even though the test hole size lies within the manufacturer's recommended hole size range (Reference 9.4.1.3.3).

The strength values were established from test data and are applicable to "joints" with  $e/D \geq 2.0$ . For joints with  $e/D$  ratios less than 2.0, tests to substantiate the use of yield and ultimate strength allowables must be made. Ultimate strength values of protruding- and flush-head blind fasteners were obtained as described in Section 9.4. The analyses included dividing the average ultimate load from test data by 1.15. This factor is not applicable to shear strength cutoff values which may be either the procurement specification shear strength (S values) of the fastener, or if no specification exists, a statistical value determined from test results as described in Section 9.4.

Unless otherwise specified, yield load is defined in Section 9.4.1.3.3 as the load which results in a joint permanent set equal to  $0.04D$ , where  $D$  is the decimal equivalent of the hole or fastener shank diameter, as defined in Table 9.4.1.2(a). Some tables are footnoted to show the previous criteria used for those particular tables.

For machine countersunk joints, the sheet gage specified in the tables is that of the countersunk sheet. When the noncountersunk sheet is thinner than the countersunk sheet, the bearing allowable for the noncountersunk sheet-fastener combination should be computed, compared to the table value, and the lower of the two values selected. Increased attention should be paid to detail design in cases where  $t/D < 0.25$  because of the possibility of unsatisfactory service life.

Joint allowable strengths of blind fasteners in double-dimpled or dimpled into machine countersunk applications should be established on the basis of specific tests acceptable to the procuring or certifying agency. In the absence of such data, allowables for blind fasteners in machine countersunk sheet may be used.

Reference should be made to the requirements of the applicable procuring or certifying agency relative to the use of blind fasteners such as the limitations of usage in design standard MS33522.

### **8.1.3.1 Protruding-Head Blind Fasteners**

**8.1.3.1.1 Friction-Lock Blind Rivets**— Tables 8.1.3.1.1(a) through 8.1.3.1.1(e) contain joint allowables for various protruding-head, friction-lock blind rivet/sheet material combinations.

**8.1.3.1.2 Mechanical-Lock Spindle Blind Rivets**— Tables 8.1.3.1.2(a) through (p) contain joint allowables for various protruding-head, mechanical-lock spindle blind rivet/sheet material combinations.

### **8.1.3.2 Flush-Head Blind Fasteners**

**8.1.3.2.1 Friction-Lock Blind Rivets** — Tables 8.1.3.2.1(a) through (g) contain joint allowables for various flush-head, friction-lock blind rivet/sheet material combinations.

**8.1.3.2.2 Mechanical-Lock Spindle Blind Rivets**— Tables 8.1.3.2.2(a) through (u) contain joint allowables for various flush-head, mechanical-lock spindle blind rivet/sheet material combinations.

**8.1.3.2.3 Flush-Head Blind Bolts**— Tables 8.1.3.2.3(a) through (h) contain joint allowables for various flush-head blind bolt/sheet material combinations.

Table 8.1.3.1.1(a). Static Joint Strength of Blind Protruding Head A-286 Rivets in Alloy Steels, Titanium Alloy and A-286 Alloy Sheet

|                                                                |                                                                                                              |                 |                 |                |
|----------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|-----------------|-----------------|----------------|
| Rivet Type .....                                               | CR 6636 <sup>a</sup> ( $F_{su} = 75$ ksi)                                                                    |                 |                 |                |
| Sheet Material .....                                           | Alloy Steel, $F_{tu} = 125$ ksi, Titanium Alloys, $F_{tu} = 120$ ksi,<br>and A-286 Alloy, $F_{tu} = 140$ ksi |                 |                 |                |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) ..... | 1/8<br>(0.130)                                                                                               | 5/32<br>(0.162) | 3/16<br>(0.194) | 1/4<br>(0.258) |
| Sheet thickness, in.:                                          | Ultimate Strength <sup>b</sup> , lbs                                                                         |                 |                 |                |
|                                                                | 169                                                                                                          | ...             | ...             | ...            |
|                                                                | 290                                                                                                          | 341             | ...             | ...            |
|                                                                | 412                                                                                                          | 493             | 566             | ...            |
|                                                                | 532                                                                                                          | 645             | 748             | 924            |
|                                                                | 688                                                                                                          | 816             | 967             | 1221           |
|                                                                | 796                                                                                                          | 1050            | 1278            | 1650           |
|                                                                | 879                                                                                                          | 1233            | 1570            | 2129           |
|                                                                | 945                                                                                                          | 1354            | 1807            | 2673           |
|                                                                | 970                                                                                                          | 1461            | 1980            | 3168           |
|                                                                | ...                                                                                                          | 1490            | 2062            | 3350           |
|                                                                | ...                                                                                                          | ...             | 2150            | 3515           |
|                                                                | ...                                                                                                          | ...             | ...             | 3663           |
|                                                                | ...                                                                                                          | ...             | ...             | 3779           |
|                                                                | ...                                                                                                          | ...             | ...             | 3890           |
| Rivet shear strength <sup>c</sup> .....                        | 970                                                                                                          | 1490            | 2150            | 3890           |

a Data supplied by Cherry Fasteners.

b Yield strength is in excess of 80% of ultimate. This is based on a previous Navy “BuAer” definition that yield strength would not be considered to be critical if it exceeded 1.15 x 2.3 of design ultimate strength. There was no requirement for submission of the yield data for inclusion in ANC-5.

c Shear strength based on areas computed from nominal hole diameters in Table 8.1.2(a) and  $F_{su} = 75$  ksi.



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Table 8.1.3.1.1(b). Static Joint Strength of Protruding Head Monel Rivets in Stainless Steel Sheet

| Rivet Type .....                                            | MS20600M ( $F_{su} = 55$ ksi) |                   |                   |                   |                 |                 |                 |                |
|-------------------------------------------------------------|-------------------------------|-------------------|-------------------|-------------------|-----------------|-----------------|-----------------|----------------|
| Sheet Material .....                                        | ANSI 301-Annealed             |                   |                   |                   | AISI 301-½ Hard |                 |                 |                |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) .. | 1/8<br>(0.130)                | 5/32<br>(0.162)   | 3/16<br>(0.154)   | 1/4<br>(0.258)    | 1/8<br>(0.130)  | 5/32<br>(0.162) | 3/16<br>(0.194) | 1/4<br>(0.258) |
| Ultimate Strength, lbs                                      |                               |                   |                   |                   |                 |                 |                 |                |
| Sheet thickness, in.:                                       |                               |                   |                   |                   |                 |                 |                 |                |
| 0.010 .....                                                 | ...                           | ...               | ...               | ...               | 195             | ...             | ...             | ...            |
| 0.012 .....                                                 | ...                           | ...               | ...               | ...               | 225             | 287             | ...             | ...            |
| 0.016 .....                                                 | ...                           | ...               | ...               | ...               | 290             | 367             | 453             | ...            |
| 0.020 .....                                                 | 332 <sup>a</sup>              | ...               | ...               | ...               | 358             | 450             | 552             | 774            |
| 0.025 .....                                                 | 396 <sup>a</sup>              | 494 <sup>a</sup>  | ...               | ...               | 440             | 552             | 675             | 940            |
| 0.032 .....                                                 | 472 <sup>a</sup>              | 627 <sup>a</sup>  | 768 <sup>a</sup>  | ...               | 522             | 690             | 1040            | 1163           |
| 0.040 .....                                                 | 526 <sup>a</sup>              | 729 <sup>a</sup>  | 942 <sup>a</sup>  | 1290 <sup>a</sup> | 580             | 810             | 1200            | 1430           |
| 0.050 .....                                                 | 594 <sup>a</sup>              | 810 <sup>a</sup>  | 1070 <sup>a</sup> | 1585 <sup>a</sup> | 635             | 903             | 1325            | 1760           |
| 0.063 .....                                                 | 681 <sup>a</sup>              | 919 <sup>a</sup>  | 1280 <sup>a</sup> | 1875 <sup>a</sup> | 678             | 980             | 1385            | 2090           |
| 0.071 .....                                                 | 700 <sup>a</sup>              | 984 <sup>a</sup>  | 1370 <sup>a</sup> | 1980 <sup>a</sup> | 701             | 1013            | 1438            | 2220           |
| 0.080 .....                                                 | 713                           | 1055 <sup>a</sup> | 1470 <sup>a</sup> | 2110 <sup>a</sup> | 713             | 1050            | 1486            | 2340           |
| 0.090 .....                                                 | ...                           | 1080 <sup>a</sup> | 1530 <sup>a</sup> | 2240 <sup>a</sup> | ...             | 1081            | 1540            | 2450           |
| 0.100 .....                                                 | ...                           | 1090              | 1580              | 2380 <sup>a</sup> | ...             | 1090            | 1580            | 2540           |
| 0.125 .....                                                 | ...                           | ...               | ...               | 2700 <sup>a</sup> | ...             | ...             | ...             | 2710           |
| 0.160 .....                                                 | ...                           | ...               | ...               | 2855              | ...             | ...             | ...             | 2855           |
| Rivet shear strength <sup>b</sup> .....                     | 713                           | 1090              | 1580              | 2855              | 713             | 1090            | 1580            | 2855           |
| Yield Strength <sup>c</sup> , lbs                           |                               |                   |                   |                   |                 |                 |                 |                |
| Sheet thickness, in.:                                       |                               |                   |                   |                   |                 |                 |                 |                |
| 0.010 .....                                                 | ...                           | ...               | ...               | ...               | 195             | ...             | ...             | ...            |
| 0.012 .....                                                 | ...                           | ...               | ...               | ...               | 225             | 287             | ...             | ...            |
| 0.016 .....                                                 | ...                           | ...               | ...               | ...               | 290             | 367             | 453             | ...            |
| 0.020 .....                                                 | 128                           | ...               | ...               | ...               | 358             | 450             | 551             | 774            |
| 0.025 .....                                                 | 160                           | 199               | ...               | ...               | 440             | 552             | 675             | 940            |
| 0.032 .....                                                 | 205                           | 254               | 306               | ...               | 522             | 690             | 836             | 1163           |
| 0.040 .....                                                 | 257                           | 318               | 382               | 514               | 580             | 810             | 1040            | 1430           |
| 0.050 .....                                                 | 321                           | 397               | 477               | 642               | 635             | 903             | 1200            | 1760           |
| 0.063 .....                                                 | 405                           | 501               | 601               | 810               | 678             | 980             | 1325            | 2090           |
| 0.071 .....                                                 | 456                           | 564               | 678               | 912               | 701             | 1013            | 1385            | 2220           |
| 0.080 .....                                                 | 514                           | 635               | 764               | 1025              | 713             | 1050            | 1438            | 2340           |
| 0.090 .....                                                 | ...                           | 715               | 860               | 1155              | ...             | 1081            | 1486            | 2450           |
| 0.100 .....                                                 | ...                           | 795               | 955               | 1285              | ...             | 1090            | 1540            | 2540           |
| 0.125 .....                                                 | ...                           | ...               | ...               | 1605              | ...             | ...             | ...             | 2710           |
| 0.160 .....                                                 | ...                           | ...               | ...               | 2055              | ...             | ...             | ...             | 2855           |

a Yield value is less than 2/3 of the indicated ultimate strength value.  
b Rivet shear strength based on areas computed from nominal hole diameters in Table 8.1.2(a) and  $F_{su} = 55$  ksi.  
c Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.

Table 8.1.3.1.1(c). Static Joint Strength of Blind Protruding Head Monel Rivets in Aluminum Alloy Sheet

| Rivet Type .....                                           | MS20600M ( $F_{su} = 55$ ksi)        |                 |                 |                |                |                 |                 |                |
|------------------------------------------------------------|--------------------------------------|-----------------|-----------------|----------------|----------------|-----------------|-----------------|----------------|
| Sheet Material .....                                       | 2024-T3                              |                 |                 |                | 7075-T6        |                 |                 |                |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) . | 1/8<br>(0.130)                       | 5/32<br>(0.162) | 3/16<br>(0.194) | 1/4<br>(0.258) | 1/8<br>(0.130) | 5/32<br>(0.162) | 3/16<br>(0.194) | 1/4<br>(0.258) |
| Sheet thickness, in.:                                      | Ultimate Strength <sup>b</sup> , lbs |                 |                 |                |                |                 |                 |                |
|                                                            | 0.025 .....                          | 268             | ...             | ...            | ...            | 297             | ...             | ...            |
|                                                            | 0.032 .....                          | 365             | 429             | ...            | ...            | 405             | 472             | ...            |
|                                                            | 0.040 .....                          | 478             | 569             | 650            | ...            | 485             | 631             | 720            |
|                                                            | 0.050 .....                          | 545             | 738             | 860            | 1070           | 545             | 747             | 955            |
|                                                            | 0.063 .....                          | 622             | 844             | 1110           | 1430           | 622             | 844             | 1110           |
|                                                            | 0.071 .....                          | 652             | 903             | 1180           | 1665           | 652             | 903             | 1180           |
|                                                            | 0.080 .....                          | 684             | 968             | 1255           | 1910           | 684             | 968             | 1255           |
|                                                            | 0.090 .....                          | 713             | 1010            | 1345           | 2060           | 713             | 1010            | 1345           |
|                                                            | 0.100 .....                          | ...             | 1050            | 1415           | 2180           | ...             | 1050            | 1415           |
|                                                            | 0.125 .....                          | ...             | 1090            | 1545           | 2480           | ...             | 1090            | 1545           |
|                                                            | 0.160 .....                          | ...             | ...             | 1580           | 2735           | ...             | ...             | 1580           |
|                                                            | 0.190 .....                          | ...             | ...             | ...            | 2855           | ...             | ...             | 2855           |
| Rivet shear strength <sup>a</sup> .....                    | 713                                  | 1090            | 1580            | 2855           | 713            | 1090            | 1580            | 2855           |
| Sheet thickness, in.:                                      | Yield Strength <sup>b</sup> , lbs    |                 |                 |                |                |                 |                 |                |
|                                                            | 0.025 .....                          | 234             | ...             | ...            | ...            | 272             | ...             | ...            |
|                                                            | 0.032 .....                          | 297             | 370             | ...            | ...            | 343             | 430             | ...            |
|                                                            | 0.040 .....                          | 368             | 460             | 556            | ...            | 425             | 533             | 644            |
|                                                            | 0.050 .....                          | 458             | 570             | 688            | 936            | 492             | 657             | 797            |
|                                                            | 0.063 .....                          | 529             | 715             | 863            | 1170           | 529             | 759             | 996            |
|                                                            | 0.071 .....                          | 552             | 786             | 970            | 1315           | 552             | 786             | 1075           |
|                                                            | 0.080 .....                          | 577             | 818             | 1090           | 1470           | 577             | 818             | 1110           |
|                                                            | 0.090 .....                          | 605             | 853             | 1155           | 1650           | 605             | 853             | 1155           |
|                                                            | 0.100 .....                          | ...             | 888             | 1200           | 1830           | ...             | 888             | 1200           |
|                                                            | 0.125 .....                          | ...             | 976             | 1300           | 2110           | ...             | 976             | 1300           |
|                                                            | 0.160 .....                          | ...             | ...             | 1450           | 2310           | ...             | ...             | 1450           |
|                                                            | 0.190 .....                          | ...             | ...             | ...            | 2480           | ...             | ...             | ...            |

a Shear strength based on areas computed from nominal hole diameters in Table 8.1.2(a) and  $F_{su} = 55$  ksi.  
b Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.

Table 8.1.3.1.1(d). Static Joint Strength of Blind Protruding Head Alloy (2117-T3) Rivets in Aluminum Alloy Sheet

|                                                                                                                                                              |                                              |                 |                 |                |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|-----------------|-----------------|----------------|
| Rivet Type .....                                                                                                                                             | MS20600AD and MS20602AD ( $F_{su} = 30$ ksi) |                 |                 |                |
| Sheet Material .....                                                                                                                                         | Clad 2024 T3                                 |                 |                 |                |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) .....                                                                                               | 1/8<br>(0.130)                               | 5/32<br>(0.162) | 3/16<br>(0.194) | 1/4<br>(0.258) |
| Sheet thickness, in.:<br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 ..... | Ultimate Strength, lbs                       |                 |                 |                |
|                                                                                                                                                              | 233                                          | ...             | ...             | ...            |
|                                                                                                                                                              | 277                                          | 368             | ...             | ...            |
|                                                                                                                                                              | 321                                          | 425             | 544             | ...            |
|                                                                                                                                                              | 388                                          | 506             | 643             | 961            |
|                                                                                                                                                              | ...                                          | 596             | 753             | 1110           |
|                                                                                                                                                              | ...                                          | ...             | 823             | 1200           |
|                                                                                                                                                              | ...                                          | ...             | 862             | 1305           |
|                                                                                                                                                              | ...                                          | ...             | ...             | 1415           |
|                                                                                                                                                              | ...                                          | ...             | ...             | 1550           |
|                                                                                                                                                              | 388                                          | 596             | 862             | 1550           |
| Sheet thickness, in.:<br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 ..... | Yield Strength <sup>b</sup> , lbs            |                 |                 |                |
|                                                                                                                                                              | 226                                          | ...             | ...             | ...            |
|                                                                                                                                                              | 264                                          | 356             | ...             | ...            |
|                                                                                                                                                              | 304                                          | 406             | 523             | ...            |
|                                                                                                                                                              | 362                                          | 475             | 610             | 925            |
|                                                                                                                                                              | 388                                          | 560             | 709             | 1058           |
|                                                                                                                                                              | ...                                          | 596             | 771             | 1135           |
|                                                                                                                                                              | ...                                          | ...             | 862             | 1230           |
|                                                                                                                                                              | ...                                          | ...             | ...             | 1330           |
|                                                                                                                                                              | ...                                          | ...             | ...             | 1450           |

a Rivet shear strength based on areas computed from nominal hole diameters in Table 8.1.2(a) and  $F_{su} = 30$  ksi.  
b Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.

**Table 8.1.3.1.1(e). Static Joint Strength of Blind Protruding Head Aluminum Alloy (5056) Rivets in Magnesium Alloy Sheet**

|                                                          |                                      |                 |                 |                |
|----------------------------------------------------------|--------------------------------------|-----------------|-----------------|----------------|
| Rivet Type .....                                         | MS20600B ( $F_{su} = 28$ ksi)        |                 |                 |                |
| Sheet Material .....                                     | AZ31B-H24                            |                 |                 |                |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) | 1/8<br>(0.130)                       | 5/32<br>(0.162) | 3/16<br>(0.194) | 1/4<br>(0.258) |
| Sheet thickness, in.:                                    | Ultimate Strength <sup>a</sup> , lbs |                 |                 |                |
|                                                          |                                      |                 |                 |                |
|                                                          | 0.025 .....                          | 178             | ...             | ...            |
|                                                          | 0.032 .....                          | 218             | 282             | ...            |
|                                                          | 0.040 .....                          | 256             | 339             | 420            |
|                                                          | 0.050 .....                          | 290             | 392             | 502            |
|                                                          | 0.063 .....                          | 330             | 449             | 584            |
|                                                          | 0.071 .....                          | 352             | 481             | 627            |
|                                                          | 0.080 .....                          | 363             | 512             | 667            |
|                                                          | 0.090 .....                          | ...             | 550             | 714            |
|                                                          | 0.100 .....                          | ...             | 556             | 757            |
|                                                          | 0.125 .....                          | ...             | ...             | 802            |
|                                                          | 0.160 .....                          | ...             | ...             | ...            |
| Rivet shear strength <sup>b</sup> .....                  | 363                                  | 556             | 802             | 1450           |

a Yield strength is in excess of 80% of ultimate. This is based on a previous Navy “Bureau of Aeronautics” definition that yield strength was not considered to be critical if it exceeded 1.15 x 2/3 of design ultimate strength. There was no requirement for submission of the yield data for inclusion in ANC-5.

b Shear strength based on areas computed from nominal hole diameters in Table 8.1.2(a) and  $F_{su} = 28$  ksi.

**Table 8.1.3.1.2(a). Static Joint Strength of Blind Protruding Head Locked Spindle A-286 Rivets in Alloy Steel Sheet**

|                                                             |                                                                                 |                   |                   |                                           |                   |                   |
|-------------------------------------------------------------|---------------------------------------------------------------------------------|-------------------|-------------------|-------------------------------------------|-------------------|-------------------|
| Rivet Type . . . . .                                        | NAS1398C <sup>a</sup> and NAS1398C,<br>Code A <sup>b</sup> ( $F_{su}$ = 75 ksi) |                   |                   | CR 2643 <sup>a</sup> ( $F_{su}$ = 95 ksi) |                   |                   |
|                                                             | Alloy Steel $F_u$ = 180 ksi                                                     |                   |                   |                                           |                   |                   |
| Rivet Diameter, in. . . . .<br>(Nominal Hole Diameter, in.) | 1/8<br>(0.130)                                                                  | 5/32<br>(0.162)   | 3/16<br>(0.194)   | 1/8<br>(0.130)                            | 5/32<br>(0.162)   | 3/16<br>(0.194)   |
|                                                             | Ultimate Strength <sup>c</sup> , lbs                                            |                   |                   |                                           |                   |                   |
| Sheet thickness, in.:                                       |                                                                                 |                   |                   |                                           |                   |                   |
| 0.025 . . . . .                                             | 697                                                                             | ...               | ...               | 697                                       | ...               | ...               |
| 0.032 . . . . .                                             | 785                                                                             | 1112              | ...               | 807                                       | 1112              | ...               |
| 0.040 . . . . .                                             | 860                                                                             | 1211              | 1628              | 911                                       | 1246              | 1639              |
| 0.050 . . . . .                                             | 956                                                                             | 1325              | 1772              | 1043                                      | 1406              | 1833              |
| 0.063 . . . . .                                             | 970                                                                             | 1480              | 1958              | 1215                                      | 1615              | 2090              |
| 0.071 . . . . .                                             | ...                                                                             | 1490              | 2070              | 1230                                      | 1748              | 2240              |
| 0.080 . . . . .                                             | ...                                                                             | ...               | 2150              | ...                                       | 1885              | 2420              |
| 0.090 . . . . .                                             | ...                                                                             | ...               | ...               | ...                                       | ...               | 2610              |
| 0.100 . . . . .                                             | ...                                                                             | ...               | ...               | ...                                       | ...               | 2720              |
| Rivet shear strength . . . . .                              | 970 <sup>d</sup>                                                                | 1490 <sup>d</sup> | 2150 <sup>d</sup> | 1230 <sup>e</sup>                         | 1885 <sup>e</sup> | 2720 <sup>e</sup> |

a Data supplied by Cherry Fasteners.  
b Confirmatory data supplied by Olympic Fastening Systems, Inc.  
c Yield strength is in excess of 80% of ultimate. This is based on a previous Navy “Bureau of Aeronautics” definition that yield strength would not be considered to be critical if it exceeded 1.15 x 2/3 of design ultimate strength. There was no requirement for submission of the yield data for inclusion in ANC-5.  
d Rivet shear strength is documented in NAS1400.  
e Shear strength based on areas computed from nominal hole diameters in Table 8.1.2(a) and  $F_{su} = 95$  ksi.

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**Table 8.1.3.1.2(b). Static Joint Strength of Blind Protruding Head Locked Spindle Monel Rivets in Stainless Steel Sheet**

| Rivet Type .....                                         | NAS1398 MS or MW <sup>a</sup> and NAS1398 MS or MW, Code A <sup>b</sup><br>( $F_{su} = 55$ ksi) |                 |                 |
|----------------------------------------------------------|-------------------------------------------------------------------------------------------------|-----------------|-----------------|
|                                                          | AISI 301-½ Hard                                                                                 |                 |                 |
| Sheet Material .....                                     |                                                                                                 |                 |                 |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) | 1/8<br>(0.130)                                                                                  | 5/32<br>(0.162) | 3/16<br>(0.194) |
| Sheet thickness, in.:                                    | Ultimate Strength <sup>c</sup> , lbs                                                            |                 |                 |
|                                                          |                                                                                                 |                 |                 |
| 0.025 .....                                              | 462                                                                                             | ...             | ...             |
| 0.032 .....                                              | 568                                                                                             | 734             | ...             |
| 0.040 .....                                              | 594                                                                                             | 870             | 1094            |
| 0.050 .....                                              | 632                                                                                             | 915             | 1270            |
| 0.063 .....                                              | 678                                                                                             | 971             | 1335            |
| 0.071 .....                                              | 706                                                                                             | 1009            | 1380            |
| 0.080 .....                                              | 710                                                                                             | 1048            | 1428            |
| 0.090 .....                                              | ...                                                                                             | 1090            | 1532            |
| 0.100 .....                                              | ...                                                                                             | ...             | 1580            |
| Rivet shear strength <sup>d</sup> .....                  | 710                                                                                             | 1090            | 1580            |

a Data supplied by Cherry Fasteners.

b Confirmatory data supplied by Olympic Fastening Systems, Inc.

c Yield strength is in excess of 80% of ultimate strength. This is based on a previous Navy “Bureau of Aeronautics” definition that yield strength was not considered to be critical if it exceeded 1.15 x 2/3 of design ultimate strength. There was no requirement for submission of the yield strength data for inclusion in ANC-5.

d Rivet shear strength is documented in NAS1400.

**Table 8.1.3.1.2(c). Static Joint Strength of Blind Protruding Head Locked Spindle Monel Rivets in Aluminum Alloy Sheet**

|                                                                                                                                                                             |                                                                                                 |                 |                 |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-----------------|-----------------|
| Rivet Type .....                                                                                                                                                            | NAS1398 MS or MW <sup>a</sup> and NAS1398 MS or MW, Code A <sup>b</sup><br>( $F_{su} = 55$ ksi) |                 |                 |
| Sheet Material .....                                                                                                                                                        | Clad 7075-T6                                                                                    |                 |                 |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) .....                                                                                                              | 1/8<br>(0.130)                                                                                  | 5/32<br>(0.162) | 3/16<br>(0.194) |
| Sheet thickness, in.:<br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 ..... | Ultimate Strength <sup>c</sup> , lbs                                                            |                 |                 |
|                                                                                                                                                                             | 318                                                                                             | ...             | ...             |
|                                                                                                                                                                             | 404                                                                                             | 506             | ...             |
|                                                                                                                                                                             | 466                                                                                             | 624             | 774             |
|                                                                                                                                                                             | 546                                                                                             | 720             | 922             |
|                                                                                                                                                                             | 647                                                                                             | 845             | 1072            |
|                                                                                                                                                                             | 710                                                                                             | 921             | 1168            |
|                                                                                                                                                                             | ...                                                                                             | 1009            | 1272            |
|                                                                                                                                                                             | ...                                                                                             | 1090            | 1387            |
|                                                                                                                                                                             | ...                                                                                             | ...             | 1507            |
| Rivet shear strength <sup>d</sup> .....                                                                                                                                     | 710                                                                                             | 1090            | 1580            |

a Data supplied by Cherry Fasteners.  
b Confirmatory data supplied by Olympic Fastening Systems, Inc.  
c Yield strength is in excess of 80% of ultimate. This is based on a previous Navy “Bureau of Aeronautics” definition that yield strength would not be considered to be critical if it exceeded 1.15 x 1/3 of design ultimate strength. There was no requirement for submission of the yield data for inclusion in ANC-5.  
d Rivet shear strength is documented in NAS1400.

Table 8.1.3.1.2(d<sub>1</sub>). Static Joint Strength of Blind Protruding Head Locked Spindle Aluminum Alloy Rivets in Aluminum Alloy Sheet

| Rivet Type .....                                         | NAS1398B <sup>a</sup> ( $F_{su}$ = 30 ksi) |                 |                 |                | NAS1398D <sup>a</sup> ( $F_{su}$ = 38 ksi) |                 |                 |                |      |
|----------------------------------------------------------|--------------------------------------------|-----------------|-----------------|----------------|--------------------------------------------|-----------------|-----------------|----------------|------|
| Sheet Material .....                                     | Clad 2024-T3                               |                 |                 |                |                                            |                 |                 |                |      |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) | 1/8<br>(0.130)                             | 5/32<br>(0.162) | 3/16<br>(0.194) | 1/4<br>(0.258) | 1/8<br>(0.130)                             | 5/32<br>(0.162) | 3/16<br>(0.194) | 1/4<br>(0.258) |      |
| Sheet thickness, in.:                                    | Ultimate Strength, lbs.                    |                 |                 |                |                                            |                 |                 |                |      |
|                                                          | 0.025 .....                                | 228             | ...             | ...            | ...                                        | 228             | ...             | ...            | ...  |
|                                                          | 0.032 .....                                | 289             | 364             | 412            | ...                                        | 304             | 364             | ...            | ...  |
|                                                          | 0.040 .....                                | 337             | 448             | 553            | 670                                        | 355             | 470             | 553            | ...  |
|                                                          | 0.050 .....                                | 388             | 521             | 662            | 914                                        | 418             | 548             | 696            | 914  |
|                                                          | 0.063 .....                                | ...             | 596             | 781            | 1145                                       | 494             | 647             | 816            | 1205 |
|                                                          | 0.071 .....                                | ...             | ...             | 854            | 1240                                       | ...             | 710             | 894            | 1303 |
|                                                          | 0.080 .....                                | ...             | ...             | 862            | 1350                                       | ...             | 755             | 975            | 1420 |
|                                                          | 0.090 .....                                | ...             | ...             | ...            | 1475                                       | ...             | ...             | 1069           | 1545 |
|                                                          | 0.100 .....                                | ...             | ...             | ...            | 1550                                       | ...             | ...             | 1090           | 1670 |
|                                                          | 0.125 .....                                | ...             | ...             | ...            | ...                                        | ...             | ...             | ...            | 1970 |
|                                                          | Rivet shear strength <sup>b</sup> .....    | 388             | 596             | 862            | 1550                                       | 494             | 755             | 1090           | 1970 |

a Data supplied by Cherry Fasteners.  
b Rivet shear strength documented in NAS1400.



Table 8.1.3.1.2(d<sub>2</sub>). Static Joint Strength of Blind Protruding Head Locked Spindle Aluminum Alloy Rivets in Aluminum Alloy Sheet

|                                                                                                                                                                             |                                                         |                  |                   |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|------------------|-------------------|
| Rivet Type .....                                                                                                                                                            | NAS1738B and NAS1738E <sup>a</sup> ( $F_{su} = 34$ ksi) |                  |                   |
| Sheet Material .....                                                                                                                                                        | Clad 2024-T3                                            |                  |                   |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) .....                                                                                                              | 1/8<br>(0.144)                                          | 5/32<br>(0.178)  | 3/16<br>(0.207)   |
| Sheet thickness, in.:<br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....                | Ultimate Strength, lbs                                  |                  |                   |
|                                                                                                                                                                             | 267                                                     | 305              | 330               |
|                                                                                                                                                                             | 368                                                     | 428              | 473               |
|                                                                                                                                                                             | 427                                                     | 567              | 636               |
|                                                                                                                                                                             | 480                                                     | 650              | 815               |
|                                                                                                                                                                             | 547 <sup>b</sup>                                        | 735              | 912               |
|                                                                                                                                                                             | 554 <sup>b</sup>                                        | 785 <sup>b</sup> | 976               |
|                                                                                                                                                                             | ...                                                     | 837 <sup>b</sup> | 1042 <sup>b</sup> |
|                                                                                                                                                                             | ...                                                     | ...              | 1115 <sup>b</sup> |
|                                                                                                                                                                             | ...                                                     | ...              | 1128 <sup>b</sup> |
| Rivet shear strength <sup>c</sup> .....                                                                                                                                     | 554                                                     | 837              | 1128              |
| Sheet thickness, in.:<br>0.020 .....<br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 ..... | Yield Strength <sup>d</sup> , lbs                       |                  |                   |
|                                                                                                                                                                             | 185                                                     | 213              | 228               |
|                                                                                                                                                                             | 242                                                     | 285              | 317               |
|                                                                                                                                                                             | 298                                                     | 386              | 433               |
|                                                                                                                                                                             | 321                                                     | 453              | 568               |
|                                                                                                                                                                             | 336                                                     | 489              | 625               |
|                                                                                                                                                                             | 336                                                     | 508              | 680               |
|                                                                                                                                                                             | 336                                                     | 508              | 684               |
|                                                                                                                                                                             | ...                                                     | 508              | 684               |
|                                                                                                                                                                             | ...                                                     | ...              | 684               |
|                                                                                                                                                                             | ...                                                     | ...              | 684               |

a Data supplied by Cherry Fasteners.  
b Yield value is less than 2/3 of the indicated ultimate.  
c Rivet shear strength was documented in NAS1740 prior to Revision (1), dated January 15, 1974.  
d Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.

Table 8.1.3.1.2(e). Static Joint Strength of Blind Protruding Head Locked Spindle Aluminum Alloy Rivets in Magnesium Alloy Sheet

|                                                                 |                                            |                  |                  |                  |                                                            |                  |                   |
|-----------------------------------------------------------------|--------------------------------------------|------------------|------------------|------------------|------------------------------------------------------------|------------------|-------------------|
| Rivet Type . . . . .                                            | NAS1398B <sup>a</sup> ( $F_{su}$ = 30 ksi) |                  |                  |                  | NAS1738B and NAS1738E <sup>a</sup><br>( $F_{su}$ = 34 ksi) |                  |                   |
| Sheet Material . . . . .                                        | AZ31B-H24                                  |                  |                  |                  |                                                            |                  |                   |
| Rivet Diameter, in. . . . .<br>(Nominal Hole Diameter, in.) . . | 1/8<br>(0.130)                             | 5/32<br>(0.162)  | 3/16<br>(0.194)  | 1/4<br>(0.258)   | 1/8<br>(0.144)                                             | 5/32<br>(0.178)  | 3/16<br>(0.207)   |
| Sheet thickness, in.:                                           | Ultimate Strength, lbs.                    |                  |                  |                  |                                                            |                  |                   |
|                                                                 | 163                                        | ...              | ...              | ...              | 202                                                        | ...              | ...               |
|                                                                 | 208                                        | 256              | 310              | ...              | 261                                                        | 321              | 372               |
|                                                                 | 255                                        | 324              | 388              | 519              | 325                                                        | 401              | 465               |
|                                                                 | 298                                        | 394              | 485              | 654              | 372                                                        | 501              | 579               |
|                                                                 | 352                                        | 461              | 588              | 822              | 425                                                        | 570              | 708               |
|                                                                 | 385                                        | 501              | 639              | 924              | 458                                                        | 609              | 756               |
|                                                                 | 388                                        | 550              | 695              | 1020             | 495                                                        | 656              | 809               |
|                                                                 | ...                                        | 596              | 755              | 1109             | 536 <sup>b</sup>                                           | 709              | 866               |
|                                                                 | ...                                        | ...              | 820              | 1191             | 554 <sup>b</sup>                                           | 759              | 925               |
|                                                                 | ...                                        | ...              | 862              | 1397             | ...                                                        | 837 <sup>b</sup> | 1072 <sup>b</sup> |
|                                                                 | ...                                        | ...              | ...              | 1550             | ...                                                        | ...              | 1128 <sup>b</sup> |
|                                                                 | Rivet shear strength . . . . .             | 388 <sup>c</sup> | 596 <sup>c</sup> | 862 <sup>c</sup> | 1550 <sup>c</sup>                                          | 554 <sup>d</sup> | 837 <sup>d</sup>  |
| Sheet thickness, in.:                                           | Yield Strength <sup>e</sup> , lbs.         |                  |                  |                  |                                                            |                  |                   |
|                                                                 | ...                                        | ...              | ...              | ...              | 155                                                        | ...              | ...               |
|                                                                 | ...                                        | ...              | ...              | ...              | 198                                                        | 243              | 282               |
|                                                                 | ...                                        | ...              | ...              | ...              | 248                                                        | 304              | 353               |
|                                                                 | ...                                        | ...              | ...              | ...              | 302                                                        | 380              | 441               |
|                                                                 | ...                                        | ...              | ...              | ...              | 325                                                        | 460              | 556               |
|                                                                 | ...                                        | ...              | ...              | ...              | 336                                                        | 478              | 614               |
|                                                                 | ...                                        | ...              | ...              | ...              | 336                                                        | 499              | 638               |
|                                                                 | ...                                        | ...              | ...              | ...              | 336                                                        | 508              | 664               |
|                                                                 | ...                                        | ...              | ...              | ...              | 336                                                        | 508              | 684               |
|                                                                 | ...                                        | ...              | ...              | ...              | ...                                                        | 508              | 684               |
|                                                                 | ...                                        | ...              | ...              | ...              | ...                                                        | ...              | 684               |

a Data supplied by Cherry Fasteners.  
b Yield value is less than 2/3 of the indicated ultimate strength value.  
c Rivet shear strength is documented in NAS1400.  
d Rivet shear strength was documented in NAS1740 prior to Revision (1), dated January 15, 1974.  
e Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.

Table 8.1.3.1.2(f). Static Joint Strength of Blind Protruding Head Locked Spindle Aluminum Alloy (2219) Rivets in Aluminum Alloy Sheet

|                                                                                                                                                                                                        |                                           |                 |                 |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|-----------------|-----------------|
| Rivet Type .....                                                                                                                                                                                       | CR 2A63 <sup>a</sup> ( $F_{su}$ = 36 ksi) |                 |                 |
| Sheet Material .....                                                                                                                                                                                   | Clad 2024-T81                             |                 |                 |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) .                                                                                                                                             | 1/8<br>(0.130)                            | 5/32<br>(0.162) | 3/16<br>(0.194) |
| Sheet thickness, in.<br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>Rivet shear strength <sup>b</sup> ..... | Ultimate Strength, lbs                    |                 |                 |
|                                                                                                                                                                                                        | 256                                       | ...             | ...             |
|                                                                                                                                                                                                        | 295                                       | 404             | ...             |
|                                                                                                                                                                                                        | 340                                       | 458             | 592             |
|                                                                                                                                                                                                        | 395                                       | 527             | 675             |
|                                                                                                                                                                                                        | 467                                       | 617             | 783             |
|                                                                                                                                                                                                        | 478                                       | 672             | 848             |
|                                                                                                                                                                                                        | ...                                       | 734             | 922             |
|                                                                                                                                                                                                        | ...                                       | 741             | 1005            |
|                                                                                                                                                                                                        | ...                                       | ...             | 1063            |
|                                                                                                                                                                                                        | 478                                       | 741             | 1063            |
| Sheet thickness, in.:<br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....                                           | Yield Strength <sup>c</sup> , lbs         |                 |                 |
|                                                                                                                                                                                                        | 256                                       | ...             | ...             |
|                                                                                                                                                                                                        | 295                                       | 404             | ...             |
|                                                                                                                                                                                                        | 336                                       | 458             | 592             |
|                                                                                                                                                                                                        | 383                                       | 521             | 675             |
|                                                                                                                                                                                                        | 440                                       | 598             | 770             |
|                                                                                                                                                                                                        | 445                                       | 646             | 827             |
|                                                                                                                                                                                                        | ...                                       | 683             | 890             |
|                                                                                                                                                                                                        | ...                                       | 690             | 963             |
|                                                                                                                                                                                                        | ...                                       | ...             | 984             |

a Data supplied by Cherry Fasteners.  
b Shear strength values based on indicated nominal hole diameters and  $F_{su}$  = 36 ksi.  
c Permanent set at yield load: 4% of nominal hole diameter (Ref. 9.4.1.3.3).

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**Table 8.1.3.1.2(g). Static Joint Strength of Blind Protruding Head Locked Spindle A-286 Rivets in Aluminum Alloy Sheet**

|                                                                       |                                          |                 |                 |                |
|-----------------------------------------------------------------------|------------------------------------------|-----------------|-----------------|----------------|
| Rivet Type .....                                                      | CR4623 <sup>a</sup> ( $F_{su} = 75$ ksi) |                 |                 |                |
| Sheet Material .....                                                  | Clad 7075-T6                             |                 |                 |                |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) <sup>b</sup> | 1/8<br>(0.130)                           | 5/32<br>(0.162) | 3/16<br>(0.194) | 1/4<br>(0.258) |
| Sheet thickness, in.:                                                 | Ultimate Strength, lbs.                  |                 |                 |                |
| 0.020 .....                                                           | 237                                      | ...             | ...             | ...            |
| 0.025 .....                                                           | 298                                      | 367             | ...             | ...            |
| 0.032 .....                                                           | 385                                      | 478             | 566             | ...            |
| 0.040 .....                                                           | 486                                      | 601             | 714             | 939            |
| 0.050 .....                                                           | 610                                      | 757             | 902             | 1185           |
| 0.063 .....                                                           | 772                                      | 958             | 1145            | 1505           |
| 0.071 .....                                                           | 856                                      | 1080            | 1290            | 1705           |
| 0.080 .....                                                           | 903                                      | 1220            | 1455            | 1925           |
| 0.090 .....                                                           | 956                                      | 1340            | 1645            | 2175           |
| 0.100 .....                                                           | 995                                      | 1405            | 1830            | 2425           |
| 0.125 .....                                                           | ...                                      | 1545            | 2055            | 3035           |
| 0.160 .....                                                           | ...                                      | ...             | 2215            | 3570           |
| 0.190 .....                                                           | ...                                      | ...             | ...             | 3885           |
| 0.250 .....                                                           | ...                                      | ...             | ...             | 3920           |
| Rivet shear strength <sup>c</sup> .....                               | 995                                      | 1545            | 2215            | 3920           |
| Sheet thickness, in.:                                                 | Yield Strength <sup>d</sup> , lbs.       |                 |                 |                |
| 0.020 .....                                                           | 237                                      | ...             | ...             | ...            |
| 0.025 .....                                                           | 296                                      | 367             | ...             | ...            |
| 0.032 .....                                                           | 381                                      | 475             | 565             | ...            |
| 0.040 .....                                                           | 478                                      | 594             | 709             | 938            |
| 0.050 .....                                                           | 596                                      | 745             | 890             | 1180           |
| 0.063 .....                                                           | 690                                      | 932             | 1125            | 1490           |
| 0.071 .....                                                           | 747                                      | 1005            | 1270            | 1680           |
| 0.080 .....                                                           | 812                                      | 1085            | 1385            | 1895           |
| 0.090 .....                                                           | 857                                      | 1175            | 1495            | 2140           |
| 0.100 .....                                                           | 879                                      | 1265            | 1600            | 2360           |
| 0.125 .....                                                           | ...                                      | 1365            | 1870            | 2715           |
| 0.160 .....                                                           | ...                                      | ...             | 1995            | 3215           |
| 0.190 .....                                                           | ...                                      | ...             | ...             | 3425           |
| 0.250 .....                                                           | ...                                      | ...             | ...             | 3690           |

a Data supplied by Cherry Fasteners.  
b Allowable loads developed from test with hole diameters as listed.  
c Fastener shear strength based on nominal hole diameters and  $F_{su} = 75$  ksi from data analysis.  
d Permanent set at yield load: 4% of nominal hole diameter (Ref. 9.4.1.3.3).

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**Table 8.1.3.1.2(h). Static Joint Strength of Blind Protruding Head Locked Spindle Monel Rivets in Aluminum Alloy Sheet**

|                                                                       |                                           |                 |                 |                |
|-----------------------------------------------------------------------|-------------------------------------------|-----------------|-----------------|----------------|
| Rivet Type .....                                                      | CR 4523 <sup>a</sup> ( $F_{su} = 65$ ksi) |                 |                 |                |
| Sheet Material .....                                                  | Clad 7075-T6                              |                 |                 |                |
| Rivet Diameter, in .....<br>(Nominal Hole Diameter, in.) <sup>b</sup> | 1/8<br>(0.130)                            | 5/32<br>(0.162) | 3/16<br>(0.194) | 1/4<br>(0.258) |
| Sheet thickness, in.:                                                 | Ultimate Strength, lbs.                   |                 |                 |                |
| 0.020 .....                                                           | 221                                       | ...             | ...             | ...            |
| 0.025 .....                                                           | 284                                       | 344             | ...             | ...            |
| 0.032 .....                                                           | 373                                       | 456             | 533             | ...            |
| 0.040 .....                                                           | 475                                       | 582             | 684             | 878            |
| 0.050 .....                                                           | 602                                       | 740             | 875             | 1130           |
| 0.063 .....                                                           | 701                                       | 945             | 1120            | 1455           |
| 0.071 .....                                                           | 729                                       | 1055            | 1270            | 1655           |
| 0.080 .....                                                           | 760                                       | 1095            | 1440            | 1885           |
| 0.090 .....                                                           | 796                                       | 1140            | 1540            | 2135           |
| 0.100 .....                                                           | 831                                       | 1180            | 1590            | 2390           |
| 0.125 .....                                                           | 863                                       | 1290            | 1725            | 2760           |
| 0.160 .....                                                           | ...                                       | 1340            | 1905            | 3005           |
| 0.190 .....                                                           | ...                                       | ...             | 1920            | 3215           |
| 0.250 .....                                                           | ...                                       | ...             | ...             | 3400           |
| Rivet shear strength <sup>c</sup> .....                               | 863                                       | 1340            | 1920            | 3400           |
| Sheet thickness, in.:                                                 | Yield Strength <sup>d</sup> , lbs.        |                 |                 |                |
| 0.020 .....                                                           | 221                                       | ...             | ...             | ...            |
| 0.025 .....                                                           | 279                                       | 344             | ...             | ...            |
| 0.032 .....                                                           | 360                                       | 447             | 530             | ...            |
| 0.040 .....                                                           | 453                                       | 561             | 667             | 878            |
| 0.050 .....                                                           | 569                                       | 706             | 841             | 1110           |
| 0.063 .....                                                           | 659                                       | 893             | 1065            | 1405           |
| 0.071 .....                                                           | 707                                       | 965             | 1205            | 1590           |
| 0.080 .....                                                           | 729                                       | 1035            | 1340            | 1795           |
| 0.090 .....                                                           | 752                                       | 1105            | 1430            | 2030           |
| 0.100 .....                                                           | 776                                       | 1135            | 1520            | 2260           |
| 0.125 .....                                                           | 834                                       | 1205            | 1645            | 2590           |
| 0.160 .....                                                           | ...                                       | 1305            | 1765            | 2880           |
| 0.190 .....                                                           | ...                                       | ...             | 1870            | 3015           |
| 0.250 .....                                                           | ...                                       | ...             | ...             | 3290           |

a Data supplied by Cherry Fasteners.  
b Allowable loads developed from test with hole diameters as listed.  
c Fastener shear strength based on nominal hole diameters and  $F_{su} = 65$  ksi from data analysis.  
d Permanent set at yield load: 4% of nominal hole diameter (Ref. 9.4.1.3.3).

Table 8.1.3.1.2(i). Static Joint Strength of Blind Protruding Head Locked Spindle Aluminum Alloy (7050) Rivets in Aluminum Alloy Sheet

|                                                                             |                                                                   |                 |                 |
|-----------------------------------------------------------------------------|-------------------------------------------------------------------|-----------------|-----------------|
| Rivet Type .....                                                            | NAS 1720KE and NAS 1720KE( )L <sup>a,b</sup> ( $F_{su}$ = 33 ksi) |                 |                 |
| Sheet Material .....                                                        | Clad 2024-T3                                                      |                 |                 |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) <sup>c</sup> ..... | 1/8<br>(0.130)                                                    | 5/32<br>(0.162) | 3/16<br>(0.194) |
| Sheet thickness, in.:                                                       | Ultimate Strength, lbs.                                           |                 |                 |
| 0.020 .....                                                                 | 174                                                               | ...             | ...             |
| 0.025 .....                                                                 | 219                                                               | 272             | ...             |
| 0.032 .....                                                                 | 282                                                               | 350             | 417             |
| 0.040 .....                                                                 | 354                                                               | 440             | 525             |
| 0.050 .....                                                                 | 376                                                               | 552             | 659             |
| 0.063 .....                                                                 | 392                                                               | 585             | 816             |
| 0.071 .....                                                                 | 402                                                               | 597             | 831             |
| 0.080 .....                                                                 | 413                                                               | 611             | 847             |
| 0.090 .....                                                                 | 425                                                               | 626             | 866             |
| 0.100 .....                                                                 | 437                                                               | 641             | 884             |
| 0.125 .....                                                                 | 450                                                               | 680             | 929             |
| 0.160 .....                                                                 | ...                                                               | 700             | 950             |
| Rivet shear strength <sup>d</sup> .....                                     | 450                                                               | 700             | 950             |
| Sheet thickness, in.:                                                       | Yield Strength <sup>e</sup> , lbs.                                |                 |                 |
| 0.020 .....                                                                 | 174                                                               | ...             | ...             |
| 0.025 .....                                                                 | 215                                                               | 272             | ...             |
| 0.032 .....                                                                 | 261                                                               | 340             | 417             |
| 0.040 .....                                                                 | 314                                                               | 406             | 504             |
| 0.050 .....                                                                 | 366                                                               | 489             | 603             |
| 0.063 .....                                                                 | 382                                                               | 570             | 732             |
| 0.071 .....                                                                 | 391                                                               | 582             | 809             |
| 0.080 .....                                                                 | 402                                                               | 595             | 825             |
| 0.090 .....                                                                 | 414                                                               | 610             | 843             |
| 0.100 .....                                                                 | 426                                                               | 625             | 861             |
| 0.125 .....                                                                 | 450                                                               | 662             | 905             |
| 0.160 .....                                                                 | ...                                                               | 700             | 950             |

a Data supplied by Avdel Corp.  
b Fasteners should not be used for structural applications where the t/D is less than 0.15.  
c Loads developed from tests with hole diameters of 0.130, 0.162, and 0.194, +0.0005, -0.0000 inch.  
d Rivet shear strength is documented in NAS 1722.  
e Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

**Table 8.1.3.1.2(j). Static Joint Strength of Blind Protruding Head Locked Spindle A-286 Rivets in Aluminum Alloy Sheet**

|                                                                          |                                                               |                 |                 |
|--------------------------------------------------------------------------|---------------------------------------------------------------|-----------------|-----------------|
| Rivet Type .....                                                         | NAS1720C and NAS1720C( )L <sup>a,b</sup> ( $F_{su} = 75$ ksi) |                 |                 |
| Sheet Material .....                                                     | Clad 7075-T6                                                  |                 |                 |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) <sup>c</sup> .. | 1/8<br>(0.130)                                                | 5/32<br>(0.162) | 3/16<br>(0.194) |
| Sheet thickness, in:                                                     | Ultimate Strength, lbs.                                       |                 |                 |
| 0.025 .....                                                              | 329                                                           | ...             | ...             |
| 0.032 .....                                                              | 399                                                           | 528             | ...             |
| 0.040 .....                                                              | 499                                                           | 621             | 799             |
| 0.050 .....                                                              | 625                                                           | 778             | 930             |
| 0.063 .....                                                              | 789                                                           | 982             | 1170            |
| 0.071 .....                                                              | 847                                                           | 1105            | 1320            |
| 0.080 .....                                                              | 870                                                           | 1245            | 1490            |
| 0.090 .....                                                              | 896                                                           | 1320            | 1680            |
| 0.100 .....                                                              | 921                                                           | 1350            | 1865            |
| 0.125 .....                                                              | 985                                                           | 1430            | 1955            |
| 0.160 .....                                                              | 1000                                                          | 1500            | 2090            |
| 0.190 .....                                                              | ...                                                           | ...             | 2200            |
| Rivet shear strength <sup>d</sup> .....                                  | 1000                                                          | 1500            | 2200            |
| Sheet thickness, in.:                                                    | Yield Strength <sup>e</sup> , lbs.                            |                 |                 |
| 0.025 .....                                                              | 329                                                           | ...             | ...             |
| 0.032 .....                                                              | 390                                                           | 386             | ...             |
| 0.040 .....                                                              | 453                                                           | 607             | 779             |
| 0.050 .....                                                              | 531                                                           | 704             | 895             |
| 0.063 .....                                                              | 632                                                           | 831             | 1045            |
| 0.071 .....                                                              | 687                                                           | 909             | 1140            |
| 0.080 .....                                                              | 701                                                           | 996             | 1245            |
| 0.090 .....                                                              | 717                                                           | 1070            | 1360            |
| 0.100 .....                                                              | 733                                                           | 1090            | 1475            |
| 0.125 .....                                                              | 773                                                           | 1140            | 1575            |
| 0.160 .....                                                              | 829                                                           | 1210            | 1655            |
| 0.190 .....                                                              | ...                                                           | ...             | 1730            |

a Data supplied by Avdel Corp.

b Fasteners should not be used for structural applications where the t/D is less than 0.15.

c Loads developed from tests with hole diameters of 0.130, 0.162, and 0.194,  $\pm 0.0001$  inch.

d Rivet shear strength is documented in NAS1722.

e Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

Table 8.1.3.1.2(m). Static Joint Strength of Blind Protruding Head Locked Spindle Aluminum Alloy Rivets in Aluminum Alloy Sheet

|                                                                                                                                                                                                |                                                        |                 |                 |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|-----------------|-----------------|
| Rivet Type .....                                                                                                                                                                               | AF3243 (F <sub>su</sub> = 51 ksi approx.) <sup>a</sup> |                 |                 |
| Sheet Material .....                                                                                                                                                                           | Clad 2024-T3                                           |                 |                 |
| Rivet Diameter, in.<br>(Nominal Hole Diameter, in.) <sup>b</sup> .....                                                                                                                         | 1/8<br>(0.144)                                         | 5/32<br>(0.178) | 3/16<br>(0.207) |
| Sheet Thickness, in.:<br><br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 ..... | Ultimate Strength, lbs.                                |                 |                 |
|                                                                                                                                                                                                | 242                                                    | ---             | ---             |
|                                                                                                                                                                                                | 302                                                    | 382             | 453             |
|                                                                                                                                                                                                | 371                                                    | 467             | 551             |
|                                                                                                                                                                                                | 456                                                    | 572             | 674             |
|                                                                                                                                                                                                | 538                                                    | 710             | 834             |
|                                                                                                                                                                                                | 556                                                    | 795             | 932             |
|                                                                                                                                                                                                | 577                                                    | 828             | 1040            |
|                                                                                                                                                                                                | 600                                                    | 856             | 1110            |
|                                                                                                                                                                                                | 622                                                    | 885             | 1140            |
|                                                                                                                                                                                                | 679                                                    | 955             | 1225            |
|                                                                                                                                                                                                | 759                                                    | ---             | 1335            |
| THIS FASTENER HAS ONLY BEEN TESTED IN THE SHEET GAGES SHOWN IN THIS TABLE. DESIGN DATA FOR SHEET GAGES OR DIAMETERS OTHER THAN THOSE SHOWN HERE CANNOT BE EXTRAPOLATED.                        |                                                        |                 |                 |
| Rivet Shear Strength <sup>c</sup> .....                                                                                                                                                        | 814                                                    | 1245            | 1685            |
| Sheet Thickness, in.:<br><br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 ..... | Yield Strength, lbs <sup>d</sup>                       |                 |                 |
|                                                                                                                                                                                                | 242                                                    | ---             | ---             |
|                                                                                                                                                                                                | 302                                                    | 382             | 453             |
|                                                                                                                                                                                                | 371                                                    | 467             | 551             |
|                                                                                                                                                                                                | 456                                                    | 572             | 674             |
|                                                                                                                                                                                                | 538                                                    | 710             | 834             |
|                                                                                                                                                                                                | 556                                                    | 795             | 932             |
|                                                                                                                                                                                                | 577                                                    | 828             | 1040            |
|                                                                                                                                                                                                | 600                                                    | 856             | 1110            |
|                                                                                                                                                                                                | 622                                                    | 885             | 1140            |
|                                                                                                                                                                                                | 679                                                    | 955             | 1225            |
|                                                                                                                                                                                                | 759                                                    | ---             | 1335            |

a Data supplied by Allfast Fastening Systems Inc.  
b Loads developed from tests with hole diameters of 0.144, 0.178, and 0.207, +/-0.001 inch.  
c Rivet shear strength is documented on AF3243 standards drawing.  
d Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).



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Table 8.1.3.1.2(n). Static Joint Strength of Blind Protruding Head Locked Spindle Aluminum Alloy Rivets in Aluminum Alloy Sheet

|                                                                                                                                                                                                                              |                                                  |                 |                 |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------|-----------------|-----------------|
| Rivet Type .....                                                                                                                                                                                                             | HC3213 ( $F_{su} = 51$ ksi approx.) <sup>a</sup> |                 |                 |
| Sheet Material .....                                                                                                                                                                                                         | Clad 2024-T3                                     |                 |                 |
| Rivet Diameter, in.<br>(Nominal Hole Diameter, in.) <sup>b</sup> .....                                                                                                                                                       | 1/8<br>(0.130)                                   | 5/32<br>(0.162) | 3/16<br>(0.194) |
| Sheet Thickness, in.:<br><br>0.020 .....<br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 ..... | Ultimate Strength, lbs.                          |                 |                 |
|                                                                                                                                                                                                                              | 225                                              | ---             | ---             |
|                                                                                                                                                                                                                              | 265                                              | 351             | ---             |
|                                                                                                                                                                                                                              | 320                                              | 419             | 527             |
|                                                                                                                                                                                                                              | 383                                              | 498             | 621             |
|                                                                                                                                                                                                                              | 461                                              | 596             | 738             |
|                                                                                                                                                                                                                              | 538                                              | 723             | 891             |
|                                                                                                                                                                                                                              | 558                                              | 801             | 985             |
|                                                                                                                                                                                                                              | 581                                              | 840             | 1090            |
|                                                                                                                                                                                                                              | 607                                              | 872             | 1180            |
|                                                                                                                                                                                                                              | 632                                              | 904             | 1220            |
|                                                                                                                                                                                                                              | 664                                              | 983             | 1315            |
|                                                                                                                                                                                                                              | ---                                              | 1030            | 1445            |
|                                                                                                                                                                                                                              | ---                                              | ---             | 1480            |
| Rivet Shear Strength <sup>c</sup> .....                                                                                                                                                                                      | 664                                              | 1030            | 1480            |
| Sheet Thickness, in.:<br><br>0.020 .....<br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 ..... | Yield Strength, lbs <sup>d</sup>                 |                 |                 |
|                                                                                                                                                                                                                              | 182                                              | ---             | ---             |
|                                                                                                                                                                                                                              | 222                                              | 284             | ---             |
|                                                                                                                                                                                                                              | 278                                              | 354             | 431             |
|                                                                                                                                                                                                                              | 343                                              | 434             | 527             |
|                                                                                                                                                                                                                              | 423                                              | 534             | 647             |
|                                                                                                                                                                                                                              | 436                                              | 658             | 803             |
|                                                                                                                                                                                                                              | 444                                              | 668             | 898             |
|                                                                                                                                                                                                                              | 453                                              | 679             | 951             |
|                                                                                                                                                                                                                              | 463                                              | 691             | 965             |
|                                                                                                                                                                                                                              | 473                                              | 704             | 980             |
|                                                                                                                                                                                                                              | 497                                              | 734             | 1015            |
|                                                                                                                                                                                                                              | ---                                              | 777             | 1065            |
|                                                                                                                                                                                                                              | ---                                              | ---             | 1110            |

a Data supplied by Huck International Inc.  
b Loads developed from tests with hole diameters of 0.130, 0.162, and 0.194, +/- 0.001 inch.  
c Rivet shear strength is documented on HC3213 standards drawing.  
d Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

**Table 8.1.3.1.2(o). Static Joint Strength of Protruding Head Locked Spindle Aluminum Alloy Blind Rivets in Aluminum Alloy Sheet**

|                                                                |                                                  |                 |                 |
|----------------------------------------------------------------|--------------------------------------------------|-----------------|-----------------|
| Rivet Type .....                                               | HC6223 <sup>a</sup> ( $F_{su}$ = 50 ksi) Nominal |                 |                 |
| Sheet and Plate Material .....                                 | Clad 2024-T3                                     |                 |                 |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) ..... | 1/8<br>(0.130)                                   | 5/32<br>(0.162) | 3/16<br>(0.194) |
| Sheet thickness, in.:                                          | Ultimate Strength, lbs                           |                 |                 |
|                                                                |                                                  |                 |                 |
| 0.016 .....                                                    | ...                                              | ...             | ...             |
| 0.020 .....                                                    | ...                                              | ...             | ...             |
| 0.025 .....                                                    | 272                                              | ...             | ...             |
| 0.032 .....                                                    | 367                                              | 437             | ...             |
| 0.040 .....                                                    | 427                                              | 573             | 661             |
| 0.050 .....                                                    | 476                                              | 664             | 864             |
| 0.063 .....                                                    | 539                                              | 743             | 975             |
| 0.071 .....                                                    | 578                                              | 792             | 1033            |
| 0.080 .....                                                    | 622                                              | 846             | 1099            |
| 0.090 .....                                                    | 664                                              | 907             | 1171            |
| 0.100 .....                                                    | ...                                              | 967             | 1244            |
| 0.125 .....                                                    | ...                                              | 1030            | 1425            |
| 0.160 .....                                                    | ...                                              | ...             | 1480            |
| 0.190 .....                                                    | ...                                              | ...             | ...             |
| Rivet shear strength <sup>b</sup> .....                        | 664                                              | 1030            | 1480            |
| Sheet thickness, in.:                                          | Yield Strength <sup>c</sup> , lbs                |                 |                 |
|                                                                |                                                  |                 |                 |
| 0.016 .....                                                    | ...                                              | ...             | ...             |
| 0.020 .....                                                    | ...                                              | ...             | ...             |
| 0.025 .....                                                    | 255                                              | ...             | ...             |
| 0.032 .....                                                    | 320                                              | 406             | ...             |
| 0.040 .....                                                    | 394                                              | 498             | 605             |
| 0.050 .....                                                    | 417                                              | 613             | 743             |
| 0.063 .....                                                    | 437                                              | 648             | 901             |
| 0.071 .....                                                    | 449                                              | 664             | 920             |
| 0.080 .....                                                    | 463                                              | 681             | 940             |
| 0.090 .....                                                    | 478                                              | 700             | 963             |
| 0.100 .....                                                    | ...                                              | 720             | 986             |
| 0.125 .....                                                    | ...                                              | 768             | 1044            |
| 0.160 .....                                                    | ...                                              | ...             | 1125            |
| 0.190 .....                                                    | ...                                              | ...             | ...             |

a Data supplied by Huck International, Inc.  
b Rivet shear strength is documented in MIL-R-7885D.  
c Permanent set at yield load: 4% of nominal hole diameter (see 9.4.1.3.3).

**Table 8.1.3.1.2(p). Static Joint Strength of Protruding Head Locked Spindle Aluminum Alloy Blind Rivets in Aluminum Alloy Sheet**

|                                                                     |                                          |                  |                  |
|---------------------------------------------------------------------|------------------------------------------|------------------|------------------|
| Rivet Type . . . . .                                                | HC6253 <sup>a</sup> ( $F_{su} = 50$ ksi) |                  |                  |
| Sheet Material . . . . .                                            | Clad 2024-T3                             |                  |                  |
| Rivet Diameter, in. . . . .<br>(Nominal Hole Diameter, in.) . . . . | 1/8<br>(0.144)                           | 5/32<br>(0.178)  | 3/16<br>(0.207)  |
| Sheet thickness, in.:                                               | Ultimate Strength, lbs                   |                  |                  |
|                                                                     |                                          |                  |                  |
| 0.016 . . . . .                                                     | ...                                      | ...              | ...              |
| 0.020 . . . . .                                                     | ...                                      | ...              | ...              |
| 0.025 . . . . .                                                     | ...                                      | ...              | ...              |
| 0.032 . . . . .                                                     | 344                                      | 419              | ...              |
| 0.040 . . . . .                                                     | 436                                      | 532              | 613              |
| 0.050 . . . . .                                                     | 513                                      | 674              | 777              |
| 0.063 . . . . .                                                     | 559                                      | 789              | 992              |
| 0.071 . . . . .                                                     | 588                                      | 824              | 1055             |
| 0.080 . . . . .                                                     | 620                                      | 864              | 1101             |
| 0.090 . . . . .                                                     | 656                                      | 908              | 1152             |
| 0.100 . . . . .                                                     | 691                                      | 952              | 1204             |
| 0.125 . . . . .                                                     | 781                                      | 1063             | 1332             |
| 0.160 . . . . .                                                     | 814                                      | 1217             | 1512             |
| 0.190 . . . . .                                                     | ...                                      | 1245             | 1666             |
| 0.250 . . . . .                                                     | ...                                      | ...              | 1685             |
| Rivet shear strength <sup>b</sup> . . . . .                         | 814                                      | 1245             | 1685             |
| Sheet thickness, in.:                                               | Yield Strength <sup>c</sup> , lbs        |                  |                  |
|                                                                     |                                          |                  |                  |
| 0.016 . . . . .                                                     | ...                                      | ...              | ...              |
| 0.020 . . . . .                                                     | ...                                      | ...              | ...              |
| 0.025 . . . . .                                                     | ...                                      | ...              | ...              |
| 0.032 . . . . .                                                     | 344 <sup>d</sup>                         | 419 <sup>d</sup> | ...              |
| 0.040 . . . . .                                                     | 403                                      | 532 <sup>d</sup> | 613 <sup>d</sup> |
| 0.050 . . . . .                                                     | 462                                      | 619              | 731              |
| 0.063 . . . . .                                                     | 523                                      | 715              | 879              |
| 0.071 . . . . .                                                     | 541                                      | 774              | 948              |
| 0.080 . . . . .                                                     | 560                                      | 805              | 1025             |
| 0.090 . . . . .                                                     | 583                                      | 832              | 1079             |
| 0.100 . . . . .                                                     | 605                                      | 859              | 1110             |
| 0.125 . . . . .                                                     | 660                                      | 928              | 1190             |
| 0.160 . . . . .                                                     | 738                                      | 1024             | 1302             |
| 0.190 . . . . .                                                     | ...                                      | 1245             | 1397             |
| 0.250 . . . . .                                                     | ...                                      | ...              | 1588             |

a Data supplied by Huck International, Inc.  
b Rivet shear strength is documented in MIL-R-7885D.  
c Permanent set at yield load: 4% of nominal hole diameter (see 9.4.1.3.3).  
d Yield reduced to match ultimate strength.

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Table 8.1.3.1.2(q). Static Joint Strength of Blind Protruding Head Locked Spindle Aluminum Alloy Rivets in Aluminum Alloy Sheet

|                                                                                                                                                                                                                              |                                                        |                 |                 |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|-----------------|-----------------|
| Rivet Type .....                                                                                                                                                                                                             | AF3213 (F <sub>su</sub> = 51 ksi approx.) <sup>a</sup> |                 |                 |
| Sheet Material .....                                                                                                                                                                                                         | Clad 2024-T3                                           |                 |                 |
| Rivet Diameter, in.<br>(Nominal Hole Diameter, in.) <sup>b</sup> .....                                                                                                                                                       | 1/8<br>(0.130)                                         | 5/32<br>(0.162) | 3/16<br>(0.194) |
| Sheet Thickness, in.:<br><br>0.020 .....<br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 ..... | Ultimate Strength, lbs.                                |                 |                 |
|                                                                                                                                                                                                                              | 223                                                    | ---             | ---             |
|                                                                                                                                                                                                                              | 262                                                    | 347             | ---             |
|                                                                                                                                                                                                                              | 317                                                    | 416             | 522             |
|                                                                                                                                                                                                                              | 380                                                    | 494             | 616             |
|                                                                                                                                                                                                                              | 411                                                    | 592             | 733             |
|                                                                                                                                                                                                                              | 441                                                    | 640             | 875             |
|                                                                                                                                                                                                                              | 459                                                    | 663             | 902             |
|                                                                                                                                                                                                                              | 480                                                    | 689             | 933             |
|                                                                                                                                                                                                                              | 503                                                    | 717             | 968             |
|                                                                                                                                                                                                                              | 526                                                    | 746             | 1000            |
|                                                                                                                                                                                                                              | 583                                                    | 818             | 1085            |
|                                                                                                                                                                                                                              | ---                                                    | 918             | 1205            |
|                                                                                                                                                                                                                              | ---                                                    | ---             | 1310            |

THIS FASTENER HAS ONLY BEEN TESTED IN THE SHEET GAGES SHOWN IN THIS TABLE. DESIGN DATA FOR SHEET GAGES OR DIAMETERS OTHER THAN THOSE SHOWN HERE CANNOT BE EXTRAPOLATED.

|                                                                                                                                                                                                                              |                                  |      |      |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|------|------|
| Rivet Shear Strength <sup>c</sup> .....                                                                                                                                                                                      | 664                              | 1030 | 1480 |
| Sheet Thickness, in.:<br><br>0.020 .....<br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 ..... | Yield Strength, lbs <sup>d</sup> |      |      |
|                                                                                                                                                                                                                              | 223                              | ---  | ---  |
|                                                                                                                                                                                                                              | 262                              | 347  | ---  |
|                                                                                                                                                                                                                              | 317                              | 416  | 522  |
|                                                                                                                                                                                                                              | 362                              | 494  | 616  |
|                                                                                                                                                                                                                              | 378                              | 562  | 733  |
|                                                                                                                                                                                                                              | 398                              | 588  | 814  |
|                                                                                                                                                                                                                              | 411                              | 604  | 833  |
|                                                                                                                                                                                                                              | 425                              | 622  | 854  |
|                                                                                                                                                                                                                              | 441                              | 641  | 878  |
|                                                                                                                                                                                                                              | 457                              | 661  | 901  |
|                                                                                                                                                                                                                              | 496                              | 710  | 960  |
|                                                                                                                                                                                                                              | ---                              | 779  | 1040 |
|                                                                                                                                                                                                                              | ---                              | ---  | 1110 |

a Data supplied by Allfast Fastening Systems Inc.  
b Loads developed from tests with hole diameters of 0.130, 0.162, and 0.194, +/- 0.001 inch.  
c Rivet shear strength is documented on AF3213 standards drawing.  
d Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

Table 8.1.3.1.2(r). Static Joint Strength of Blind Protruding Head Locked Spindle Aluminum Alloy Rivets in Aluminum Alloy Sheet

|                                                                                                                                                                                                |                                                        |                 |                 |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|-----------------|-----------------|
| Rivet Type .....                                                                                                                                                                               | CR3213 (F <sub>su</sub> = 51 ksi approx.) <sup>a</sup> |                 |                 |
| Sheet Material .....                                                                                                                                                                           | Clad 2024-T3                                           |                 |                 |
| Rivet Diameter, in.<br>(Nominal Hole Diameter, in.) <sup>b</sup> .....                                                                                                                         | 1/8<br>(0.130)                                         | 5/32<br>(0.162) | 3/16<br>(0.194) |
| Sheet Thickness, in.:<br><br>0.020 .....<br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 ..... | Ultimate Strength, lbs.                                |                 |                 |
|                                                                                                                                                                                                | 250                                                    | ---             | ---             |
|                                                                                                                                                                                                | 280                                                    | 389             | ---             |
|                                                                                                                                                                                                | 322                                                    | 441             | 576             |
|                                                                                                                                                                                                | 370                                                    | 501             | 648             |
|                                                                                                                                                                                                | 430                                                    | 576             | 737             |
|                                                                                                                                                                                                | 492                                                    | 673             | 853             |
|                                                                                                                                                                                                | 513                                                    | 733             | 925             |
|                                                                                                                                                                                                | 536                                                    | 769             | 1005            |
|                                                                                                                                                                                                | 562                                                    | 801             | 1080            |
|                                                                                                                                                                                                | 587                                                    | 833             | 1115            |
|                                                                                                                                                                                                | 652                                                    | 913             | 1215            |

THIS FASTENER HAS ONLY BEEN TESTED IN THE SHEET GAGES SHOWN IN THIS TABLE. DESIGN DATA FOR SHEET GAGES OR DIAMETERS OTHER THAN THOSE SHOWN HERE CANNOT BE EXTRAPOLATED.

|                                                                                                                                                                                                |                                  |      |      |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|------|------|
| Rivet Shear Strength <sup>c</sup> .....                                                                                                                                                        | 664                              | 1030 | 1480 |
| Sheet Thickness, in.:<br><br>0.020 .....<br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 ..... | Yield Strength, lbs <sup>d</sup> |      |      |
|                                                                                                                                                                                                | 214                              | ---  | ---  |
|                                                                                                                                                                                                | 238                              | 332  | ---  |
|                                                                                                                                                                                                | 272                              | 375  | 491  |
|                                                                                                                                                                                                | 298                              | 424  | 550  |
|                                                                                                                                                                                                | 315                              | 463  | 623  |
|                                                                                                                                                                                                | 338                              | 491  | 672  |
|                                                                                                                                                                                                | 351                              | 508  | 692  |
|                                                                                                                                                                                                | 367                              | 527  | 716  |
|                                                                                                                                                                                                | 384                              | 549  | 741  |
|                                                                                                                                                                                                | 401                              | 570  | 767  |
|                                                                                                                                                                                                | 445                              | 624  | 831  |

a Data supplied by Textron Aerospace Fasteners.  
b Loads developed from tests with hole diameters of 0.130, 0.162, and 0.194, +/- 0.001 inch.  
c Rivet shear strength is documented on CR3213 standards drawing.  
d Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

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Table 8.1.3.1.2(s). Static Joint Strength of Blind Protruding Head Locked Spindle Aluminum Alloy Rivets in Aluminum Alloy Sheet

|                                                                                                                                                                                 |                                                                                                                                                                                    |                 |                 |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|-----------------|
| Rivet Type .....                                                                                                                                                                | CR3243 (F <sub>su</sub> = 51 ksi approx.) <sup>a</sup>                                                                                                                             |                 |                 |
| Sheet Material .....                                                                                                                                                            | Clad 2024-T3                                                                                                                                                                       |                 |                 |
| Rivet Diameter, in.<br>(Nominal Hole Diameter, in.) <sup>b</sup> .....                                                                                                          | 1/8<br>(0.144)                                                                                                                                                                     | 5/32<br>(0.178) | 3/16<br>(0.207) |
| Sheet Thickness, in.:<br><br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 ..... | Ultimate Strength, lbs.                                                                                                                                                            |                 |                 |
|                                                                                                                                                                                 | 317                                                                                                                                                                                | ---             | ---             |
|                                                                                                                                                                                 | 366                                                                                                                                                                                | 494             | 617             |
|                                                                                                                                                                                 | 421                                                                                                                                                                                | 562             | 696             |
|                                                                                                                                                                                 | 489                                                                                                                                                                                | 647             | 795             |
|                                                                                                                                                                                 | 579                                                                                                                                                                                | 758             | 924             |
|                                                                                                                                                                                 | 623                                                                                                                                                                                | 826             | 1000            |
|                                                                                                                                                                                 | 640                                                                                                                                                                                | 902             | 1090            |
|                                                                                                                                                                                 | 660                                                                                                                                                                                | 957             | 1190            |
|                                                                                                                                                                                 | 679                                                                                                                                                                                | 981             | 1280            |
|                                                                                                                                                                                 | 728                                                                                                                                                                                | 1040            | 1350            |
|                                                                                                                                                                                 | <div>THIS FASTENER HAS ONLY BEEN TESTED IN THE SHEET GAGES SHOWN IN THIS TABLE. DESIGN DATA FOR SHEET GAGES OR DIAMETERS OTHER THAN THOSE SHOWN HERE CANNOT BE EXTRAPOLATED.</div> |                 |                 |
| Rivet Shear Strength <sup>c</sup> .....                                                                                                                                         | 814                                                                                                                                                                                | 1245            | 1685            |
| Sheet Thickness, in.:<br><br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 ..... | Yield Strength, lbs <sup>d</sup>                                                                                                                                                   |                 |                 |
|                                                                                                                                                                                 | 272                                                                                                                                                                                | ---             | ---             |
|                                                                                                                                                                                 | 317                                                                                                                                                                                | 425             | 527             |
|                                                                                                                                                                                 | 368                                                                                                                                                                                | 488             | 600             |
|                                                                                                                                                                                 | 432                                                                                                                                                                                | 567             | 692             |
|                                                                                                                                                                                 | 451                                                                                                                                                                                | 664             | 811             |
|                                                                                                                                                                                 | 462                                                                                                                                                                                | 677             | 884             |
|                                                                                                                                                                                 | 475                                                                                                                                                                                | 693             | 911             |
|                                                                                                                                                                                 | 489                                                                                                                                                                                | 710             | 931             |
|                                                                                                                                                                                 | 503                                                                                                                                                                                | 728             | 951             |
|                                                                                                                                                                                 | 538                                                                                                                                                                                | 771             | 1000            |

a Data supplied by Textron Aerospace Fasteners.  
b Loads developed from tests with hole diameters of 0.144, 0.178, and 0.207, +/-0.001 inch.  
c Rivet shear strength is documented on CR3243 standards drawing.  
d Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

Table 8.1.3.1.2(t). Static Joint Strength of Blind Protruding Head Locked Spindle Aluminum Alloy Rivets in Aluminum Alloy Sheet

| Rivet Type .....                                                                                                                                                                                                             |  | HC3243 (F <sub>su</sub> = 51 ksi approx.) <sup>a</sup> |                 |                 |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|--------------------------------------------------------|-----------------|-----------------|
| Sheet Material .....                                                                                                                                                                                                         |  | Clad 2024-T3                                           |                 |                 |
| Rivet Diameter, in.<br>(Nominal Hole Diameter, in.) <sup>b</sup> .....                                                                                                                                                       |  | 1/8<br>(0.144)                                         | 5/32<br>(0.178) | 3/16<br>(0.207) |
| Sheet Thickness, in.:<br><br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 ..... |  | Ultimate Strength, lbs.                                |                 |                 |
|                                                                                                                                                                                                                              |  |                                                        |                 |                 |
|                                                                                                                                                                                                                              |  | 252                                                    | ---             | ---             |
|                                                                                                                                                                                                                              |  | 312                                                    | 397             | 473             |
|                                                                                                                                                                                                                              |  | 380                                                    | 481             | 571             |
|                                                                                                                                                                                                                              |  | 465                                                    | 586             | 693             |
|                                                                                                                                                                                                                              |  | 546                                                    | 723             | 852             |
|                                                                                                                                                                                                                              |  | 576                                                    | 803             | 950             |
|                                                                                                                                                                                                                              |  | 610                                                    | 844             | 1060            |
|                                                                                                                                                                                                                              |  | 647                                                    | 891             | 1125            |
|                                                                                                                                                                                                                              |  | 685                                                    | 937             | 1175            |
|                                                                                                                                                                                                                              |  | 779                                                    | 1050            | 1310            |
|                                                                                                                                                                                                                              |  | 814                                                    | 1215            | 1500            |
|                                                                                                                                                                                                                              |  | ---                                                    | 1245            | 1665            |
|                                                                                                                                                                                                                              |  | ---                                                    | ---             | 1685            |
|                                                                                                                                                                                                                              |  | Rivet Shear Strength <sup>c</sup> .....                | 814             | 1245            |
| Sheet Thickness, in.:<br><br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 ..... |  | Yield Strength, lbs <sup>d</sup>                       |                 |                 |
|                                                                                                                                                                                                                              |  |                                                        |                 |                 |
|                                                                                                                                                                                                                              |  | 252                                                    | ---             | ---             |
|                                                                                                                                                                                                                              |  | 312                                                    | 397             | 473             |
|                                                                                                                                                                                                                              |  | 371                                                    | 481             | 571             |
|                                                                                                                                                                                                                              |  | 401                                                    | 569             | 693             |
|                                                                                                                                                                                                                              |  | 440                                                    | 617             | 790             |
|                                                                                                                                                                                                                              |  | 464                                                    | 646             | 824             |
|                                                                                                                                                                                                                              |  | 491                                                    | 680             | 863             |
|                                                                                                                                                                                                                              |  | 521                                                    | 717             | 906             |
|                                                                                                                                                                                                                              |  | 551                                                    | 754             | 949             |
|                                                                                                                                                                                                                              |  | 626                                                    | 846             | 1055            |
|                                                                                                                                                                                                                              |  | 730                                                    | 976             | 1205            |
|                                                                                                                                                                                                                              |  | ---                                                    | 1085            | 1335            |
|                                                                                                                                                                                                                              |  | ---                                                    | ---             | 1595            |

a Data supplied by Huck International Inc.  
b Loads developed from tests with hole diameters of 0.144, 0.178, and 0.207, +/-0.001 inch.  
c Rivet shear strength is documented on HC3243 standards drawing.  
d Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

Table 8.1.3.1.2(u). Static Joint Strength of Blind Protruding Head Locked Spindle Aluminum Alloy Rivets in Aluminum Alloy Sheet

|                                                                                                                                                                                                               |                                                        |                 |                 |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|-----------------|-----------------|
| Rivet Type .....                                                                                                                                                                                              | AF3223 (F <sub>su</sub> = 50 ksi approx.) <sup>a</sup> |                 |                 |
| Sheet Material .....                                                                                                                                                                                          | Clad 2024-T3                                           |                 |                 |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) <sup>b</sup> .....                                                                                                                                   | 1/8<br>(0.130)                                         | 5/32<br>(0.162) | 3/16<br>(0.194) |
| Sheet thickness, in.:<br><br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 ..... | Ultimate Strength, lbs.                                |                 |                 |
|                                                                                                                                                                                                               | 272                                                    | ...             | ...             |
|                                                                                                                                                                                                               | 331                                                    | 431             | ...             |
|                                                                                                                                                                                                               | 390                                                    | 516             | 640             |
|                                                                                                                                                                                                               | 421                                                    | 606             | 767             |
|                                                                                                                                                                                                               | 461                                                    | 656             | 883             |
|                                                                                                                                                                                                               | 486                                                    | 687             | 920             |
|                                                                                                                                                                                                               | 514                                                    | 722             | 962             |
|                                                                                                                                                                                                               | 545                                                    | 760             | 1005            |
|                                                                                                                                                                                                               | 576                                                    | 799             | 1050            |
|                                                                                                                                                                                                               | 653                                                    | 896             | 1170            |
|                                                                                                                                                                                                               | 664                                                    | 1030            | 1330            |
|                                                                                                                                                                                                               | ...                                                    | ...             | 1460            |
| Rivet shear strength <sup>c</sup> .....                                                                                                                                                                       | 664                                                    | 1030            | 1460            |
| Sheet thickness, in.:<br><br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 ..... | Yield Strength <sup>d</sup> , lbs.                     |                 |                 |
|                                                                                                                                                                                                               | 243                                                    | ...             | ...             |
|                                                                                                                                                                                                               | 312                                                    | 387             | ...             |
|                                                                                                                                                                                                               | 390                                                    | 485             | 580             |
|                                                                                                                                                                                                               | 421                                                    | 606             | 727             |
|                                                                                                                                                                                                               | 448                                                    | 656             | 883             |
|                                                                                                                                                                                                               | 463                                                    | 678             | 920             |
|                                                                                                                                                                                                               | 481                                                    | 700             | 958             |
|                                                                                                                                                                                                               | 500                                                    | 723             | 987             |
|                                                                                                                                                                                                               | 519                                                    | 747             | 1015            |
|                                                                                                                                                                                                               | 566                                                    | 806             | 1085            |
|                                                                                                                                                                                                               | 633                                                    | 889             | 1185            |
|                                                                                                                                                                                                               | ...                                                    | ...             | 1270            |

a Data supplied by Allfast Fastening Systems Inc.  
b Loads developed from tests with hole diameters of 0.130, 0.162, and 0.194, +/- 0.001 inch.  
c Rivet shear strength as documented in Allfast Fastening Systems Inc P-127.  
d Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).



Table 8.1.3.1.2(v). Static Joint Strength of Protruding Head 5056 Aluminum Alloy Rivets in Clad Aluminum Alloy Sheet

|                                                                                                                                                                                                               |                                                        |                   |                   |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|-------------------|-------------------|
| Rivet Type .....                                                                                                                                                                                              | CR3223 (F <sub>su</sub> = 50 ksi approx.) <sup>a</sup> |                   |                   |
| Sheet Material .....                                                                                                                                                                                          | Clad 2024-T3                                           |                   |                   |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) <sup>b</sup> .....                                                                                                                                   | 1/8<br>(0.130)                                         | 5/32<br>(0.162)   | 3/16<br>(0.194)   |
| Sheet thickness, in.:<br><br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 ..... | Ultimate Strength, lbs.                                |                   |                   |
|                                                                                                                                                                                                               | 257                                                    | ...               | ...               |
|                                                                                                                                                                                                               | 316                                                    | 408               | ...               |
|                                                                                                                                                                                                               | 383                                                    | 492               | 606               |
|                                                                                                                                                                                                               | 450                                                    | 596               | 731               |
|                                                                                                                                                                                                               | 486                                                    | 701               | 894               |
|                                                                                                                                                                                                               | 509                                                    | 729               | 987               |
|                                                                                                                                                                                                               | 534                                                    | 760               | 1025              |
|                                                                                                                                                                                                               | 562                                                    | 795               | 1065              |
|                                                                                                                                                                                                               | 590                                                    | 830               | 1105              |
|                                                                                                                                                                                                               | 659 <sup>c</sup>                                       | 917               | 1210              |
|                                                                                                                                                                                                               | 664 <sup>c</sup>                                       | 1030 <sup>c</sup> | 1355 <sup>c</sup> |
|                                                                                                                                                                                                               | ...                                                    | ...               | 1480 <sup>c</sup> |
|                                                                                                                                                                                                               | 664                                                    | 1030              | 1480              |
| Rivet shear strength <sup>d</sup> .....                                                                                                                                                                       |                                                        |                   |                   |
| Sheet thickness, in.:<br><br>0.025 .....<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 ..... | Yield Strength <sup>e</sup> , lbs.                     |                   |                   |
|                                                                                                                                                                                                               | 221                                                    | ...               | ...               |
|                                                                                                                                                                                                               | 279                                                    | 351               | ...               |
|                                                                                                                                                                                                               | 321                                                    | 434               | 525               |
|                                                                                                                                                                                                               | 333                                                    | 498               | 649               |
|                                                                                                                                                                                                               | 350                                                    | 519               | 720               |
|                                                                                                                                                                                                               | 360                                                    | 531               | 736               |
|                                                                                                                                                                                                               | 371                                                    | 545               | 752               |
|                                                                                                                                                                                                               | 384                                                    | 561               | 771               |
|                                                                                                                                                                                                               | 396                                                    | 577               | 790               |
|                                                                                                                                                                                                               | 428                                                    | 616               | 837               |
|                                                                                                                                                                                                               | 472                                                    | 671               | 903               |
|                                                                                                                                                                                                               | ...                                                    | ...               | 959               |

a Data supplied by Textron Aerospace Fasteners.  
b Loads developed from tests with hole diameters of 0.130, 0.162, and 0.194, +/- 0.0005 inch.  
c Yield value is less than 2/3 of indicated ultimate strength value.  
d Rivet shear strength as documented in Textron Aerospace Fasteners PS-CMR-3000.  
e Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

**Table 8.1.3.2.1(a). Static Joint Strength of Blind 100° Flush Head A-286 Rivets in Machine-Countersunk Alloy Steel, Titanium Alloy, and A-286 Alloy Sheet**

| Rivet Type .....                                               | CR 6626 <sup>a</sup> ( $F_{su} = 75$ ksi)                                                                |                               |                                |                   |
|----------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|-------------------------------|--------------------------------|-------------------|
| Sheet Material .....                                           | Alloy Steel, $F_{tu} = 125$ ksi, Titanium Alloy, $F_{tu} = 120$ ksi, and A-286 Alloy, $F_{tu} = 140$ ksi |                               |                                |                   |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) ..... | 1/8<br>(0.130)                                                                                           | 5/32<br>(0.162)               | 3/16<br>(0.194)                | 1/4<br>(0.258)    |
| Ultimate Strength, lbs                                         |                                                                                                          |                               |                                |                   |
| Sheet thickness, in.:                                          |                                                                                                          |                               |                                |                   |
| 0.040 .....                                                    | 582 <sup>b</sup>                                                                                         | ...                           | ...                            | ...               |
| 0.050 .....                                                    | 693                                                                                                      | <sup>c</sup> 898 <sup>b</sup> | ...                            | ...               |
| 0.063 .....                                                    | 842                                                                                                      | 1082                          | <sup>c</sup> 1351 <sup>b</sup> | ...               |
| 0.071 .....                                                    | 891                                                                                                      | 1189                          | 1478                           | <sup>c</sup> ...  |
| 0.080 .....                                                    | 949                                                                                                      | 1303                          | 1633                           | ...               |
| 0.090 .....                                                    | 970                                                                                                      | 1379                          | 1798                           | 2558 <sup>b</sup> |
| 0.100 .....                                                    | ...                                                                                                      | 1461                          | 1916                           | 2772 <sup>c</sup> |
| 0.112 .....                                                    | ...                                                                                                      | 1490                          | 2026                           | 3036              |
| 0.125 .....                                                    | ...                                                                                                      | ...                           | 2150                           | 3333              |
| 0.140 .....                                                    | ...                                                                                                      | ...                           | ...                            | 3531              |
| 0.160 .....                                                    | ...                                                                                                      | ...                           | ...                            | 3795              |
| 0.190 .....                                                    | ...                                                                                                      | ...                           | ...                            | 3890              |
| Rivet shear strength <sup>d</sup> .....                        | 970                                                                                                      | 1490                          | 2150                           | 3890              |
| Yield Strength <sup>e</sup> , lbs                              |                                                                                                          |                               |                                |                   |
| Sheet thickness, in.:                                          |                                                                                                          |                               |                                |                   |
| 0.040 .....                                                    | 355                                                                                                      | ...                           | ...                            | ...               |
| 0.050 .....                                                    | 499                                                                                                      | 557                           | ...                            | ...               |
| 0.063 .....                                                    | 681                                                                                                      | 784                           | 858                            | ...               |
| 0.071 .....                                                    | 771                                                                                                      | 923                           | 1031                           | ...               |
| 0.080 .....                                                    | 858                                                                                                      | 1082                          | 1223                           | ...               |
| 0.090 .....                                                    | 920                                                                                                      | 1202                          | 1424                           | 1700              |
| 0.100 .....                                                    | ...                                                                                                      | 1297                          | 1643                           | 1997              |
| 0.112 .....                                                    | ...                                                                                                      | 1417                          | 1779                           | 2327              |
| 0.125 .....                                                    | ...                                                                                                      | ...                           | 1925                           | 2690              |
| 0.140 .....                                                    | ...                                                                                                      | ...                           | ...                            | 3053              |
| 0.160 .....                                                    | ...                                                                                                      | ...                           | ...                            | 3432              |
| 0.190 .....                                                    | ...                                                                                                      | ...                           | ...                            | 3845              |
| Head height (ref.), in. ....                                   | 0.042                                                                                                    | 0.055                         | 0.070                          | 0.095             |

a Data supplied by Cherry Fasteners.  
b Yield value is less than 2/3 of the indicated ultimate strength value.  
c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
d Rivet shear strength based on areas computed from nominal hole diameters in Table 8.1.2(a) and  $F_{su} = 75$  ksi.  
e Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.

**Table 8.1.3.2.1(b). Static Joint Strength of Blind 100° Flush Head Monel Rivets in Machine-Countersunk Stainless Steel**

| Rivet Type .....                                                                                                                                                            | MS20601M (R.T. $F_{su}$ = 55 ksi) |                               |                               |                   |                  |                               |                               |                   |                  |                               |                               |                   |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|-------------------------------|-------------------------------|-------------------|------------------|-------------------------------|-------------------------------|-------------------|------------------|-------------------------------|-------------------------------|-------------------|
| Sheet Material .....                                                                                                                                                        | 17-7PH, TH 1050                   |                               |                               |                   |                  |                               |                               |                   |                  |                               |                               |                   |
| Temperature .....                                                                                                                                                           | Room                              |                               |                               |                   | 500°F            |                               |                               |                   | 700°F            |                               |                               |                   |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.)                                                                                                                    | 1/8<br>(0.130)                    | 5/32<br>(0.162)               | 3/16<br>(0.194)               | 1/4<br>(0.258)    | 1/8<br>(0.130)   | 5/32<br>(0.162)               | 3/16<br>(0.194)               | 1/4<br>(0.258)    | 1/8<br>(0.130)   | 5/32<br>(0.162)               | 3/16<br>(0.194)               | 1/4<br>(0.258)    |
| Sheet thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.180 ..... | Ultimate Strength, lbs            |                               |                               |                   |                  |                               |                               |                   |                  |                               |                               |                   |
|                                                                                                                                                                             | 373 <sup>a</sup>                  | ...                           | ...                           | ...               | 373 <sup>a</sup> | ...                           | ...                           | ...               | 373 <sup>a</sup> | ...                           | ...                           | ...               |
|                                                                                                                                                                             | 429                               | <sup>b</sup> 574 <sup>a</sup> | ...                           | ...               | 429              | <sup>b</sup> 574 <sup>a</sup> | ...                           | ...               | 429              | <sup>b</sup> 574 <sup>a</sup> | ...                           | ...               |
|                                                                                                                                                                             | 495                               | 664                           | <sup>b</sup> 866 <sup>a</sup> | ...               | 495              | 664                           | <sup>b</sup> 866 <sup>a</sup> | ...               | 495              | 664                           | <sup>b</sup> 866 <sup>a</sup> | ...               |
|                                                                                                                                                                             | 535                               | 714                           | 924                           | <sup>b</sup> ...  | 535              | 714                           | 924                           | <sup>b</sup> ...  | 535              | 714                           | 924                           | <sup>b</sup> ...  |
|                                                                                                                                                                             | 579                               | 771                           | 991                           | ...               | 579              | 771                           | 991                           | ...               | 574              | 771                           | 991                           | ...               |
|                                                                                                                                                                             | 630                               | 833                           | 1065                          | 1615 <sup>a</sup> | 625              | 833                           | 1065                          | 1615 <sup>a</sup> | 590              | 833                           | 1065                          | 1615 <sup>a</sup> |
|                                                                                                                                                                             | ...                               | 896                           | 1140                          | 1720              | <sup>b</sup> ... | 896                           | 1140                          | 1720              | <sup>b</sup> ... | 884                           | 1140                          | 1720 <sup>b</sup> |
|                                                                                                                                                                             | ...                               | ...                           | 1325                          | 1970              | ...              | ...                           | 1325                          | 1970              | ...              | 904                           | 1290                          | 1970              |
|                                                                                                                                                                             | ...                               | ...                           | ...                           | 2320              | ...              | ...                           | ...                           | 2320              | ...              | ...                           | 1305                          | 2300              |
|                                                                                                                                                                             | ...                               | ...                           | ...                           | 2520              | ...              | ...                           | ...                           | 2500              | ...              | ...                           | ...                           | 2360              |
| Rivet shear strength <sup>c</sup> .....                                                                                                                                     | 713                               | 1090                          | 1580                          | 2855              | 648              | 993                           | 1430                          | 2590              | 590              | 904                           | 1305                          | 2360              |
| Sheet thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.180 ..... | Yield Strength <sup>d</sup> , lbs |                               |                               |                   |                  |                               |                               |                   |                  |                               |                               |                   |
|                                                                                                                                                                             | 213                               | ...                           | ...                           | ...               | 213              | ...                           | ...                           | ...               | 213              | ...                           | ...                           | ...               |
|                                                                                                                                                                             | 303                               | 332                           | ...                           | ...               | 303              | 332                           | ...                           | ...               | 303              | 332                           | ...                           | ...               |
|                                                                                                                                                                             | 439                               | 476                           | 518                           | ...               | 439              | 476                           | 518                           | ...               | 439              | 476                           | 518                           | ...               |
|                                                                                                                                                                             | 528                               | 569                           | 621                           | ...               | 528              | 569                           | 621                           | ...               | 528              | 569                           | 621                           | ...               |
|                                                                                                                                                                             | 579                               | 696                           | 741                           | ...               | 579              | 696                           | 741                           | ...               | 574              | 696                           | 741                           | ...               |
|                                                                                                                                                                             | 630                               | 833                           | 910                           | 1030              | 625              | 833                           | 910                           | 1030              | 590              | 833                           | 910                           | 1030              |
|                                                                                                                                                                             | ...                               | 896                           | 1075                          | 1212              | ...              | 896                           | 1075                          | 1212              | ...              | 884                           | 1075                          | 1212              |
|                                                                                                                                                                             | ...                               | ...                           | 1325                          | 1731              | ...              | ...                           | 1325                          | 1731              | ...              | 904                           | 1290                          | 1731              |
|                                                                                                                                                                             | ...                               | ...                           | ...                           | 2320              | ...              | ...                           | ...                           | 2320              | ...              | ...                           | 1305                          | 2300              |
|                                                                                                                                                                             | ...                               | ...                           | ...                           | 2520              | ...              | ...                           | ...                           | 2500              | ...              | ...                           | ...                           | 2360              |
| Head height (ref.), in. ....                                                                                                                                                | 0.042                             | 0.055                         | 0.070                         | 0.095             | 0.042            | 0.055                         | 0.070                         | 0.095             | 0.042            | 0.055                         | 0.070                         | 0.095             |

a Yield value is less than 2/3 of the indicated ultimate strength value.

b Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.

c Rivet shear strength based on areas computed from nominal hole diameters in Table 8.1.2(a) and  $F_{su}$  values at 55 ksi, 50 ksi, and 45 ksi at room temperature, 500°F and 700°F, respectively.

d Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.

Table 8.1.3.2.1(c). Static Joint Strength of Blind 100° Flush Head Monel Rivets in Dimpled Stainless Steel Sheet

| Rivet Type                                          | MS20601M ( $F_{su}$ = 55 ksi)      |                 |                   |                |                   |                 |                 |                |
|-----------------------------------------------------|------------------------------------|-----------------|-------------------|----------------|-------------------|-----------------|-----------------|----------------|
| Sheet Material                                      | AISI 301-Annealed                  |                 |                   |                | AISI 301-1/4 Hard |                 |                 |                |
| Rivet Diameter, in.<br>(Nominal Hole Diameter, in.) | 1/8<br>(0.130)                     | 5/32<br>(0.162) | 3/16<br>(0.194)   | 1/4<br>(0.258) | 1/8<br>(0.130)    | 5/32<br>(0.162) | 3/16<br>(0.194) | 1/4<br>(0.258) |
|                                                     | Ultimate Strength, lbs.            |                 |                   |                |                   |                 |                 |                |
| Sheet thickness, in.:                               |                                    |                 |                   |                |                   |                 |                 |                |
| 0.010                                               | 224                                | ...             | ...               | ...            | 277               | 377             | ...             | ...            |
| 0.012                                               | 254                                | 338             | ...               | ...            | 302               | 428             | 560             | ...            |
| 0.016                                               | 313                                | 412             | 519               | ...            | 358               | 485             | 632             | ...            |
| 0.020                                               | 375                                | 486             | 610               | ...            | 415               | 542             | 705             | 1135           |
| 0.025                                               | 447                                | 576             | 722               | 1045           | 482               | 642             | 808             | 1230           |
| 0.032                                               | 516                                | 705             | 876               | 1255           | 543               | 750             | 963             | 1400           |
| 0.040                                               | 536                                | 793             | 1055              | 1490           | 585               | 833             | 1110            | 1660           |
| 0.050                                               | 565                                | 825             | 1150 <sup>a</sup> | 1790           | 628               | 910             | 1240            | 1930           |
| 0.063                                               | ...                                | 868             | 1200 <sup>a</sup> | 2065           | ...               | 964             | 1330            | 2175           |
| 0.071                                               | ...                                | ...             | ...               | 2100           | ...               | 973             | 1375            | 2275           |
| 0.080                                               | ...                                | ...             | ...               | 2150           | ...               | ...             | 1405            | 2340           |
| 0.090                                               | ...                                | ...             | ...               | 2200           | ...               | ...             | ...             | 2440           |
| 0.100                                               | ...                                | ...             | ...               | ...            | ...               | ...             | ...             | 2510           |
| Rivet shear strength <sup>b</sup>                   | 635                                | 973             | 1405              | 2540           | 635               | 973             | 1405            | 2540           |
|                                                     | Yield Strength <sup>a</sup> , lbs. |                 |                   |                |                   |                 |                 |                |
| Sheet thickness, in.:                               |                                    |                 |                   |                |                   |                 |                 |                |
| 0.010                                               | 188                                | ...             | ...               | ...            | 244               | 291             | ...             | ...            |
| 0.012                                               | 214                                | 281             | ...               | ...            | 259               | 335             | 423             | ...            |
| 0.016                                               | 270                                | 352             | 438               | ...            | 333               | 428             | 535             | ...            |
| 0.020                                               | 328                                | 422             | 518               | ...            | 398               | 528             | 639             | 896            |
| 0.025                                               | 397                                | 506             | 627               | 873            | 443               | 612             | 774             | 1080           |
| 0.032                                               | 498                                | 627             | 770               | 1070           | 505               | 689             | 912             | 1330           |
| 0.040                                               | 536                                | 772             | 939               | 1310           | 576               | 779             | 1015            | 1590           |
| 0.050                                               | 565                                | 825             | 1150              | 1590           | 619               | 883             | 1145            | 1770           |
| 0.063                                               | ...                                | 868             | 1200              | 1970           | ...               | 954             | 1305            | 2000           |
| 0.071                                               | ...                                | ...             | ...               | 2100           | ...               | 973             | 1350            | 2140           |
| 0.080                                               | ...                                | ...             | ...               | 2150           | ...               | ...             | 1400            | 2305           |
| 0.090                                               | ...                                | ...             | ...               | 2200           | ...               | ...             | ...             | 2395           |
| 0.100                                               | ...                                | ...             | ...               | ...            | ...               | ...             | ...             | 2475           |
| Head height (ref.), in.                             | 0.042                              | 0.055           | 0.070             | 0.095          | 0.042             | 0.055           | 0.070           | 0.095          |

a Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.  
b Rivet shear strength from Table 8.1.2(b).

**Table 8.1.3.2.1(d<sub>1</sub>). Static Joint Strength of Blind 100° Flush Head Monel Rivets in Machine-Countersunk Stainless Steel Sheet**

|                                                                                                                                                            |                                   |                               |                                |                   |
|------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|-------------------------------|--------------------------------|-------------------|
| Rivet Type .....                                                                                                                                           | MS20601M ( $F_{su} = 55$ ksi)     |                               |                                |                   |
| Sheet Material .....                                                                                                                                       | AISI 301-Annealed                 |                               |                                |                   |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) .....                                                                                             | 1/8<br>(0.130)                    | 5/32<br>(0.162)               | 3/16<br>(0.194)                | 1/4<br>(0.258)    |
| Sheet thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>Rivet shear strength <sup>c</sup> ..... | Ultimate Strength, lbs            |                               |                                |                   |
|                                                                                                                                                            | 469 <sup>a</sup>                  | ...                           | ...                            | ...               |
|                                                                                                                                                            | 555 <sup>a</sup>                  | <sup>b</sup> 721 <sup>a</sup> | ...                            | ...               |
|                                                                                                                                                            | ...                               | 864 <sup>a</sup>              | <sup>b</sup> 1075 <sup>a</sup> | ...               |
|                                                                                                                                                            | ...                               | ...                           | 1187 <sup>a</sup>              | <sup>b</sup> ...  |
|                                                                                                                                                            | ...                               | ...                           | ...                            | ...               |
|                                                                                                                                                            | ...                               | ...                           | ...                            | 2040              |
|                                                                                                                                                            | 713                               | 1090                          | 1580                           | 2855 <sup>b</sup> |
|                                                                                                                                                            | Yield Strength <sup>d</sup> , lbs |                               |                                |                   |
|                                                                                                                                                            | 231                               | ...                           | ...                            | ...               |
| 0.040 .....                                                                                                                                                | 321                               | 359                           | ...                            | ...               |
| 0.050 .....                                                                                                                                                | ...                               | 500                           | 566                            | ...               |
| 0.063 .....                                                                                                                                                | ...                               | ...                           | 678                            | ...               |
| 0.071 .....                                                                                                                                                | ...                               | ...                           | ...                            | ...               |
| 0.080 .....                                                                                                                                                | ...                               | ...                           | ...                            | ...               |
| 0.090 .....                                                                                                                                                | ...                               | ...                           | ...                            | 1135              |
| Head height (ref.), in. ....                                                                                                                               | 0.042                             | 0.055                         | 0.070                          | 0.095             |

a Yield value is less than 2/3 of the indicated ultimate strength value.

b Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.

c Rivet shear strength based on areas computed from nominal hole diameters in Table 8.1.2(a) and  $F_{su} = 55$  ksi.

d Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.

**Table 8.1.3.2.1(d<sub>2</sub>). Static Joint Strength of Blind 100° Flush Head Monel Rivets in Machine-Countersunk Stainless Steel Sheet**

|                                                                                                                                                                                                                        |                                   |                               |                               |                  |                  |                               |                               |                   |                  |                               |                               |                                |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|-------------------------------|-------------------------------|------------------|------------------|-------------------------------|-------------------------------|-------------------|------------------|-------------------------------|-------------------------------|--------------------------------|
| Rivet Type .....                                                                                                                                                                                                       | MS20601M (R.T. $F_{su}$ = 55 ksi) |                               |                               |                  |                  |                               |                               |                   |                  |                               |                               |                                |
| Sheet Material .....                                                                                                                                                                                                   | AISI 301-¼ Hard                   |                               |                               |                  |                  |                               |                               |                   |                  |                               |                               |                                |
| Temperature .....                                                                                                                                                                                                      | Room                              |                               |                               |                  | 500°F            |                               |                               |                   | 700°F            |                               |                               |                                |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.)                                                                                                                                                               | 1/8<br>(0.130)                    | 5/32<br>(0.162)               | 3/16<br>(0.194)               | 1/4<br>(0.258)   | 1/8<br>(0.130)   | 5/32<br>(0.162)               | 3/16<br>(0.194)               | 1/4<br>(0.258)    | 1/8<br>(0.130)   | 5/32<br>(0.162)               | 3/16<br>(0.194)               | 1/4<br>(0.258)                 |
| Sheet thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.180 .....<br>Rivet shear strength <sup>c</sup> ..... | Ultimate Strength, lbs            |                               |                               |                  |                  |                               |                               |                   |                  |                               |                               |                                |
|                                                                                                                                                                                                                        | 373 <sup>a</sup>                  | ...                           | ...                           | ...              | 373 <sup>a</sup> | ...                           | ...                           | ...               | 373 <sup>a</sup> | ...                           | ...                           | ...                            |
|                                                                                                                                                                                                                        | 450                               | <sup>b</sup> 574 <sup>a</sup> | ...                           | ...              | 450 <sup>a</sup> | <sup>b</sup> 574 <sup>a</sup> | ...                           | ...               | 450 <sup>a</sup> | <sup>b</sup> 574 <sup>a</sup> | ...                           | ...                            |
|                                                                                                                                                                                                                        | 538                               | 704                           | <sup>b</sup> 866 <sup>a</sup> | ...              | 538              | 704 <sup>a</sup>              | <sup>b</sup> 866 <sup>a</sup> | ...               | 538              | 704 <sup>a</sup>              | <sup>b</sup> 866 <sup>a</sup> | ...                            |
|                                                                                                                                                                                                                        | 584                               | 773                           | 960                           | <sup>b</sup> ... | 584              | 773                           | 960 <sup>a</sup>              | <sup>b</sup> ...  | 584              | 773                           | 960 <sup>a</sup>              | <sup>b</sup> ...               |
|                                                                                                                                                                                                                        | 637                               | 838                           | 1065                          | ...              | 637              | 838                           | 1065 <sup>a</sup>             | ...               | 590              | 838                           | 1065 <sup>a</sup>             | ...                            |
|                                                                                                                                                                                                                        | 695                               | 910                           | 1155                          | 1645             | 648              | 910                           | 1155                          | 1645 <sup>a</sup> | ...              | 904                           | 1155                          | 1645 <sup>a</sup>              |
|                                                                                                                                                                                                                        | 713                               | 984                           | 1240                          | 1800             | <sup>b</sup> ... | 984                           | 1240                          | 1800 <sup>a</sup> | <sup>b</sup> ... | ...                           | 1240                          | 1800 <sup>a</sup> <sup>b</sup> |
|                                                                                                                                                                                                                        | ...                               | 1090                          | 1460                          | 2135             | ...              | 993                           | 1430                          | 2135              | ...              | ...                           | 1305                          | 2135                           |
|                                                                                                                                                                                                                        | ...                               | ...                           | 1580                          | 2550             | ...              | ...                           | ...                           | 2550              | ...              | ...                           | ...                           | 2360                           |
|                                                                                                                                                                                                                        | ...                               | ...                           | ...                           | 2780             | ...              | ...                           | ...                           | 2590              | ...              | ...                           | ...                           | ...                            |
|                                                                                                                                                                                                                        | 713                               | 1090                          | 1580                          | 2855             | 648              | 993                           | 1430                          | 2590              | 590              | 904                           | 1305                          | 2360                           |
| Sheet thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.180 .....                                            | Yield Strength <sup>d</sup> , lbs |                               |                               |                  |                  |                               |                               |                   |                  |                               |                               |                                |
|                                                                                                                                                                                                                        | 231                               | ...                           | ...                           | ...              | 192              | ...                           | ...                           | ...               | 192              | ...                           | ...                           | ...                            |
|                                                                                                                                                                                                                        | 336                               | 359                           | ...                           | ...              | 279              | 298                           | ...                           | ...               | 279              | 298                           | ...                           | ...                            |
|                                                                                                                                                                                                                        | 459                               | 531                           | 566                           | ...              | 425              | 440                           | 471                           | ...               | 425              | 440                           | 471                           | ...                            |
|                                                                                                                                                                                                                        | 530                               | 625                           | 698                           | ...              | 525              | 546                           | 576                           | ...               | 525              | 546                           | 576                           | ...                            |
|                                                                                                                                                                                                                        | 607                               | 725                           | 835                           | ...              | 607              | 683                           | 690                           | ...               | 590              | 683                           | 690                           | ...                            |
|                                                                                                                                                                                                                        | 693                               | 832                           | 966                           | 1135             | 648              | 832                           | 872                           | 945               | ...              | 832                           | 872                           | 945                            |
|                                                                                                                                                                                                                        | 713                               | 943                           | 1095                          | 1345             | ...              | 943                           | 1060                          | 1115              | ...              | ...                           | 1060                          | 1115                           |
|                                                                                                                                                                                                                        | ...                               | 1090                          | 1420                          | 1815             | ...              | 993                           | 1420                          | 1670              | ...              | ...                           | 1305                          | 1670                           |
|                                                                                                                                                                                                                        | ...                               | ...                           | 1580                          | 2430             | ...              | ...                           | ...                           | 2430              | ...              | ...                           | ...                           | 2360                           |
|                                                                                                                                                                                                                        | ...                               | ...                           | ...                           | 2775             | ...              | ...                           | ...                           | 2590              | ...              | ...                           | ...                           | ...                            |
| Head height (ref.), in. ....                                                                                                                                                                                           | 0.042                             | 0.055                         | 0.070                         | 0.095            | 0.042            | 0.055                         | 0.070                         | 0.095             | 0.042            | 0.055                         | 0.070                         | 0.095                          |

a Yield value is less than 2/3 of the indicated ultimate strength value.

b Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.

c Rivet shear strength based on areas computed from nominal hole diameters in Table 8.1.2(a) and  $F_{su}$  = 55 ksi at R.T.,  $F_{tu}$  = 50 ksi at 500°F, and  $F_{su}$  = 45 ksi at 700°F.

d Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.

**Table 8.1.3.2.1(d<sub>3</sub>). Static Joint Strength of Blind 100° Flush Head Monel Rivets in Machine-Countersunk Stainless Steel Sheet**

|                                                          |                                   |                               |                  |                  |                  |                               |                  |                  |                  |                               |                  |                   |
|----------------------------------------------------------|-----------------------------------|-------------------------------|------------------|------------------|------------------|-------------------------------|------------------|------------------|------------------|-------------------------------|------------------|-------------------|
| Rivet Type .....                                         | MS20601M (R.T. $F_{su}$ = 55 ksi) |                               |                  |                  |                  |                               |                  |                  |                  |                               |                  |                   |
| Sheet Material .....                                     | AISI 301-½ Hard                   |                               |                  |                  |                  |                               |                  |                  |                  |                               |                  |                   |
| Temperature .....                                        | Room                              |                               |                  |                  | 500°F            |                               |                  |                  | 700°F            |                               |                  |                   |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) | 1/8<br>(0.130)                    | 5/32<br>(0.162)               | 3/16<br>(0.194)  | 1/4<br>(0.258)   | 1/8<br>(0.130)   | 5/32<br>(0.162)               | 3/16<br>(0.194)  | 1/4<br>(0.258)   | 1/8<br>(0.130)   | 5/32<br>(0.162)               | 3/16<br>(0.194)  | 1/4<br>(0.258)    |
| Sheet thickness, in.:                                    | Ultimate Strength, lbs            |                               |                  |                  |                  |                               |                  |                  |                  |                               |                  |                   |
| 0.040 .....                                              | 350 <sup>a</sup>                  | ...                           | ...              | ...              | 350 <sup>a</sup> | ...                           | ...              | ...              | 350 <sup>a</sup> | ...                           | ...              | ...               |
| 0.050 .....                                              | 444                               | <sup>b</sup> 540 <sup>a</sup> | ...              | ...              | 444              | <sup>b</sup> 540 <sup>a</sup> | ...              | ...              | 444              | <sup>b</sup> 540 <sup>a</sup> | ...              | ...               |
| 0.063 .....                                              | 538                               | 694                           | <sup>b</sup> 821 | ...              | 538              | 694                           | <sup>b</sup> 821 | ...              | 538              | 694                           | <sup>b</sup> 821 | ...               |
| 0.071 .....                                              | 584                               | 773                           | 935              | <sup>b</sup> ... | 584              | 773                           | 935              | <sup>b</sup> ... | 575              | 773                           | 935              | <sup>b</sup> ...  |
| 0.080 .....                                              | 637                               | 838                           | 1065             | ...              | 624              | 838                           | 1065             | ...              | 586              | 838                           | 1065             | ...               |
| 0.090 .....                                              | 695                               | 910                           | 1155             | 1585             | 648              | 910                           | 1155             | 1585             | 590              | 886                           | 1155             | 1585              |
| 0.100 .....                                              | 713                               | 984                           | 1240             | 1780             | <sup>b</sup> ... | 962                           | 1240             | 1780             | <sup>b</sup> ... | 904                           | 1240             | 1780 <sup>b</sup> |
| 0.125 .....                                              | ...                               | 1090                          | 1460             | 2135             | ...              | 993                           | 1410             | 2135             | ...              | ...                           | 1305             | 2135              |
| 0.160 .....                                              | ...                               | ...                           | 1580             | 2550             | ...              | ...                           | 1430             | 2500             | ...              | ...                           | ...              | 2345              |
| 0.180 .....                                              | ...                               | ...                           | ...              | 2780             | ...              | ...                           | ...              | 2590             | ...              | ...                           | ...              | 2360              |
| Rivet shear strength <sup>c</sup> .....                  | 713                               | 1090                          | 1580             | 2855             | 648              | 993                           | 1430             | 2590             | 590              | 904                           | 1305             | 2360              |
| Sheet thickness, in.:                                    | Yield Strength <sup>d</sup> , lbs |                               |                  |                  |                  |                               |                  |                  |                  |                               |                  |                   |
| 0.040 .....                                              | 231                               | ...                           | ...              | ...              | 231              | ...                           | ...              | ...              | 231              | ...                           | ...              | ...               |
| 0.050 .....                                              | 336                               | 359                           | ...              | ...              | 336              | 359                           | ...              | ...              | 336              | 359                           | ...              | ...               |
| 0.063 .....                                              | 459                               | 531                           | 566              | ...              | 459              | 531                           | 566              | ...              | 459              | 531                           | 566              | ...               |
| 0.071 .....                                              | 530                               | 625                           | 698              | ...              | 530              | 625                           | 698              | ...              | 530              | 625                           | 698              | ...               |
| 0.080 .....                                              | 607                               | 725                           | 835              | ...              | 607              | 725                           | 835              | ...              | 586              | 725                           | 835              | ...               |
| 0.090 .....                                              | 693                               | 832                           | 966              | 1135             | 648              | 832                           | 966              | 1135             | 590              | 832                           | 966              | 1135              |
| 0.100 .....                                              | 713                               | 943                           | 1095             | 1345             | ...              | 943                           | 1095             | 1345             | ...              | 904                           | 1095             | 1345              |
| 0.125 .....                                              | ...                               | 1090                          | 1420             | 1815             | ...              | 993                           | 1410             | 1815             | ...              | ...                           | 1305             | 1815              |
| 0.160 .....                                              | ...                               | ...                           | 1580             | 2430             | ...              | ...                           | 1430             | 2430             | ...              | ...                           | ...              | 2345              |
| 0.180 .....                                              | ...                               | ...                           | ...              | 2775             | ...              | ...                           | ...              | 2590             | ...              | ...                           | ...              | 2360              |
| Head height (ref.), in. ....                             | 0.042                             | 0.055                         | 0.070            | 0.095            | 0.042            | 0.055                         | 0.070            | 0.095            | 0.042            | 0.055                         | 0.070            | 0.095             |

a Yield value is less than 2/3 of the indicated ultimate strength value.

b Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.

c Rivet shear strength based on areas computed from nominal hole diameters in Table 8.1.2(a) and  $F_{su}$  = 55 ksi at R.T.,  $F_{su}$  = 50 ksi at 500°F, and  $F_{su}$  = 45 ksi at 700°F.

d Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.

Table 8.1.3.2.1(e). Static Joint Strength of Blind 100° Flush Head Monel Rivets in Machine-Countersunk Aluminum Alloy Sheet

|                                                                                                                                                                                                                        |                                   |                  |                  |                                |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|------------------|------------------|--------------------------------|
| Rivet Type .....                                                                                                                                                                                                       | MS20601M ( $F_{su} = 55$ ksi)     |                  |                  |                                |
| Sheet Material .....                                                                                                                                                                                                   | 7075-T6                           |                  |                  |                                |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) .....                                                                                                                                                         | 1/8<br>(0.130)                    | 5/32<br>(0.162)  | 3/16<br>(0.194)  | 1/4<br>(0.258)                 |
| Sheet thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>Rivet shear strength <sup>c</sup> ..... | Ultimate Strength, lbs            |                  |                  |                                |
|                                                                                                                                                                                                                        | 320 <sup>a</sup>                  | ...              | ...              | ...                            |
|                                                                                                                                                                                                                        | 393                               | 494 <sup>a</sup> | ...              | ...                            |
|                                                                                                                                                                                                                        | 487                               | 612 <sup>a</sup> | 747 <sup>a</sup> | ...                            |
|                                                                                                                                                                                                                        | 545                               | 684              | 832 <sup>a</sup> | ...                            |
|                                                                                                                                                                                                                        | 565                               | 766              | 930 <sup>a</sup> | ...                            |
|                                                                                                                                                                                                                        | 587                               | 840              | 1040             | 1425 <sup>a</sup> <sup>b</sup> |
|                                                                                                                                                                                                                        | 610                               | 867              | 1150             | 1570 <sup>a</sup>              |
|                                                                                                                                                                                                                        | ...                               | 937              | 1270             | 1940                           |
|                                                                                                                                                                                                                        | ...                               | ...              | 1385             | 2260                           |
|                                                                                                                                                                                                                        | ...                               | ...              | ...              | 2390                           |
|                                                                                                                                                                                                                        | 713                               | 1090             | 1580             | 2855                           |
|                                                                                                                                                                                                                        | Yield Strength <sup>d</sup> , lbs |                  |                  |                                |
|                                                                                                                                                                                                                        | 146                               | ...              | ...              | ...                            |
|                                                                                                                                                                                                                        | 228                               | 226              | ...              | ...                            |
|                                                                                                                                                                                                                        | 395                               | 369              | 343              | ...                            |
|                                                                                                                                                                                                                        | 496                               | 495              | 444              | ...                            |
|                                                                                                                                                                                                                        | 526                               | 640              | 615              | ...                            |
|                                                                                                                                                                                                                        | 561                               | 769              | 806              | 660                            |
|                                                                                                                                                                                                                        | 595                               | 811              | 1000             | 912                            |
|                                                                                                                                                                                                                        | ...                               | 918              | 1195             | 1560                           |
|                                                                                                                                                                                                                        | ...                               | ...              | 1375             | 2105                           |
|                                                                                                                                                                                                                        | ...                               | ...              | ...              | 2310                           |
| Head height (ref.), in. ....                                                                                                                                                                                           | 0.042                             | 0.055            | 0.070            | 0.095                          |

a Yield value is less than 2/3 of the indicated ultimate strength value.  
b Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
c Rivet shear strength based on areas computed from nominal hole diameters in Table 8.1.2(a) and  $F_{su} = 55$  ksi.  
d Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.



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Table 8.1.3.2.1(f). Static Joint Strength of Blind 100° Flush Head Aluminum Alloy (2117-T3) Rivets in Machine-Countersunk Aluminum Alloy Sheet

|                                                                                                                                               |                                              |                  |                  |                  |
|-----------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|------------------|------------------|------------------|
| Rivet Type .....                                                                                                                              | MS20601AD and MS20603AD ( $F_{su} = 30$ ksi) |                  |                  |                  |
| Sheet Material .....                                                                                                                          | Clad 2024-T3                                 |                  |                  |                  |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) .....                                                                                | 1/8<br>(0.130)                               | 5/32<br>(0.162)  | 3/16<br>(0.194)  | 1/4<br>(0.258)   |
| Sheet thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 ..... | Ultimate Strength, lbs                       |                  |                  |                  |
|                                                                                                                                               | 159 <sup>a</sup>                             | ...              | ...              | ...              |
|                                                                                                                                               | 236                                          | 258 <sup>a</sup> | ...              | ...              |
|                                                                                                                                               | 327                                          | 369              | 398 <sup>a</sup> | ...              |
|                                                                                                                                               | 360                                          | 439              | 485              | ...              |
|                                                                                                                                               | 388                                          | 511              | 577              | ...              |
|                                                                                                                                               | ...                                          | 561              | 684              | 795 <sup>a</sup> |
|                                                                                                                                               | ...                                          | 596              | 768              | 945              |
|                                                                                                                                               | ...                                          | ...              | 862              | 1270             |
|                                                                                                                                               | Rivet shear strength <sup>b</sup> .....      | 388              | 596              | 862              |
| Sheet thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 ..... | Yield Strength <sup>c</sup> , lbs            |                  |                  |                  |
|                                                                                                                                               | 110                                          | ...              | ...              | ...              |
|                                                                                                                                               | 198                                          | 185              | ...              | ...              |
|                                                                                                                                               | 300                                          | 308              | 296              | ...              |
|                                                                                                                                               | 336                                          | 384              | 391              | ...              |
|                                                                                                                                               | 377                                          | 468              | 497              | ...              |
|                                                                                                                                               | ...                                          | 524              | 614              | 621              |
|                                                                                                                                               | ...                                          | 592              | 709              | 793              |
|                                                                                                                                               | ...                                          | ...              | 862              | 1150             |
|                                                                                                                                               | Head height (ref.), in. ....                 | 0.042            | 0.055            | 0.070            |
|                                                                                                                                               |                                              |                  |                  | 0.095            |

a Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.

b Rivet shear strength based on areas computed from nominal hole diameters in Table 8.1.2(a) and  $F_{su} = 30$  ksi.

c Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.

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**Table 8.1.3.2.1(g). Static Joint Strength of Blind 100° Flush Head Aluminum Alloy (5056-H321) Rivets in Machine-Countersunk Magnesium Alloy Sheet**

|                                                                |                               |                  |                  |                  |
|----------------------------------------------------------------|-------------------------------|------------------|------------------|------------------|
| Rivet Type .....                                               | MS20601B ( $F_{su} = 28$ ksi) |                  |                  |                  |
| Sheet Material .....                                           | AZ31B-H24                     |                  |                  |                  |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) ..... | 1/8<br>(0.130)                | 5/32<br>(0.162)  | 3/16<br>(0.194)  | 1/4<br>(0.258)   |
| Ultimate Strength, lbs                                         |                               |                  |                  |                  |
| Sheet thickness, in.:                                          |                               |                  |                  |                  |
| 0.040 .....                                                    | 167                           | ...              | ...              | ...              |
| 0.050 .....                                                    | 208                           | <sup>a</sup> 257 | ...              | ...              |
| 0.063 .....                                                    | 262                           | 324              | <sup>a</sup> 390 | ...              |
| 0.071 .....                                                    | 295                           | 366              | 440              | <sup>a</sup> ... |
| 0.080 .....                                                    | 333                           | 413              | 495              | ...              |
| 0.090 .....                                                    | 363                           | 464              | 557              | 749              |
| 0.100 .....                                                    | ...                           | 516              | 620              | 833 <sup>a</sup> |
| 0.125 .....                                                    | ...                           | 556              | 774              | 1040             |
| 0.160 .....                                                    | ...                           | ...              | 802              | 1332             |
| 0.190 .....                                                    | ...                           | ...              | ...              | 1450             |
| Rivet shear strength <sup>b</sup> .....                        | 363                           | 556              | 802              | 1450             |
| Yield Strength <sup>c</sup> , lbs                              |                               |                  |                  |                  |
| Sheet thickness, in.:                                          |                               |                  |                  |                  |
| 0.040 .....                                                    | 158                           | ...              | ...              | ...              |
| 0.050 .....                                                    | 197                           | 244              | ...              | ...              |
| 0.063 .....                                                    | 248                           | 308              | 370              | ...              |
| 0.071 .....                                                    | 279                           | 346              | 417              | ...              |
| 0.080 .....                                                    | 315                           | 391              | 469              | ...              |
| 0.090 .....                                                    | 354                           | 440              | 527              | 710              |
| 0.100 .....                                                    | ...                           | 489              | 587              | 789              |
| 0.125 .....                                                    | ...                           | 556              | 734              | 986              |
| 0.160 .....                                                    | ...                           | ...              | 802              | 1262             |
| 0.190 .....                                                    | ...                           | ...              | ...              | 1450             |
| Head height (ref.), in. ....                                   | 0.042                         | 0.055            | 0.070            | 0.095            |

a Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.

b Rivet shear strength based on areas computed from nominal hole diameters in Table 8.1.2(a) and  $F_{su} = 28$  ksi.

c Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.

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**Table 8.1.3.2.2(a). Static Joint Strength of Blind 100° Flush Head Locked Spindle A-286 Rivets in Machine-Countersunk Alloy Steel Sheet**

| Rivet Type .....                                                                                                                                                                                 | NAS1399C <sup>a</sup> ( $F_{su}$ = 75 ksi) |                               |                               | CR 2642 <sup>a</sup> ( $F_{su}$ = 95 ksi) |                               |                               |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|-------------------------------|-------------------------------|-------------------------------------------|-------------------------------|-------------------------------|
| Sheet Material .....                                                                                                                                                                             | Alloy Steel, $F_{tu}$ = 180 ksi            |                               |                               |                                           |                               |                               |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) ..                                                                                                                                      | 1/8<br>(0.130)                             | 5/32<br>(0.162)               | 3/16<br>(0.194)               | 1/8<br>(0.130)                            | 5/32<br>(0.162)               | 3/16<br>(0.194)               |
| Sheet thickness, in.:<br><br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>Rivet shear strength .....   | Ultimate Strength, lbs.                    |                               |                               |                                           |                               |                               |
|                                                                                                                                                                                                  |                                            |                               |                               |                                           |                               |                               |
|                                                                                                                                                                                                  | 380 <sup>b</sup>                           | ...                           | ...                           | 380 <sup>b</sup>                          | ...                           | ...                           |
|                                                                                                                                                                                                  | 475 <sup>b</sup>                           | <sup>c</sup> 588 <sup>b</sup> | ...                           | 475                                       | <sup>c</sup> 588 <sup>b</sup> | ...                           |
|                                                                                                                                                                                                  | 698                                        | 741 <sup>b</sup>              | <sup>c</sup> 890 <sup>b</sup> | 698                                       | 741                           | <sup>c</sup> 890 <sup>b</sup> |
|                                                                                                                                                                                                  | 840                                        | 908                           | 1004 <sup>b</sup>             | <sup>c</sup> 840                          | 908                           | 1004 <sup>b</sup>             |
|                                                                                                                                                                                                  | 970                                        | 1108                          | 1171 <sup>b</sup>             | 1002                                      | 1108                          | 1171                          |
|                                                                                                                                                                                                  | ...                                        | 1333                          | 1438                          | 1185                                      | 1333                          | 1438                          |
|                                                                                                                                                                                                  | ...                                        | 1490                          | 1710                          | 1230                                      | 1559                          | 1710                          |
|                                                                                                                                                                                                  | ...                                        | ...                           | 2150                          | ...                                       | 1885                          | 2380                          |
|                                                                                                                                                                                                  | ...                                        | ...                           | ...                           | ...                                       | ...                           | 2720                          |
|                                                                                                                                                                                                  | 970 <sup>d</sup>                           | 1490 <sup>d</sup>             | 2150 <sup>d</sup>             | 1230 <sup>e</sup>                         | 1885 <sup>e</sup>             | 2720 <sup>e</sup>             |
| Sheet thickness, in.:<br><br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>Head height (ref.), in. .... | Yield Strength <sup>f</sup> , lbs.         |                               |                               |                                           |                               |                               |
|                                                                                                                                                                                                  |                                            |                               |                               |                                           |                               |                               |
|                                                                                                                                                                                                  | 137                                        | ...                           | ...                           | 180                                       | ...                           | ...                           |
|                                                                                                                                                                                                  | 292                                        | 219                           | ...                           | 320                                       | 278                           | ...                           |
|                                                                                                                                                                                                  | 494                                        | 468                           | 387                           | 536                                       | 513                           | 432                           |
|                                                                                                                                                                                                  | 614                                        | 620                           | 570                           | 665                                       | 675                           | 628                           |
|                                                                                                                                                                                                  | 755                                        | 793                           | 776                           | 816                                       | 860                           | 847                           |
|                                                                                                                                                                                                  | ...                                        | 983                           | 1003                          | 981                                       | 1063                          | 1090                          |
|                                                                                                                                                                                                  | ...                                        | 1176                          | 1236                          | 1144                                      | 1267                          | 1337                          |
|                                                                                                                                                                                                  | ...                                        | ...                           | 1809                          | ...                                       | 1777                          | 1950                          |
|                                                                                                                                                                                                  | ...                                        | ...                           | ...                           | ...                                       | ...                           | 2720                          |
|                                                                                                                                                                                                  | 0.042                                      | 0.055                         | 0.070                         | 0.042                                     | 0.055                         | 0.070                         |

- a Data supplied by Cherry Fasteners.  
b Yield value is less than 2/3 of the indicated ultimate strength value.  
c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
d Rivet shear strength is documented in NAS1400.  
e Shear strength is based on areas computed from nominal hole diameters in Table 8.1.2(a) and  $F_{su} = 95$  ksi.  
f Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.

**Table 8.1.3.2.2(b). Static Joint Strength of Blind 100° Flush Head Locked Spindle Monel Rivets in Machine-Countersunk Stainless Steel Sheet**

|                                                                                                                                                                                              |                                                    |                               |                               |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------|-------------------------------|-------------------------------|
| Rivet Type .....                                                                                                                                                                             | NAS1399 MS or MW <sup>a</sup> ( $F_{su} = 55$ ksi) |                               |                               |
| Sheet Material .....                                                                                                                                                                         | AISI 301-1/2 Hard                                  |                               |                               |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) ..                                                                                                                                  | 1/8<br>(0.130)                                     | 5/32<br>(0.162)               | 3/16<br>(0.194)               |
| Sheet thickness, in.:<br><br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>Rivet shear strength <sup>d</sup> ..... | Ultimate Strength, lbs.                            |                               |                               |
|                                                                                                                                                                                              | 287 <sup>b</sup>                                   | ...                           | ...                           |
|                                                                                                                                                                                              | 363                                                | <sup>c</sup> 445 <sup>b</sup> | ...                           |
|                                                                                                                                                                                              | 491                                                | 569                           | <sup>c</sup> 671 <sup>b</sup> |
|                                                                                                                                                                                              | 569                                                | 668                           | 755 <sup>b</sup> <sup>c</sup> |
|                                                                                                                                                                                              | 657                                                | 776                           | 886                           |
|                                                                                                                                                                                              | 710                                                | 898                           | 1032                          |
|                                                                                                                                                                                              | ...                                                | 1019                          | 1182                          |
|                                                                                                                                                                                              | ...                                                | 1090                          | 1580                          |
|                                                                                                                                                                                              | 710                                                | 1090                          | 1580                          |
| Sheet thickness, in.:<br><br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....                                            | Yield Strength <sup>e</sup> , lbs.                 |                               |                               |
|                                                                                                                                                                                              | 163                                                | ...                           | ...                           |
|                                                                                                                                                                                              | 243                                                | 253                           | ...                           |
|                                                                                                                                                                                              | 348                                                | 384                           | 401                           |
|                                                                                                                                                                                              | 413                                                | 463                           | 496                           |
|                                                                                                                                                                                              | 487                                                | 554                           | 606                           |
|                                                                                                                                                                                              | 568                                                | 655                           | 726                           |
|                                                                                                                                                                                              | ...                                                | 753                           | 846                           |
|                                                                                                                                                                                              | ...                                                | 1004                          | 1156                          |
| Head height (ref.), in. ....                                                                                                                                                                 | 0.042                                              | 0.055                         | 0.070                         |

a Data supplied by Cherry Fasteners.  
b Yield value is less than 2/3 of the indicated ultimate strength value.  
c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
d Rivet shear strength is documented in NAS1400.  
e Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.

**Table 8.1.3.2.2(c). Static Joint Strength of 100° Flush Head Locked Spindle A-286 Blind Rivets in Machine-Countersunk Aluminum Alloy Steel Sheet**

|                                                          |                                            |                   |                   |
|----------------------------------------------------------|--------------------------------------------|-------------------|-------------------|
| Rivet Type .....                                         | NAS1921C <sup>a</sup> ( $F_{su} = 80$ ksi) |                   |                   |
| Sheet Material .....                                     | Clad 7075-T6                               |                   |                   |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) | 1/8<br>(0.130)                             | 5/32<br>(0.162)   | 3/16<br>(0.194)   |
| Ultimate Strength, lbs                                   |                                            |                   |                   |
| Sheet thickness, in.                                     |                                            |                   |                   |
| 0.050 .....                                              | 612 <sup>b</sup>                           | ...               | ...               |
| 0.063 .....                                              | 749 <sup>b</sup>                           | 956 <sup>b</sup>  | ...               |
| 0.071 .....                                              | 831 <sup>b</sup>                           | 1060 <sup>b</sup> | ...               |
| 0.080 .....                                              | 923 <sup>b</sup>                           | 1180 <sup>b</sup> | 1450 <sup>b</sup> |
| 0.090 .....                                              | 1110 <sup>b</sup>                          | 1305 <sup>b</sup> | 1605 <sup>b</sup> |
| 0.100 .....                                              | 1090 <sup>b</sup>                          | 1435 <sup>b</sup> | 1755 <sup>b</sup> |
| 0.125 .....                                              | ...                                        | 1670 <sup>b</sup> | 2130 <sup>b</sup> |
| 0.160 .....                                              | ...                                        | ...               | 2400 <sup>b</sup> |
| Rivet shear strength <sup>c</sup> .....                  | 1090                                       | 1670              | 2400              |
| Yield Strength <sup>d</sup> , lbs                        |                                            |                   |                   |
| Sheet thickness, in.:                                    |                                            |                   |                   |
| 0.050 .....                                              | 365                                        | ...               | ...               |
| 0.063 .....                                              | 466                                        | 571               | ...               |
| 0.071 .....                                              | 528                                        | 649               | ...               |
| 0.080 .....                                              | 598                                        | 737               | 873               |
| 0.090 .....                                              | 639                                        | 835               | 990               |
| 0.100 .....                                              | 686                                        | 931               | 1105              |
| 0.125 .....                                              | 804                                        | 1065              | 1325              |
| 0.160 .....                                              | ...                                        | ...               | 1605              |
| Head height (ref.), in. ....                             | 0.042                                      | 0.055             | 0.070             |

a Data supplied by Huck Manufacturing Company.

b Yield value is less than 2/3 of indicated ultimate strength value.

c Rivet shear strength is documented in NAS1900.

d Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3) (revised May 1, 1985 from the greater of 0.012 inch or 4% of nominal diameter).

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**Table 8.1.3.2.2(d). Static Joint Strength of Blind 100° Flush Head Locked Spindle Monel Rivets in Machine-Countersunk Aluminum Alloy Sheet**

|                                                                                                                                                                             |                                                    |                               |                               |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------|-------------------------------|-------------------------------|
| Rivet Type .....                                                                                                                                                            | NAS1399 MS or MW <sup>a</sup> ( $F_{su} = 55$ ksi) |                               |                               |
| Sheet Material .....                                                                                                                                                        | Clad 7075-T6                                       |                               |                               |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) ..                                                                                                                 | 1/8<br>(0.130)                                     | 5/32<br>(0.162)               | 3/16<br>(0.194)               |
| Sheet thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 ..... | Ultimate Strength, lbs.                            |                               |                               |
|                                                                                                                                                                             | 323 <sup>b</sup>                                   | ...                           | ...                           |
|                                                                                                                                                                             | 404 <sup>b</sup>                                   | <sup>c</sup> 499 <sup>b</sup> | ...                           |
|                                                                                                                                                                             | 500 <sup>b</sup>                                   | 631 <sup>b</sup>              | <sup>c</sup> 757 <sup>b</sup> |
|                                                                                                                                                                             | 557                                                | 703 <sup>b</sup>              | 855 <sup>b</sup>              |
|                                                                                                                                                                             | 610                                                | 784                           | 958 <sup>b</sup>              |
|                                                                                                                                                                             | 636                                                | 873                           | 1065 <sup>b</sup>             |
|                                                                                                                                                                             | 662                                                | 937                           | 1175                          |
|                                                                                                                                                                             | 710                                                | 1015                          | 1370                          |
|                                                                                                                                                                             | ...                                                | 1090                          | 1505                          |
|                                                                                                                                                                             | ...                                                | ...                           | 1580                          |
|                                                                                                                                                                             | 710                                                | 1090                          | 1580                          |
| Rivet shear strength <sup>d</sup> .....                                                                                                                                     |                                                    |                               |                               |
| Sheet thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 ..... | Yield Strength <sup>e</sup> , lbs.                 |                               |                               |
|                                                                                                                                                                             | 139                                                | ...                           | ...                           |
|                                                                                                                                                                             | 223                                                | 218                           | ...                           |
|                                                                                                                                                                             | 331                                                | 353                           | 351                           |
|                                                                                                                                                                             | 397                                                | 436                           | 451                           |
|                                                                                                                                                                             | 472                                                | 529                           | 563                           |
|                                                                                                                                                                             | 556                                                | 633                           | 687                           |
|                                                                                                                                                                             | 562                                                | 737                           | 811                           |
|                                                                                                                                                                             | 574                                                | 873                           | 1120                          |
|                                                                                                                                                                             | ...                                                | 894                           | 1260                          |
|                                                                                                                                                                             | ...                                                | ...                           | 1280                          |
| Head height (ref.), in. ....                                                                                                                                                | 0.042                                              | 0.055                         | 0.070                         |

a Data supplied by Cherry Fasteners.  
b Yield value is less than 2/3 of the indicated ultimate strength value.  
c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
d Rivet shear strength is documented in NAS1400.  
e Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3) (revised May 1, 1985, from the greater of 0.005 inch or 2.5% of nominal diameter).

**Table 8.1.3.2.2(e). Static Joint Strength of 100° Flush Head Locked Spindle Monel Blind Rivets in Machine-Countersunk Aluminum Alloy Sheet**

|                                                          |                                              |                   |                   |
|----------------------------------------------------------|----------------------------------------------|-------------------|-------------------|
| Rivet Type .....                                         | NAS 1921 M <sup>a</sup> ( $F_{su} = 75$ ksi) |                   |                   |
| Sheet Material .....                                     | Clad 7075-T6                                 |                   |                   |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) | 1/8<br>(0.130)                               | 5/32<br>(0.162)   | 3/16<br>(0.194)   |
| Ultimate Strength, lbs                                   |                                              |                   |                   |
| Sheet thickness, in.                                     |                                              |                   |                   |
| 0.050 .....                                              | 595 <sup>b</sup>                             | ...               | ...               |
| 0.063 .....                                              | 732 <sup>b</sup>                             | 927 <sup>b</sup>  | ...               |
| 0.071 .....                                              | 816 <sup>b</sup>                             | 1035 <sup>b</sup> | ...               |
| 0.080 .....                                              | 913 <sup>b</sup>                             | 1158 <sup>b</sup> | 1400 <sup>b</sup> |
| 0.090 .....                                              | 946 <sup>b</sup>                             | 1289 <sup>b</sup> | 1570 <sup>b</sup> |
| 0.100 .....                                              | 980 <sup>b</sup>                             | 1415 <sup>b</sup> | 1720 <sup>b</sup> |
| 0.125 .....                                              | 1020                                         | 1525 <sup>b</sup> | 2055 <sup>b</sup> |
| 0.160 .....                                              | ...                                          | 1565 <sup>b</sup> | 2245 <sup>b</sup> |
| 0.190 .....                                              | ...                                          | ...               | 2260              |
| Rivet shear strength <sup>c</sup> .....                  | 1020                                         | 1565              | 2260              |
| Yield Strength <sup>d</sup> , lbs                        |                                              |                   |                   |
| Sheet thickness, in.:                                    |                                              |                   |                   |
| 0.050 .....                                              | 354                                          | ...               | ...               |
| 0.063 .....                                              | 447                                          | 554               | ...               |
| 0.071 .....                                              | 504                                          | 625               | ...               |
| 0.080 .....                                              | 569                                          | 707               | 843               |
| 0.090 .....                                              | 607                                          | 796               | 952               |
| 0.100 .....                                              | 626                                          | 885               | 1060              |
| 0.125 .....                                              | 686                                          | 972               | 1265              |
| 0.160 .....                                              | ...                                          | 1080              | 1430              |
| 0.190 .....                                              | ...                                          | ...               | 1540              |
| Head height (ref.), in. ....                             | 0.042                                        | 0.055             | 0.070             |

- a Data supplied by Huck Manufacturing Company.  
b Yield value is less than 2/3 of indicated ultimate strength value.  
c Rivet shear strength is documented in NAS 1900.  
d Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3) (revised May 1, 1985 from the greater of 0.012 inch or 4% of nominal diameter).

Table 8.1.3.2.2(f). Static Joint Strength of Blind 100° Flush Head Aluminum Alloy (2219) Rivets in Machine-Countersunk Aluminum Alloy Sheet

|                                                                                                                                                                                                  |                                           |                 |                 |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|-----------------|-----------------|
| Rivet Type . . . . .                                                                                                                                                                             | CR 2A62 <sup>a</sup> ( $F_{su}$ = 36 ksi) |                 |                 |
| Sheet Material . . . . .                                                                                                                                                                         | Clad 2024-T81                             |                 |                 |
| Rivet Diameter, in. . . . .<br>(Nominal Hole Diameter, in.)                                                                                                                                      | 1/8<br>(0.130)                            | 5/32<br>(0.162) | 3/16<br>(0.194) |
| Sheet thickness, in.<br>0.050 . . . . .<br>0.063 . . . . .<br>0.071 . . . . .<br>0.080 . . . . .<br>0.090 . . . . .<br>0.100 . . . . .<br>0.125 . . . . .<br>0.160 . . . . .<br>0.190 . . . . .  | Ultimate Strength, lbs                    |                 |                 |
|                                                                                                                                                                                                  | 203                                       | ...             | ...             |
|                                                                                                                                                                                                  | 289                                       | 319             | ...             |
|                                                                                                                                                                                                  | 342                                       | 385             | ...             |
|                                                                                                                                                                                                  | 393                                       | 461             | 503             |
|                                                                                                                                                                                                  | 416                                       | 542             | 603             |
|                                                                                                                                                                                                  | 439                                       | 610             | 701             |
|                                                                                                                                                                                                  | 478                                       | 682             | 894             |
|                                                                                                                                                                                                  | ...                                       | 741             | 1013            |
|                                                                                                                                                                                                  | ...                                       | ...             | 1063            |
| Rivet shear strength <sup>b</sup> . . . . .                                                                                                                                                      | 478                                       | 741             | 1063            |
| Sheet thickness, in.:<br>0.050 . . . . .<br>0.063 . . . . .<br>0.071 . . . . .<br>0.080 . . . . .<br>0.090 . . . . .<br>0.100 . . . . .<br>0.125 . . . . .<br>0.160 . . . . .<br>0.190 . . . . . | Yield Strength <sup>c</sup> , lbs         |                 |                 |
|                                                                                                                                                                                                  | 169                                       | ...             | ...             |
|                                                                                                                                                                                                  | 247                                       | 267             | ...             |
|                                                                                                                                                                                                  | 295                                       | 326             | ...             |
|                                                                                                                                                                                                  | 349                                       | 394             | 423             |
|                                                                                                                                                                                                  | 409                                       | 468             | 514             |
|                                                                                                                                                                                                  | 424                                       | 544             | 603             |
|                                                                                                                                                                                                  | 448                                       | 658             | 827             |
|                                                                                                                                                                                                  | ...                                       | 670             | 960             |
|                                                                                                                                                                                                  | ...                                       | ...             | 1002            |
| Head height (ref.), in. . . . .                                                                                                                                                                  | 0.042                                     | 0.055           | 0.070           |

a Data supplied by Cherry Fasteners.  
b Shear strength values are based on indicated nominal hole diameters and  $F_{su}$  = 36 ksi.  
c Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).



**Table 8.1.3.2.2(g). Static Joint Strength of Blind 100 degree Flush Head Locked Aluminum Alloy Rivets in Machine-Countersunk Aluminum Alloy Sheet**

|                                                                                                                                                                  |                                                                                             |                  |                  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|------------------|------------------|
| Rivet Type .....                                                                                                                                                 | NAS1921B0()-00), NAS1921B0(S0(),<br>NAS1921B0(S0()U <sup>a</sup> (F <sub>su</sub> = 36 ksi) |                  |                  |
| Sheet Material .....                                                                                                                                             | Clad 7075-T6                                                                                |                  |                  |
| Rivet Diameter, in.<br>(Nominal Hole Diameter, in.) .....                                                                                                        | 1/8<br>(0.130)                                                                              | 5/32<br>(0.162)  | 3/16<br>(0.194)  |
| Sheet Thickness, in.:<br><br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 ..... | Ultimate Strength, lbs.                                                                     |                  |                  |
|                                                                                                                                                                  | 171 <sup>b</sup>                                                                            | ---              | ---              |
|                                                                                                                                                                  | 232                                                                                         | 267 <sup>b</sup> | ---              |
|                                                                                                                                                                  | 313                                                                                         | 366              | 411 <sup>b</sup> |
|                                                                                                                                                                  | 360                                                                                         | 427              | 484              |
|                                                                                                                                                                  | 416                                                                                         | 498              | 566              |
|                                                                                                                                                                  | 477                                                                                         | 571              | 658              |
|                                                                                                                                                                  | 494                                                                                         | 647              | 748              |
|                                                                                                                                                                  | ---                                                                                         | 755              | 978              |
|                                                                                                                                                                  | ---                                                                                         | ---              | 1090             |
| Rivet Shear Strength <sup>c</sup> .....                                                                                                                          | 495                                                                                         | 755              | 1090             |
| Sheet Thickness, in.:<br><br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 ..... | Yield Strength, lbs <sup>d</sup>                                                            |                  |                  |
|                                                                                                                                                                  | 110                                                                                         | ---              | ---              |
|                                                                                                                                                                  | 161                                                                                         | 171              | ---              |
|                                                                                                                                                                  | 247                                                                                         | 254              | 270              |
|                                                                                                                                                                  | 303                                                                                         | 315              | 330              |
|                                                                                                                                                                  | 354                                                                                         | 395              | 399              |
|                                                                                                                                                                  | 373                                                                                         | 484              | 506              |
|                                                                                                                                                                  | 393                                                                                         | 549              | 611              |
|                                                                                                                                                                  | ---                                                                                         | 610              | 803              |
|                                                                                                                                                                  | ---                                                                                         | ---              | 906              |
| Head Height [ref.], in. ....                                                                                                                                     | 0.042                                                                                       | 0.055            | 0.070            |

a Data supplied by Huck Manufacturing Company.  
b Values above the horizontal line in each column are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring activity.  
c Rivet shear strength is documented in NAS1900.  
d Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

Table 8.1.3.2.2(h). Static Joint Strength of Blind 100° Flush Head Locked Spindle Aluminum Alloy Rivets in Machine-Countersunk Aluminum Alloy Sheet

|                                                             |                                                   |                               |                               |                                                   |                               |                               |
|-------------------------------------------------------------|---------------------------------------------------|-------------------------------|-------------------------------|---------------------------------------------------|-------------------------------|-------------------------------|
| Rivet Type . . . . .                                        | NAS1399B <sup>a</sup> (5056) ( $F_{su}$ = 30 ksi) |                               |                               | NAS1399D <sup>a</sup> (2017) ( $F_{su}$ = 36 ksi) |                               |                               |
| Sheet Material . . . . .                                    | Clad 2024-T3                                      |                               |                               |                                                   |                               |                               |
| Rivet Diameter, in. . . . .<br>(Nominal Hole Diameter, in.) | 1/8<br>(0.130)                                    | 5/32<br>(0.162)               | 3/16<br>(0.194)               | 1/8<br>(0.130)                                    | 5/32<br>(0.162)               | 3/16<br>(0.194)               |
| Sheet thickness, in.:                                       | Ultimate Strength, lbs.                           |                               |                               |                                                   |                               |                               |
|                                                             | 149 <sup>b</sup>                                  | ...                           | ...                           | 149 <sup>b</sup>                                  | ...                           | ...                           |
|                                                             | 223 <sup>b</sup>                                  | <sup>c</sup> 230 <sup>b</sup> | ...                           | 223 <sup>b</sup>                                  | <sup>c</sup> 230 <sup>b</sup> | ...                           |
|                                                             | 310 <sup>b</sup>                                  | 349 <sup>b</sup>              | <sup>c</sup> 356 <sup>b</sup> | 319 <sup>b</sup>                                  | 349 <sup>b</sup>              | <sup>c</sup> 356 <sup>b</sup> |
|                                                             | 366                                               | 415 <sup>b</sup>              | 448 <sup>b</sup>              | <sup>c</sup> 379 <sup>b</sup>                     | 420 <sup>b</sup>              | 448 <sup>b</sup>              |
|                                                             | 388                                               | 492 <sup>b</sup>              | 544 <sup>b</sup>              | 423                                               | 506 <sup>b</sup>              | 547 <sup>b</sup>              |
|                                                             | ...                                               | 578                           | 646 <sup>b</sup>              | 459                                               | 600 <sup>b</sup>              | 660 <sup>b</sup>              |
|                                                             | ...                                               | 596                           | 751 <sup>b</sup>              | 494                                               | 652                           | 775 <sup>b</sup>              |
|                                                             | ...                                               | ...                           | 862                           | ...                                               | 755                           | 969                           |
|                                                             | ...                                               | ...                           | ...                           | ...                                               | ...                           | 1090                          |
|                                                             | Rivet shear strength <sup>d</sup> . . . . .       | 388                           | 596                           | 862                                               | 494                           | 755                           |
| Sheet thickness, in.:                                       | Yield Strength <sup>e</sup> , lbs.                |                               |                               |                                                   |                               |                               |
|                                                             | 72                                                | ...                           | ...                           | 72                                                | ...                           | ...                           |
|                                                             | 114                                               | 113                           | ...                           | 114                                               | 113                           | ...                           |
|                                                             | 197                                               | 182                           | 170                           | 197                                               | 182                           | 170                           |
|                                                             | 247                                               | 245                           | 220                           | 247                                               | 245                           | 220                           |
|                                                             | 304                                               | 316                           | 304                           | 304                                               | 316                           | 304                           |
|                                                             | ...                                               | 396                           | 399                           | 367                                               | 396                           | 399                           |
|                                                             | ...                                               | 473                           | 493                           | 431                                               | 473                           | 493                           |
|                                                             | ...                                               | ...                           | 729                           | ...                                               | 672                           | 729                           |
|                                                             | ...                                               | ...                           | ...                           | ...                                               | ...                           | 1060                          |
| Head height (ref.), in. . . . .                             | 0.042                                             | 0.055                         | 0.070                         | 0.042                                             | 0.055                         | 0.070                         |

a Data supplied by Cherry Fasteners.  
b Yield value is less than 2/3 of the indicated ultimate strength value.  
c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
d Rivet shear strength is documented in NAS1900.  
e Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3) (revised May 1, 1985, from the greater of 0.005 inch or 2.5% of nominal diameter).

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**Table 8.1.3.2.2(i). Static Joint Strength of Blind 100° Flush Head Locked Spindle Aluminum Alloy Rivets in Machine-Countersunk and Dimpled Aluminum Alloy Sheet**

| Rivet Type . . . . .                                                                                                                                                                                                                                                                      | NAS1739B <sup>a</sup> and NAS1739E <sup>a,c</sup><br>( <i>F<sub>su</sub></i> = 34 ksi)                                                                                                                                                                                        |                                    |                  | NAS1739B <sup>b</sup> and NAS1739E <sup>b,c</sup><br>( <i>F<sub>su</sub></i> = 34 ksi) |                 |                 |     |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|------------------|----------------------------------------------------------------------------------------|-----------------|-----------------|-----|
| Sheet Material . . . . .                                                                                                                                                                                                                                                                  | Clad 2024-T3                                                                                                                                                                                                                                                                  |                                    |                  |                                                                                        |                 |                 |     |
| Rivet Diameter, in. . . . .<br>(Nominal Hole Diameter, in.) . . .                                                                                                                                                                                                                         | 1/8<br>(0.144)                                                                                                                                                                                                                                                                | 5/32<br>(0.178)                    | 3/16<br>(0.207)  | 1/8<br>(0.144)                                                                         | 5/32<br>(0.178) | 3/16<br>(0.207) |     |
| Sheet thickness, in.:<br><br>0.020 . . . . .<br>0.025 . . . . .<br>0.032 . . . . .<br>0.040 . . . . .<br>0.050 . . . . .<br>0.063 . . . . .<br>0.071 . . . . .<br>0.080 . . . . .<br>0.090 . . . . .<br>0.100 . . . . .<br>0.125 . . . . .<br>Rivet shear strength <sup>e</sup> . . . . . | Ultimate Strength, lbs.                                                                                                                                                                                                                                                       |                                    |                  |                                                                                        |                 |                 |     |
|                                                                                                                                                                                                                                                                                           | ...                                                                                                                                                                                                                                                                           | ...                                | ...              | 246                                                                                    | 334             | 418             |     |
|                                                                                                                                                                                                                                                                                           | ...                                                                                                                                                                                                                                                                           | ...                                | ...              | 281                                                                                    | 376             | 465             |     |
|                                                                                                                                                                                                                                                                                           | 212                                                                                                                                                                                                                                                                           | ...                                | ...              | 330                                                                                    | 436             | 536             |     |
|                                                                                                                                                                                                                                                                                           | 266                                                                                                                                                                                                                                                                           | <sup>d</sup> 326                   | ...              | 386                                                                                    | 506             | 616             |     |
|                                                                                                                                                                                                                                                                                           | 344                                                                                                                                                                                                                                                                           | 410                                | <sup>d</sup> ... | 456                                                                                    | 592             | 716             |     |
|                                                                                                                                                                                                                                                                                           | 441                                                                                                                                                                                                                                                                           | 533                                | 606              | 546                                                                                    | 703             | 845             |     |
|                                                                                                                                                                                                                                                                                           | 504                                                                                                                                                                                                                                                                           | 608                                | 696              | <sup>d</sup> ...                                                                       | 771             | 926             |     |
|                                                                                                                                                                                                                                                                                           | 554                                                                                                                                                                                                                                                                           | 693                                | 794              | ...                                                                                    | 837             | 1015            |     |
|                                                                                                                                                                                                                                                                                           | ...                                                                                                                                                                                                                                                                           | 787                                | 900              | ...                                                                                    | ...             | 1110            |     |
|                                                                                                                                                                                                                                                                                           | ...                                                                                                                                                                                                                                                                           | 837                                | 1015             | ...                                                                                    | ...             | ...             |     |
|                                                                                                                                                                                                                                                                                           | ...                                                                                                                                                                                                                                                                           | ...                                | 1128             | ...                                                                                    | ...             | ...             |     |
|                                                                                                                                                                                                                                                                                           | 554                                                                                                                                                                                                                                                                           | 837                                | 1128             | 554                                                                                    | 837             | 1128            |     |
|                                                                                                                                                                                                                                                                                           | Sheet thickness, in.:<br><br>0.020 . . . . .<br>0.025 . . . . .<br>0.032 . . . . .<br>0.040 . . . . .<br>0.050 . . . . .<br>0.063 . . . . .<br>0.071 . . . . .<br>0.080 . . . . .<br>0.090 . . . . .<br>0.100 . . . . .<br>0.125 . . . . .<br>Head height (ref.), in. . . . . | Yield Strength <sup>f</sup> , lbs. |                  |                                                                                        |                 |                 |     |
|                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                               | ...                                | ...              | ...                                                                                    | ...             | ...             | ... |
| ...                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                               | ...                                | ...              | ...                                                                                    | ...             | ...             |     |
| 159                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                               | ...                                | ...              | ...                                                                                    | ...             | ...             |     |
| 212                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                               | 247                                | ...              | ...                                                                                    | ...             | ...             |     |
| 279                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                               | 331                                | ...              | ...                                                                                    | ...             | ...             |     |
| 365                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                               | 437                                | 492              | ...                                                                                    | ...             | ...             |     |
| 418                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                               | 503                                | 568              | ...                                                                                    | ...             | ...             |     |
| 448                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                               | 577                                | 654              | ...                                                                                    | ...             | ...             |     |
| ...                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                               | 659                                | 750              | ...                                                                                    | ...             | ...             |     |
| ...                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                               | 689                                | 845              | ...                                                                                    | ...             | ...             |     |
| ...                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                               | ...                                | 960              | ...                                                                                    | ...             | ...             |     |
| 0.035                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                               | 0.047                              | 0.063            | 0.035                                                                                  | 0.047           | 0.063           |     |

a Machine-countersunk holes.  
b Dimpled holes. These allowables apply to double dimpled sheets and to the upper sheet dimpled into a machine-countersunk lower sheet. Sheet gauge is that of the thinnest sheet for double dimpled joints and of the upper dimpled, machine-countersunk joints. The thickness of the machine-countersunk sheet must be at least one tabulated gauge thicker than the upper sheet. In no case shall allowables be obtained by extrapolation for gauges other than those shown.  
c Data supplied by Cherry Fasteners. Confirmatory data for machine-countersunk holes provided by Allfast Fastening Systems, Inc.  
d The values in the table above the horizontal line in each column are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
e Rivet shear strength is documented in NAS1740.  
f Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3) (revised May 1, 1985, from the greater of 0.005 inch or 2.5% of nominal diameter).

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**Table 8.1.3.2.2(j). Static Joint Strength of Blind 100° Flush Head Locked Spindle Aluminum Alloy Rivets in Machine-Countersunk Magnesium Alloy Sheet**

| Rivet Type .....                                                                                                                                                                                                | NAS1399B <sup>a</sup> ( $F_{su}$ = 30 ksi) |                 |                 |                | NAS1739B and NAS 1739E <sup>a</sup> ( $F_{su}$ = 34 ksi) |                               |                               |                   |                  |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|-----------------|-----------------|----------------|----------------------------------------------------------|-------------------------------|-------------------------------|-------------------|------------------|
| Sheet Material .....                                                                                                                                                                                            | AZ31B-H24                                  |                 |                 |                |                                                          |                               |                               |                   |                  |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) .....                                                                                                                                                  | 1/8<br>(0.130)                             | 5/32<br>(0.162) | 3/16<br>(0.194) | 1/4<br>(0.258) | 1/8<br>(0.144)                                           | 5/32<br>(0.178)               | 3/16<br>(0.207)               |                   |                  |
| Sheet thickness, in.:<br><br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>Rivet shear strength .....   | Ultimate Strength, lbs.                    |                 |                 |                |                                                          |                               |                               |                   |                  |
|                                                                                                                                                                                                                 | ...                                        | ...             | ...             | ...            | 188 <sup>b</sup>                                         | ...                           | ...                           |                   |                  |
|                                                                                                                                                                                                                 |                                            |                 |                 |                | 178 <sup>b</sup>                                         | <sup>c</sup> 292 <sup>b</sup> | ...                           |                   |                  |
|                                                                                                                                                                                                                 |                                            |                 |                 |                | 223 <sup>b</sup>                                         | <sup>c</sup> 274 <sup>b</sup> | ...                           |                   |                  |
|                                                                                                                                                                                                                 |                                            |                 |                 |                | 292 <sup>b</sup>                                         | 349 <sup>b</sup>              | <sup>c</sup> 418 <sup>b</sup> |                   |                  |
|                                                                                                                                                                                                                 |                                            |                 |                 |                | 334 <sup>b</sup>                                         | 399 <sup>b</sup>              | 471 <sup>b</sup>              | <sup>c</sup> ...  |                  |
|                                                                                                                                                                                                                 |                                            |                 |                 |                | 383 <sup>b</sup>                                         | 459 <sup>b</sup>              | 536 <sup>b</sup>              | ...               |                  |
|                                                                                                                                                                                                                 |                                            |                 |                 |                | 388                                                      | 526 <sup>b</sup>              | 613 <sup>b</sup>              | 803 <sup>b</sup>  |                  |
|                                                                                                                                                                                                                 |                                            |                 |                 |                | ...                                                      | 593 <sup>b</sup>              | 693 <sup>b</sup>              | 892 <sup>b</sup>  | <sup>c</sup> 554 |
|                                                                                                                                                                                                                 |                                            |                 |                 |                | ...                                                      | 596                           | 862                           | 1153 <sup>b</sup> | ...              |
|                                                                                                                                                                                                                 |                                            |                 |                 |                | ...                                                      | ...                           | ...                           | 1532 <sup>b</sup> | ...              |
|                                                                                                                                                                                                                 |                                            |                 |                 |                | 388 <sup>d</sup>                                         | 596 <sup>d</sup>              | 862 <sup>d</sup>              | 1550 <sup>d</sup> | 554 <sup>e</sup> |
| Sheet thickness, in.:<br><br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>Head height (ref.), in. .... | Yield Strength <sup>f</sup> , lbs.         |                 |                 |                |                                                          |                               |                               |                   |                  |
|                                                                                                                                                                                                                 | ...                                        | ...             | ...             | ...            | 106                                                      | ...                           | ...                           |                   |                  |
|                                                                                                                                                                                                                 |                                            |                 |                 |                | 49                                                       | ...                           | ...                           |                   |                  |
|                                                                                                                                                                                                                 |                                            |                 |                 |                | 94                                                       | 76                            | ...                           |                   |                  |
|                                                                                                                                                                                                                 |                                            |                 |                 |                | 158                                                      | 152                           | 128                           |                   |                  |
|                                                                                                                                                                                                                 |                                            |                 |                 |                | 197                                                      | 200                           | 186                           |                   |                  |
|                                                                                                                                                                                                                 |                                            |                 |                 |                | 242                                                      | 254                           | 250                           |                   |                  |
|                                                                                                                                                                                                                 |                                            |                 |                 |                | 291                                                      | 315                           | 323                           | 277               |                  |
|                                                                                                                                                                                                                 |                                            |                 |                 |                | ...                                                      | 375                           | 396                           | 376               |                  |
|                                                                                                                                                                                                                 |                                            |                 |                 |                | ...                                                      | 530                           | 580                           | 621               | ...              |
|                                                                                                                                                                                                                 |                                            |                 |                 |                | ...                                                      | ...                           | ...                           | 968               | ...              |
|                                                                                                                                                                                                                 |                                            |                 |                 |                | 0.042                                                    | 0.055                         | 0.070                         | 0.095             | 0.035            |

a Data supplied by Cherry Fasteners.  
b Yield value is less than 2/3 of the indicated ultimate strength value.  
c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
d Rivet shear strength is documented in NAS1400.  
e Rivet shear strength is documented in NAS1740 dated March 1968.  
f Permanent set at yield load: the greater of 0.005 inch or 2.5% of nominal diameter.

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**Table 8.1.3.2.2(k). Static Joint Strength of Blind 100° Flush Head Locked Spindle A-286 Rivets in Machine-Countersunk Aluminum Alloy Sheet**

|                                                                   |                                           |                  |                   |                   |
|-------------------------------------------------------------------|-------------------------------------------|------------------|-------------------|-------------------|
| Rivet Type .....                                                  | CR 4622 <sup>a</sup> ( $F_{su} = 75$ ksi) |                  |                   |                   |
| Sheet Material .....                                              | Clad 7075-T6                              |                  |                   |                   |
| Rivet Diameter .....<br>(Nominal Hole Diameter, in.) <sup>b</sup> | 1/8<br>(0.130)                            | 5/32<br>(0.162)  | 3/16<br>(0.194)   | 1/4<br>(0.258)    |
| Sheet thickness, in.:                                             | Ultimate Strength, lbs                    |                  |                   |                   |
|                                                                   | 0.050                                     | 595 <sup>c</sup> | ...               | ...               |
|                                                                   | 0.063                                     | 733 <sup>c</sup> | 932 <sup>c</sup>  | ...               |
|                                                                   | 0.071                                     | 817 <sup>c</sup> | 1035 <sup>c</sup> | ...               |
|                                                                   | 0.080                                     | 913              | 1160 <sup>c</sup> | 1410 <sup>c</sup> |
|                                                                   | 0.090                                     | 947              | 1290 <sup>c</sup> | 1570 <sup>c</sup> |
|                                                                   | 0.100                                     | 982              | 1420              | 1725 <sup>c</sup> |
|                                                                   | 0.125                                     | 995              | 1525              | 2060              |
|                                                                   | 0.160                                     | ...              | 1545              | 2215              |
|                                                                   | 0.190                                     | ...              | ...               | 3810              |
|                                                                   | 0.250                                     | ...              | ...               | 3920              |
| Rivet shear strength <sup>d</sup> .....                           | 995                                       | 1545             | 2215              | 3920              |
| Sheet thickness, in.:                                             | Yield Strength <sup>e</sup> , lbs         |                  |                   |                   |
|                                                                   | 0.050                                     | 211              | ...               | ...               |
|                                                                   | 0.063                                     | 348              | 339               | ...               |
|                                                                   | 0.071                                     | 489              | 470               | ...               |
|                                                                   | 0.080                                     | 608              | 620               | 574               |
|                                                                   | 0.090                                     | 664              | 787               | 774               |
|                                                                   | 0.100                                     | 720              | 947               | 970               |
|                                                                   | 0.125                                     | 860              | 1120              | 1400              |
|                                                                   | 0.160                                     | ...              | 1365              | 1695              |
|                                                                   | 0.190                                     | ...              | ...               | 2740              |
|                                                                   | 0.250                                     | ...              | ...               | 3405              |
| Head height (ref.), in. ....                                      | 0.041                                     | 0.054            | 0.069             | 0.095             |

a Data supplied by Cherry Fasteners.

b Allowable loads developed from test with nominal hole diameters as listed.

c Yield value is less than 2/3 of the indicated ultimate strength value.

d Fastener shear strength based upon nominal hole diameters and  $F_{su} = 75$  ksi from data analysis.

e Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

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**Table 8.1.3.2.2(I). Static Joint Strength of Blind 100° Flush Head Locked Spindle Monel Rivets in Machine-Countersunk Aluminum Alloy Sheet and Plate**

|                                           |                                           |                  |                   |                   |
|-------------------------------------------|-------------------------------------------|------------------|-------------------|-------------------|
| Rivet Type .....                          | CR 4522 <sup>a</sup> ( $F_{su} = 65$ ksi) |                  |                   |                   |
| Sheet and Plate Material .....            | Clad 7075-T6 and T651                     |                  |                   |                   |
| Rivet Diameter .....                      | 1/8                                       | 5/32             | 3/16              | 1/4               |
| (Nominal Hole Diameter, in.) <sup>b</sup> | (0.130)                                   | (0.162)          | (0.194)           | (0.258)           |
| Ultimate Strength, lbs                    |                                           |                  |                   |                   |
| Sheet or plate thickness, in.:            |                                           |                  |                   |                   |
| 0.050 .....                               | 529 <sup>c</sup>                          | ...              | ...               | ...               |
| 0.063 .....                               | 632 <sup>c</sup>                          | 828 <sup>c</sup> | ...               | ...               |
| 0.071 .....                               | 694 <sup>c</sup>                          | 906 <sup>c</sup> | ...               | ...               |
| 0.080 .....                               | 754                                       | 995 <sup>c</sup> | 1240 <sup>c</sup> | ...               |
| 0.090 .....                               | 776                                       | 1095             | 1360 <sup>c</sup> | ...               |
| 0.100 .....                               | 797                                       | 1170             | 1475 <sup>c</sup> | ...               |
| 0.125 .....                               | 852                                       | 1240             | 1695              | 2485 <sup>c</sup> |
| 0.160 .....                               | 863                                       | 1335             | 1810              | 2975              |
| 0.190 .....                               | ...                                       | 1340             | 1910              | 3105              |
| 0.250 .....                               | ...                                       | ...              | 1920              | 3365              |
| 0.312 .....                               | ...                                       | ...              | ...               | 3400              |
| Rivet shear strength <sup>d</sup> .....   | 863                                       | 1340             | 1920              | 3400              |
| Yield Strength <sup>e</sup> , lbs         |                                           |                  |                   |                   |
| Sheet or plate thickness, in.:            |                                           |                  |                   |                   |
| 0.050 .....                               | 169                                       | ...              | ...               | ...               |
| 0.063 .....                               | 346                                       | 273              | ...               | ...               |
| 0.071 .....                               | 454                                       | 408              | ...               | ...               |
| 0.080 .....                               | 561                                       | 562              | 483               | ...               |
| 0.090 .....                               | 621                                       | 732              | 688               | ...               |
| 0.100 .....                               | 682                                       | 874              | 888               | ...               |
| 0.125 .....                               | 833                                       | 1060             | 1300              | 1355              |
| 0.160 .....                               | 863                                       | 1325             | 1615              | 2225              |
| 0.190 .....                               | ...                                       | 1340             | 1885              | 2585              |
| 0.250 .....                               | ...                                       | ...              | 1920              | 3300              |
| 0.312 .....                               | ...                                       | ...              | ...               | 3400              |
| Head height (ref.), in. ....              | 0.042                                     | 0.055            | 0.070             | 0.095             |

a Data supplied by Cherry Fasteners.

b Allowable loads developed from test with nominal hole diameters as listed.

c Yield value is less than 2/3 of the indicated ultimate strength value.

d Fastener shear strength based upon nominal hole diameters and  $F_{su} = 65$  ksi from data analysis.

e Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

**Table 8.1.3.2.2(m). Static Joint Strength of Blind 100° Flush Head Locked Spindle Aluminum Alloy (7050) Rivets in Machine-Countersunk Aluminum Alloy Sheet**

|                                                                                                                                                                                          |                                                                |                  |                  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|------------------|------------------|
| Rivet Type .....                                                                                                                                                                         | NAS1721KE and NAS1721KE ( )L <sup>a</sup> ( $F_{su}$ = 33 ksi) |                  |                  |
| Sheet Material .....                                                                                                                                                                     | Clad 2024-T3                                                   |                  |                  |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) <sup>b</sup> ..                                                                                                                 | 1/8<br>(0.130)                                                 | 5/32<br>(0.162)  | 3/16<br>(0.194)  |
| Sheet thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>Rivet shear strength <sup>e</sup> ..... | Ultimate Strength, lbs.                                        |                  |                  |
|                                                                                                                                                                                          | 221 <sup>d</sup>                                               | ...              | ...              |
|                                                                                                                                                                                          | 277 <sup>d</sup>                                               | 342 <sup>d</sup> | ...              |
|                                                                                                                                                                                          | 351                                                            | 435 <sup>d</sup> | 518 <sup>d</sup> |
|                                                                                                                                                                                          | 396                                                            | 491 <sup>d</sup> | 586 <sup>d</sup> |
|                                                                                                                                                                                          | 448                                                            | 555              | 662 <sup>d</sup> |
|                                                                                                                                                                                          | 450                                                            | 626              | 747              |
|                                                                                                                                                                                          | ...                                                            | 697              | 832              |
|                                                                                                                                                                                          | ...                                                            | 700              | 950              |
|                                                                                                                                                                                          | 450                                                            | 700              | 950              |
| Sheet thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....                                            | Yield Strength <sup>f</sup> , lbs.                             |                  |                  |
|                                                                                                                                                                                          | 62                                                             | ...              | ...              |
|                                                                                                                                                                                          | 150                                                            | 99               | ...              |
|                                                                                                                                                                                          | 263                                                            | 240              | 182              |
|                                                                                                                                                                                          | 333                                                            | 327              | 287              |
|                                                                                                                                                                                          | 386                                                            | 425              | 404              |
|                                                                                                                                                                                          | 403                                                            | 534              | 534              |
|                                                                                                                                                                                          | ...                                                            | 600              | 665              |
|                                                                                                                                                                                          | ...                                                            | 653              | 874              |
| Head height (ref.), in. ....                                                                                                                                                             | 0.042                                                          | 0.055            | 0.070            |

a Data supplied by Avdel Corp.  
b Loads developed from tests with hole diameters of 0.130, 0.162, and 0.194, ±0.001 inch.  
c The values in the table above the horizontal line in each column are for knife-edge conditions, and the use of fasteners in this condition is undesirable. The use of knife-edge conditions in the design of military aircraft requires the specific approval of the procuring agency.  
d Yield value is less than 2/3 of indicated ultimate value.  
e Rivet shear strength is documented in NAS1722.  
f Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

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**Table 8.1.3.2.2(n). Static Joint Strength of Blind 100° Flush Head Locked Spindle A-286 Rivets in Machine-Countersunk Aluminum Alloy Sheet**

|                                                                             |                                                             |                     |                      |
|-----------------------------------------------------------------------------|-------------------------------------------------------------|---------------------|----------------------|
| Rivet Type .....                                                            | NAS1721C and NAS1721C( )L <sup>a</sup> ( $F_{su} = 75$ ksi) |                     |                      |
| Sheet Material .....                                                        | Clad 7075-T6                                                |                     |                      |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) <sup>b</sup> ..... | 1/8<br>(0.130)                                              | 5/32<br>(0.162)     | 3/16<br>(0.194)      |
| Ultimate Strength, lbs.                                                     |                                                             |                     |                      |
| Sheet thickness, in.:                                                       |                                                             |                     |                      |
| 0.040 .....                                                                 | 454 <sup>c, d</sup>                                         | ...                 | ...                  |
| 0.050 .....                                                                 | 585 <sup>d</sup>                                            | 707 <sup>c, d</sup> | ...                  |
| 0.063 .....                                                                 | 751 <sup>d</sup>                                            | 919 <sup>d</sup>    | 1075 <sup>c, d</sup> |
| 0.071 .....                                                                 | 853 <sup>d</sup>                                            | 1045 <sup>d</sup>   | 1230 <sup>d</sup>    |
| 0.080 .....                                                                 | 881 <sup>d</sup>                                            | 1190 <sup>d</sup>   | 1405 <sup>d</sup>    |
| 0.090 .....                                                                 | 896                                                         | 1345 <sup>d</sup>   | 1595 <sup>d</sup>    |
| 0.100 .....                                                                 | 912                                                         | 1365 <sup>d</sup>   | 1785 <sup>d</sup>    |
| 0.125 .....                                                                 | 951                                                         | 1415                | 1970                 |
| 0.160 .....                                                                 | 1000                                                        | 1485                | 2055                 |
| 0.190 .....                                                                 | ...                                                         | 1500                | 2125                 |
| 0.250 .....                                                                 | ...                                                         | ...                 | 2200                 |
| Rivet shear strength <sup>e</sup> .....                                     | 1000                                                        | 1500                | 2200                 |
| Yield Strength <sup>f</sup> , lbs.                                          |                                                             |                     |                      |
| Sheet thickness, in.:                                                       |                                                             |                     |                      |
| 0.040 .....                                                                 | 77                                                          | ...                 | ...                  |
| 0.050 .....                                                                 | 220                                                         | 122                 | ...                  |
| 0.063 .....                                                                 | 375                                                         | 352                 | 246                  |
| 0.071 .....                                                                 | 470                                                         | 471                 | 425                  |
| 0.080 .....                                                                 | 578                                                         | 604                 | 585                  |
| 0.090 .....                                                                 | 615                                                         | 753                 | 763                  |
| 0.100 .....                                                                 | 641                                                         | 902                 | 942                  |
| 0.125 .....                                                                 | 707                                                         | 997                 | 1330                 |
| 0.160 .....                                                                 | 799                                                         | 1110                | 1470                 |
| 0.190 .....                                                                 | ...                                                         | 1210                | 1585                 |
| 0.250 .....                                                                 | ...                                                         | ...                 | 1820                 |
| Head height (ref.), in. ....                                                | 0.042                                                       | 0.055               | 0.070                |

a Data supplied by Avdel Corp.

b Loads developed from tests with hole diameters of 0.130, 0.162, and 0.194,  $\pm 0.001$  inch.

c The values in the table above the horizontal line in each column are for knife-edge conditions and the use of fasteners in this condition is undesirable. The use of knife-edge conditions in the design of military aircraft requires the specific approval of the procuring agency.

d Yield value is less than 2/3 of indicated ultimate value.

e Rivet shear strength is documented in NAS1722.

f Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).



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Table 8.1.3.2.2(q). Static Joint Strength of Blind Flush Head Locked Aluminum Alloy Rivets in Machine-Countersunk Aluminum Alloy Sheets

|                                                                        |                                                  |                    |                    |
|------------------------------------------------------------------------|--------------------------------------------------|--------------------|--------------------|
| Rivet Type .....                                                       | HC3212 ( $F_{su} = 51$ ksi approx.) <sup>a</sup> |                    |                    |
| Sheet Material .....                                                   | Clad 2024-T3                                     |                    |                    |
| Rivet Diameter, in.<br>(Nominal Hole Diameter, in.) <sup>b</sup> ..... | 1/8<br>(0.130)                                   | 5/32<br>(0.162)    | 3/16<br>(0.194)    |
| Ultimate Strength, lbs.                                                |                                                  |                    |                    |
| Sheet Thickness, in.:                                                  |                                                  |                    |                    |
| 0.040 .....                                                            | 280 <sup>c,d</sup>                               | ---                | ---                |
| 0.050 .....                                                            | 318                                              | 436 <sup>c,d</sup> | ---                |
| 0.063 .....                                                            | 367                                              | 497                | 643 <sup>c,d</sup> |
| 0.071 .....                                                            | 397                                              | 535                | 688                |
| 0.080 .....                                                            | 431                                              | 577                | 739                |
| 0.090 .....                                                            | 469                                              | 624                | 795                |
| 0.100 .....                                                            | 507                                              | 671                | 851                |
| 0.125 .....                                                            | 602                                              | 789                | 992                |
| 0.160 .....                                                            | 664                                              | 954                | 1190               |
| 0.190 .....                                                            | ---                                              | 1030               | 1355               |
| 0.250 .....                                                            | ---                                              | ---                | 1480               |
| Rivet Shear Strength <sup>e</sup> .....                                | 664                                              | 1030               | 1480               |
| Yield Strength, lbs <sup>f</sup>                                       |                                                  |                    |                    |
| Sheet Thickness, in.:                                                  |                                                  |                    |                    |
| 0.040 .....                                                            | 151                                              | ---                | ---                |
| 0.050 .....                                                            | 244                                              | 236                | ---                |
| 0.063 .....                                                            | 366                                              | 387                | 382                |
| 0.071 .....                                                            | 397                                              | 480                | 494                |
| 0.080 .....                                                            | 431                                              | 577                | 619                |
| 0.090 .....                                                            | 454                                              | 624                | 758                |
| 0.100 .....                                                            | 476                                              | 671                | 851                |
| 0.125 .....                                                            | 532                                              | 740                | 979                |
| 0.160 .....                                                            | 610                                              | 837                | 1095               |
| 0.190 .....                                                            | ---                                              | 921                | 1195               |
| 0.250 .....                                                            | ---                                              | ---                | 1395               |
| Head Height [ref.], in. ....                                           | 0.042                                            | 0.055              | 0.070              |

a Data supplied by Huck International Inc.  
b Loads developed from tests with hole diameters of 0.130, 0.162, and 0.194, +/- 0.001 inch.  
c The values in the table above the horizontal line in each column are for knife-edge conditions and the use of fasteners in this condition is undesirable. The use of knife-edge conditions in the design of military aircraft requires specific approval of the procuring activity.  
d Yield value is less than 2/3 of indicated ultimate strength value.  
e Rivet shear strength is documented on HC3212 standards drawing.  
f Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

**Table 8.1.3.2.2(r). Static Joint Strength of Blind 100° Flush Head Locked Spindle 2014 Aluminum Alloy Rivets in Machine Countersunk Aluminum Alloy Sheet**

|                                           |                                                             |         |         |
|-------------------------------------------|-------------------------------------------------------------|---------|---------|
| Rivet Type .....                          | MBC 4807 and 4907 ( $F_{su} = 33$ ksi approx.) <sup>a</sup> |         |         |
| Sheet Material .....                      | Clad 2024-T3                                                |         |         |
| Rivet Diameter, in. ....                  | 1/8                                                         | 5/32    | 3/16    |
| (Nominal Hole Diameter, in.) <sup>b</sup> | (0.130)                                                     | (0.162) | (0.194) |
| Sheet thickness, in.:                     | Ultimate Strength, lbs.                                     |         |         |
|                                           |                                                             |         |         |
|                                           | 0.040 .....                                                 | 183     | ...     |
|                                           | 0.050 .....                                                 | 243     | ...     |
|                                           | 0.063 .....                                                 | 320     | 437     |
|                                           | 0.071 .....                                                 | 368     | 508     |
|                                           | 0.080 .....                                                 | 412     | 588     |
|                                           | 0.090 .....                                                 | 435     | 677     |
|                                           | 0.100 .....                                                 | 450     | 766     |
|                                           | 0.125 .....                                                 | ...     | 937     |
|                                           | 0.160 .....                                                 | ...     | 950     |
| Rivet shear strength <sup>d</sup> .....   | 450                                                         | 700     | 950     |
| Sheet thickness, in.:                     | Yield Strength, lbs. <sup>e</sup>                           |         |         |
|                                           |                                                             |         |         |
|                                           | 0.040 .....                                                 | 102     | ...     |
|                                           | 0.050 .....                                                 | 173     | ...     |
|                                           | 0.063 .....                                                 | 264     | 263     |
|                                           | 0.071 .....                                                 | 309     | 347     |
|                                           | 0.080 .....                                                 | 333     | 441     |
|                                           | 0.090 .....                                                 | 360     | 546     |
|                                           | 0.100 .....                                                 | 387     | 651     |
|                                           | 0.125 .....                                                 | ...     | 765     |
|                                           | 0.160 .....                                                 | ...     | 904     |
| Head height (ref.), in. ....              | 0.041                                                       | 0.053   | 0.068   |

a A product of Avdel Systems Ltd.  
b Loads developed from tests with hole diameters of 0.130, 0.162, and 0.194, +/- 0.001 inch.  
c The values in the table above the horizontal line in each column are for knife-edge conditions, and the use of fasteners in this condition is undesirable. The use of knife-edge conditions in the design of military aircraft requires the specific approval of the procuring agency.  
d Rivet shear strength is documented in NAS 1722, and rivets meet the requirements of NAS 1721.  
e Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

Table 8.1.3.2.2(s). Static Joint Strength of Blind Protruding Head Locked Spindle Aluminum Alloy Rivets in Aluminum Alloy Sheet

|                                                                                                                                                                                                                                                                    |                                                             |                 |                 |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------|-----------------|-----------------|
| Rivet Type . . . . .                                                                                                                                                                                                                                               | MBC 4801 and 4901 ( $F_{su} = 33$ ksi approx.) <sup>a</sup> |                 |                 |
| Sheet Material . . . . .                                                                                                                                                                                                                                           | Clad 2024-T3                                                |                 |                 |
| Rivet Diameter, in. . . . .<br>(Nominal Hole Diameter, in.) <sup>b</sup> . .                                                                                                                                                                                       | 1/8<br>(0.130)                                              | 5/32<br>(0.162) | 3/16<br>(0.194) |
| Sheet thickness, in.:<br>0.025 . . . . .<br>0.032 . . . . .<br>0.040 . . . . .<br>0.050 . . . . .<br>0.063 . . . . .<br>0.071 . . . . .<br>0.080 . . . . .<br>0.090 . . . . .<br>0.100 . . . . .<br>0.125 . . . . .<br>Rivet shear strength <sup>c</sup> . . . . . | Ultimate Strength, lbs.                                     |                 |                 |
|                                                                                                                                                                                                                                                                    | 247                                                         | ...             | ...             |
|                                                                                                                                                                                                                                                                    | 284                                                         | 389             | ...             |
|                                                                                                                                                                                                                                                                    | 326                                                         | 441             | 571             |
|                                                                                                                                                                                                                                                                    | 378                                                         | 507             | 650             |
|                                                                                                                                                                                                                                                                    | 415                                                         | 589             | 751             |
|                                                                                                                                                                                                                                                                    | 437                                                         | 617             | 814             |
|                                                                                                                                                                                                                                                                    | 450                                                         | 649             | 864             |
|                                                                                                                                                                                                                                                                    | ...                                                         | 684             | 906             |
|                                                                                                                                                                                                                                                                    | ...                                                         | 700             | 948             |
|                                                                                                                                                                                                                                                                    | ...                                                         | ...             | 950             |
|                                                                                                                                                                                                                                                                    | 450                                                         | 700             | 950             |
| Sheet thickness, in.:<br>0.025 . . . . .<br>0.032 . . . . .<br>0.040 . . . . .<br>0.050 . . . . .<br>0.063 . . . . .<br>0.071 . . . . .<br>0.080 . . . . .<br>0.090 . . . . .<br>0.100 . . . . .<br>0.125 . . . . .                                                | Yield Strength, lbs. <sup>d</sup>                           |                 |                 |
|                                                                                                                                                                                                                                                                    | 238                                                         | ...             | ...             |
|                                                                                                                                                                                                                                                                    | 277                                                         | 375             | ...             |
|                                                                                                                                                                                                                                                                    | 321                                                         | 431             | 552             |
|                                                                                                                                                                                                                                                                    | 368                                                         | 500             | 635             |
|                                                                                                                                                                                                                                                                    | 381                                                         | 572             | 743             |
|                                                                                                                                                                                                                                                                    | 389                                                         | 583             | 810             |
|                                                                                                                                                                                                                                                                    | 399                                                         | 594             | 828             |
|                                                                                                                                                                                                                                                                    | ...                                                         | 607             | 843             |
|                                                                                                                                                                                                                                                                    | ...                                                         | 619             | 858             |
|                                                                                                                                                                                                                                                                    | ...                                                         | ...             | 896             |

a A product of Avdel Systems Ltd.  
b Loads developed from tests with hole diameters of 0.130, 0.162, and 0.194, ±0.001 inch.  
c Rivet shear strength is documented in NAS 1722, and rivets meet the requirements of NAS 1720.  
d Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

**Table 8.1.3.2.2(t). Static Joint Strength of Blind 100° Flush Head Locked Spindle Aluminum Alloy Blind Rivets in Machine-Countersunk Aluminum Alloy Sheet**

|                                                                                                                                                                                                                                           |                                                  |                  |                  |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------|------------------|------------------|
| Rivet Type .....                                                                                                                                                                                                                          | HC6222 <sup>a</sup> ( $F_{su} = 50$ ksi) Nominal |                  |                  |
| Sheet Material .....                                                                                                                                                                                                                      | Clad 2024-T3                                     |                  |                  |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) ...                                                                                                                                                                              | 1/8<br>(0.130)                                   | 5/32<br>(0.162)  | 3/16<br>(0.194)  |
| Sheet thickness, in.:<br><br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 .....<br>Rivet shear strength <sup>d</sup> ..... | Ultimate Strength, lbs                           |                  |                  |
|                                                                                                                                                                                                                                           | 270 <sup>c</sup>                                 | ...              | ...              |
|                                                                                                                                                                                                                                           | 317                                              | 420 <sup>c</sup> | ...              |
|                                                                                                                                                                                                                                           | 377                                              | 496              | 624 <sup>c</sup> |
|                                                                                                                                                                                                                                           | 414                                              | 542              | 680              |
|                                                                                                                                                                                                                                           | 456                                              | 594              | 743              |
|                                                                                                                                                                                                                                           | 503                                              | 652              | 812              |
|                                                                                                                                                                                                                                           | 550                                              | 711              | 882              |
|                                                                                                                                                                                                                                           | 664                                              | 856              | 1055             |
|                                                                                                                                                                                                                                           | ...                                              | 1030             | 1299             |
|                                                                                                                                                                                                                                           | ...                                              | ...              | 1480             |
|                                                                                                                                                                                                                                           | ...                                              | ...              | ...              |
|                                                                                                                                                                                                                                           | 664                                              | 1030             | 1480             |
|                                                                                                                                                                                                                                           | Yield Strength <sup>e</sup> , lbs                |                  |                  |
|                                                                                                                                                                                                                                           | 196                                              | 237 <sup>b</sup> | ...              |
|                                                                                                                                                                                                                                           | 252                                              | 306              | ...              |
|                                                                                                                                                                                                                                           | 323                                              | 395              | 464              |
|                                                                                                                                                                                                                                           | 368                                              | 451              | 530              |
|                                                                                                                                                                                                                                           | 417                                              | 512              | 605              |
|                                                                                                                                                                                                                                           | 445                                              | 581              | 687              |
|                                                                                                                                                                                                                                           | 459                                              | 650              | 770              |
|                                                                                                                                                                                                                                           | 494                                              | 714              | 972              |
|                                                                                                                                                                                                                                           | ...                                              | 775              | 1045             |
|                                                                                                                                                                                                                                           | ...                                              | ...              | 1108             |
|                                                                                                                                                                                                                                           | ...                                              | ...              | ...              |
| Head height (ref.), in. ....                                                                                                                                                                                                              | 0.042                                            | 0.055            | 0.070            |

a Data supplied by Huck International, Inc.  
b Yield value is less than 2/3 of the indicated ultimate.  
c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
d Rivet shear strength is documented in MIL-R-7885D.  
e Permanent set at yield load: 4% of nominal hole diameter (see 9.4.1.3.3).

**Table 8.1.3.2.2(u). Static Joint Strength of Blind 100° Flush Head Locked Spindle Aluminum Alloy Blind Rivets in Machine-Countersunk Aluminum Alloy Sheet**

|                                                             |                                          |                    |                  |
|-------------------------------------------------------------|------------------------------------------|--------------------|------------------|
| Rivet Type .....                                            | HC6252 <sup>a</sup> ( $F_{su} = 50$ ksi) |                    |                  |
| Sheet Material .....                                        | Clad 2024-T3                             |                    |                  |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) .. | 1/8<br>(0.144)                           | 5/32<br>(0.178)    | 3/16<br>(0.207)  |
| Ultimate Strength, lbs                                      |                                          |                    |                  |
| Sheet thickness, in.:                                       |                                          |                    |                  |
| 0.032 .....                                                 | 265 <sup>b,c</sup>                       | ...                | ...              |
| 0.040 .....                                                 | 304                                      | 408 <sup>b,c</sup> | ...              |
| 0.050 .....                                                 | 352                                      | 467                | ...              |
| 0.063 .....                                                 | 414                                      | 544                | 665 <sup>c</sup> |
| 0.071 .....                                                 | 452                                      | 591                | 720              |
| 0.080 .....                                                 | 495                                      | 645                | 782              |
| 0.090 .....                                                 | 543                                      | 704                | 851              |
| 0.100 .....                                                 | 591                                      | 763                | 920              |
| 0.125 .....                                                 | 701                                      | 911                | 1092             |
| 0.160 .....                                                 | 814                                      | 1097               | 1332             |
| 0.190 .....                                                 | ...                                      | 1237               | 1505             |
| 0.250 .....                                                 | ...                                      | 1245               | 1685             |
| Rivet shear strength <sup>d</sup> .....                     | 814                                      | 1245               | 1685             |
| Yield Strength <sup>e</sup> , lbs                           |                                          |                    |                  |
| Sheet thickness, in.:                                       |                                          |                    |                  |
| 0.032 .....                                                 | 154                                      | ...                | ...              |
| 0.040 .....                                                 | 214                                      | 240                | ...              |
| 0.050 .....                                                 | 288                                      | 332                | ...              |
| 0.063 .....                                                 | 384                                      | 451                | 500              |
| 0.071 .....                                                 | 444                                      | 524                | 586              |
| 0.080 .....                                                 | 494                                      | 607                | 682              |
| 0.090 .....                                                 | 513                                      | 698                | 788              |
| 0.100 .....                                                 | 531                                      | 758                | 895              |
| 0.125 .....                                                 | 576                                      | 814                | 1048             |
| 0.160 .....                                                 | 640                                      | 893                | 1139             |
| 0.190 .....                                                 | ...                                      | 961                | 1218             |
| 0.250 .....                                                 | ...                                      | 1096               | 1376             |
| Head height (ref.), in. ....                                | 0.035                                    | 0.047              | 0.063            |

a Data supplied by Huck International, Inc.  
b Yield value is less than 2/3 of the indicated ultimate.  
c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring activity.  
d Rivet shear strength is documented in MIL-R-7885D.  
e Permanent set at yield load: 4% of nominal hole diameter (see 9.4.1.3.3).

**Table 8.1.3.2.2(v). Static Joint Strength of 100° Flush Shear Head Locked Spindle Aluminum Alloy Blind Rivets in Machine-Countersunk Aluminum Alloy Sheet**

|                                                                                                                                                                                                                                       |                                                        |                  |                  |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|------------------|------------------|
| Rivet Type .....                                                                                                                                                                                                                      | HC6224 <sup>a</sup> (F <sub>su</sub> = 50 ksi) Nominal |                  |                  |
| Sheet Material .....                                                                                                                                                                                                                  | Clad 2024-T3                                           |                  |                  |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) ..                                                                                                                                                                           | 1/8<br>(0.130)                                         | 5/32<br>(0.162)  | 3/16<br>(0.194)  |
| Sheet thickness, in.:<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>Rivet shear strength <sup>d</sup> ..... | Ultimate Strength, lbs                                 |                  |                  |
|                                                                                                                                                                                                                                       | 230                                                    | 294 <sup>c</sup> | 437 <sup>c</sup> |
|                                                                                                                                                                                                                                       |                                                        | 358              |                  |
|                                                                                                                                                                                                                                       | 282                                                    | 439              | 534              |
|                                                                                                                                                                                                                                       | 347                                                    | 544              | 660              |
|                                                                                                                                                                                                                                       | 431                                                    | 608              | 737              |
|                                                                                                                                                                                                                                       | 456                                                    | 681              | 824              |
|                                                                                                                                                                                                                                       | 493                                                    | 716              | 921              |
|                                                                                                                                                                                                                                       | 535                                                    | 768              | 979              |
|                                                                                                                                                                                                                                       | 576                                                    | 897              | 1135             |
|                                                                                                                                                                                                                                       | 664                                                    | 1030             | 1350             |
|                                                                                                                                                                                                                                       | ...                                                    | ...              | 1480             |
|                                                                                                                                                                                                                                       | ...                                                    | ...              | 1480             |
|                                                                                                                                                                                                                                       | 664                                                    | 1030             | 1480             |
| Sheet thickness, in.:<br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....                                            | Yield Strength <sup>e</sup> , lbs                      |                  |                  |
|                                                                                                                                                                                                                                       | 185                                                    | 209              | 320              |
|                                                                                                                                                                                                                                       | 248                                                    | 288              |                  |
|                                                                                                                                                                                                                                       | 328                                                    | 387              | 438              |
|                                                                                                                                                                                                                                       | 431                                                    | 516              | 592              |
|                                                                                                                                                                                                                                       | 448                                                    | 595              | 687              |
|                                                                                                                                                                                                                                       | 457                                                    | 681              | 794              |
|                                                                                                                                                                                                                                       | 467                                                    | 697              | 912              |
|                                                                                                                                                                                                                                       | 477                                                    | 710              | 979              |
|                                                                                                                                                                                                                                       | 503                                                    | 742              | 1030             |
|                                                                                                                                                                                                                                       | ...                                                    | 786              | 1080             |
|                                                                                                                                                                                                                                       | ...                                                    | ...              | 1125             |
| Head height (ref.), in. ....                                                                                                                                                                                                          | 0.028                                                  | 0.037            | 0.046            |

a Data supplied by Huck International, Inc.  
b Yield value is less than 2/3 of the indicated ultimate.  
c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring activity.  
d Rivet shear strength is documented in MIL-R-7885D.  
e Permanent set at yield load: 4% of nominal hole diameter (see 9.4.1.3.3).

Table 8.1.3.2.2(w). Static Joint Strength of Blind Flush Head Locked Spindle Aluminum Alloy Rivets in Machine-Countersunk Aluminum Alloy Sheets

|                                                                                                                                                                                                |                                                        |                  |                  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|------------------|------------------|
| Rivet Type .....                                                                                                                                                                               | AF3212 (F <sub>su</sub> = 51 ksi approx.) <sup>a</sup> |                  |                  |
| Sheet Material .....                                                                                                                                                                           | Clad 2024-T3                                           |                  |                  |
| Rivet Diameter, in.<br>(Nominal Hole Diameter, in.) <sup>b</sup> .....                                                                                                                         | 1/8<br>(0.130)                                         | 5/32<br>(0.162)  | 3/16<br>(0.194)  |
| Sheet Thickness, in.:<br><br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 ..... | Ultimate Strength, lbs.                                |                  |                  |
|                                                                                                                                                                                                | 143 <sup>c</sup>                                       | ---              | ---              |
|                                                                                                                                                                                                | 247                                                    | 224 <sup>c</sup> | ---              |
|                                                                                                                                                                                                | 383                                                    | 393              | 370 <sup>c</sup> |
|                                                                                                                                                                                                | 414                                                    | 497              | 494              |
|                                                                                                                                                                                                | 435                                                    | 614              | 634              |
|                                                                                                                                                                                                | 457                                                    | 647              | 790              |
|                                                                                                                                                                                                | 480                                                    | 676              | 902              |
|                                                                                                                                                                                                | 537                                                    | 746              | 987              |
|                                                                                                                                                                                                | 616                                                    | 846              | 1105             |
|                                                                                                                                                                                                | ---                                                    | 931              | 1205             |
|                                                                                                                                                                                                | ---                                                    | ---              | 1410             |

THIS FASTENER HAS ONLY BEEN TESTED IN THE SHEET GAGES SHOWN IN THIS TABLE. DESIGN DATA FOR SHEET GAGES OR DIAMETERS OTHER THAN THOSE SHOWN HERE CANNOT BE EXTRAPOLATED.

|                                                                                                                                                                                                |                                  |       |       |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|-------|-------|
| Rivet Shear Strength <sup>d</sup> .....                                                                                                                                                        | 664                              | 1030  | 1480  |
| Sheet Thickness, in.:<br><br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 ..... | Yield Strength, lbs <sup>e</sup> |       |       |
|                                                                                                                                                                                                | 143                              | ---   | ---   |
|                                                                                                                                                                                                | 235                              | 224   | ---   |
|                                                                                                                                                                                                | 310                              | 371   | 370   |
|                                                                                                                                                                                                | 330                              | 431   | 491   |
|                                                                                                                                                                                                | 353                              | 486   | 572   |
|                                                                                                                                                                                                | 379                              | 518   | 662   |
|                                                                                                                                                                                                | 404                              | 549   | 713   |
|                                                                                                                                                                                                | 468                              | 629   | 808   |
|                                                                                                                                                                                                | 557                              | 740   | 914   |
|                                                                                                                                                                                                | ---                              | 835   | 1055  |
|                                                                                                                                                                                                | ---                              | ---   | 1280  |
| Head Height [ref.], in. ....                                                                                                                                                                   | 0.042                            | 0.055 | 0.070 |

a Data supplied by Allfast Fastening Systems Inc.  
b Loads developed from tests with hole diameters of 0.130, 0.162, and 0.194, +/- 0.001 inch.  
c The values in the table above the horizontal line in each column are for knife-edge conditions, and the use of fasteners in this condition is undesirable. The use of knife-edge conditions in the design of military aircraft requires specific approval of the procuring activity.  
d Rivet shear strength is documented on AF3212 standards drawing.  
e Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

Table 8.1.3.2.2(x). Static Joint Strength of Blind Flush Head Locked Spindle Aluminum Alloy Rivets in Machine-Countersunk Aluminum Alloy Sheet

|                                                                                                                                                   |                                                  |                  |                  |
|---------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------|------------------|------------------|
| Rivet Type .....                                                                                                                                  | CR3212 ( $F_{su} = 51$ ksi approx.) <sup>a</sup> |                  |                  |
| Sheet Material .....                                                                                                                              | Clad 2024-T3                                     |                  |                  |
| Rivet Diameter, in.<br>(Nominal Hole Diameter, in.) <sup>b</sup> .....                                                                            | 1/8<br>(0.130)                                   | 5/32<br>(0.162)  | 3/16<br>(0.194)  |
| Sheet Thickness, in.:<br><br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 ..... | Ultimate Strength, lbs.                          |                  |                  |
|                                                                                                                                                   | 297 <sup>c,d</sup>                               | ---              | ---              |
|                                                                                                                                                   | 342 <sup>d</sup>                                 | 462 <sup>d</sup> | ---              |
|                                                                                                                                                   | 401 <sup>d</sup>                                 | 535 <sup>d</sup> | 683 <sup>d</sup> |
|                                                                                                                                                   | 437 <sup>d</sup>                                 | 580 <sup>d</sup> | 737 <sup>d</sup> |
|                                                                                                                                                   | 477                                              | 630 <sup>d</sup> | 798 <sup>d</sup> |
|                                                                                                                                                   | 513                                              | 687 <sup>d</sup> | 865 <sup>d</sup> |
|                                                                                                                                                   | 536                                              | 743              | 932              |
|                                                                                                                                                   | 594                                              | 834              | 1100             |

THIS FASTENER HAS ONLY BEEN TESTED IN THE SHEET GAGES SHOWN IN THIS TABLE. DESIGN DATA FOR SHEET GAGES OR DIAMETERS OTHER THAN THOSE SHOWN HERE CANNOT BE EXTRAPOLATED.

|                                                                                                                                                   |                                  |       |       |
|---------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|-------|-------|
| Rivet Shear Strength <sup>e</sup> .....                                                                                                           | 664                              | 1030  | 1480  |
| Sheet Thickness, in.:<br><br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 ..... | Yield Strength, lbs <sup>f</sup> |       |       |
|                                                                                                                                                   | 131                              | ---   | ---   |
|                                                                                                                                                   | 181                              | 204   | ---   |
|                                                                                                                                                   | 247                              | 286   | 317   |
|                                                                                                                                                   | 287                              | 336   | 377   |
|                                                                                                                                                   | 333                              | 393   | 444   |
|                                                                                                                                                   | 361                              | 456   | 520   |
|                                                                                                                                                   | 371                              | 518   | 595   |
|                                                                                                                                                   | 394                              | 576   | 783   |
| Head Height [ref.], in. ....                                                                                                                      | 0.042                            | 0.055 | 0.070 |

a Data supplied by Textron Aerospace Fasteners.  
b Loads developed from tests with hole diameters of 0.130, 0.162, and 0.194, +/- 0.001 inch.  
c The values in the table above the horizontal line in each column are for knife-edge conditions, and the use of fasteners in this condition is undesirable. The use of knife-edge conditions in the design of military aircraft requires specific approval of the procuring activity.  
d Yield value is less than 2/3 of indicated ultimate strength value.  
e Rivet shear strength is documented on CR3212 standards drawing.  
f Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).



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Table 8.1.3.2.2(y). Static Joint Strength of Blind Flush Head Locked Spindle Aluminum Alloy Rivets in Machine-Countersunk Aluminum Alloy Sheet

|                                                                                                                                                                                                |                                                        |                  |                  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|------------------|------------------|
| Rivet Type .....                                                                                                                                                                               | AF3242 (F <sub>su</sub> = 51 ksi approx.) <sup>a</sup> |                  |                  |
| Sheet Material .....                                                                                                                                                                           | Clad 2024-T3                                           |                  |                  |
| Rivet Diameter, in.<br>(Nominal Hole Diameter, in.) <sup>b</sup> .....                                                                                                                         | 1/8<br>(0.144)                                         | 5/32<br>(0.178)  | 3/16<br>(0.207)  |
| Sheet Thickness, in.:<br><br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 ..... | Ultimate Strength, lbs.                                |                  |                  |
|                                                                                                                                                                                                | 193 <sup>c</sup>                                       | ---              | ---              |
|                                                                                                                                                                                                | 250                                                    | 299 <sup>c</sup> | ---              |
|                                                                                                                                                                                                | 321                                                    | 387              | ---              |
|                                                                                                                                                                                                | 414                                                    | 501              | 573 <sup>c</sup> |
|                                                                                                                                                                                                | 470                                                    | 571              | 654              |
|                                                                                                                                                                                                | 524                                                    | 651              | 746              |
|                                                                                                                                                                                                | 550                                                    | 738              | 849              |
|                                                                                                                                                                                                | 577                                                    | 804              | 951              |
|                                                                                                                                                                                                | 643                                                    | 886              | 1120             |
|                                                                                                                                                                                                | 736                                                    | 1000             | 1250             |
|                                                                                                                                                                                                | 814                                                    | ---              | 1365             |
| THIS FASTENER HAS ONLY BEEN TESTED IN THE SHEET GAGES SHOWN IN THIS TABLE. DESIGN DATA FOR SHEET GAGES OR DIAMETERS OTHER THAN THOSE SHOWN HERE CANNOT BE EXTRAPOLATED.                        |                                                        |                  |                  |
| Rivet Shear Strength <sup>d</sup> .....                                                                                                                                                        | 814                                                    | 1245             | 1685             |
| Sheet Thickness, in.:<br><br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 ..... | Yield Strength, lbs <sup>e</sup>                       |                  |                  |
|                                                                                                                                                                                                | 192                                                    | ---              | ---              |
|                                                                                                                                                                                                | 250                                                    | 298              | ---              |
|                                                                                                                                                                                                | 321                                                    | 387              | ---              |
|                                                                                                                                                                                                | 414                                                    | 501              | 573              |
|                                                                                                                                                                                                | 470                                                    | 571              | 654              |
|                                                                                                                                                                                                | 524                                                    | 651              | 746              |
|                                                                                                                                                                                                | 550                                                    | 738              | 849              |
|                                                                                                                                                                                                | 577                                                    | 804              | 951              |
|                                                                                                                                                                                                | 643                                                    | 886              | 1120             |
|                                                                                                                                                                                                | 736                                                    | 1000             | 1250             |
|                                                                                                                                                                                                | 814                                                    | ---              | 1365             |
| Head Height (ref.), in.                                                                                                                                                                        | 0.035                                                  | 0.047            | 0.063            |

a Data supplied by Allfast Fastening Systems Inc.  
b Loads developed from tests with hole diameters of 0.144, 0.178, and 0.207, +/-0.001 inch.  
c The values in the table above the horizontal line in each column are for knife-edge conditions, and the use of fasteners in this condition is undesirable. The use of knife-edge conditions in the design of military aircraft requires the specific approval of the procuring activity.  
d Rivet shear strength is documented on AF3242 standards drawing.  
e Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

Table 8.1.3.2.2(z). Static Joint Strength of Blind Flush Head Locked Spindle Aluminum Alloy Rivets in Machine-Countersunk Aluminum Alloy Sheet

|                                                                                                                                                                  |                                                        |                    |                  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|--------------------|------------------|
| Rivet Type .....                                                                                                                                                 | CR3242 (F <sub>su</sub> = 51 ksi approx.) <sup>a</sup> |                    |                  |
| Sheet Material .....                                                                                                                                             | Clad 2024-T3                                           |                    |                  |
| Rivet Diameter, in.<br>(Nominal Hole Diameter, in.) <sup>b</sup> .....                                                                                           | 1/8<br>(0.144)                                         | 5/32<br>(0.178)    | 3/16<br>(0.207)  |
| Sheet Thickness, in.:<br><br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 ..... | Ultimate Strength, lbs.                                |                    |                  |
|                                                                                                                                                                  | 245 <sup>c,d</sup>                                     | ---                | ---              |
|                                                                                                                                                                  | 302                                                    | 378 <sup>c,d</sup> | ---              |
|                                                                                                                                                                  | 374                                                    | 467                | ---              |
|                                                                                                                                                                  | 467                                                    | 582                | 681 <sup>c</sup> |
|                                                                                                                                                                  | 568                                                    | 653                | 764              |
|                                                                                                                                                                  | 584                                                    | 732                | 856              |
|                                                                                                                                                                  | 602                                                    | 872                | 959              |
|                                                                                                                                                                  | 620                                                    | 894                | 1165             |
|                                                                                                                                                                  | 664                                                    | 950                | 1230             |

THIS FASTENER HAS ONLY BEEN TESTED IN THE SHEET GAGES SHOWN IN THIS TABLE. DESIGN DATA FOR SHEET GAGES OR DIAMETERS OTHER THAN THOSE SHOWN HERE CANNOT BE EXTRAPOLATED.

|                                                                                                                                                                  |                                  |       |       |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|-------|-------|
| Rivet Shear Strength <sup>e</sup> .....                                                                                                                          | 814                              | 1245  | 1685  |
| Sheet Thickness, in.:<br><br>0.032 .....<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 ..... | Yield Strength, lbs <sup>f</sup> |       |       |
|                                                                                                                                                                  | 158                              | ---   | ---   |
|                                                                                                                                                                  | 206                              | 245   | ---   |
|                                                                                                                                                                  | 265                              | 318   | ---   |
|                                                                                                                                                                  | 330                              | 413   | 472   |
|                                                                                                                                                                  | 361                              | 471   | 540   |
|                                                                                                                                                                  | 395                              | 514   | 616   |
|                                                                                                                                                                  | 434                              | 562   | 678   |
|                                                                                                                                                                  | 473                              | 609   | 734   |
|                                                                                                                                                                  | 569                              | 729   | 873   |
| Head Height (ref.), in. ....                                                                                                                                     | 0.035                            | 0.047 | 0.063 |

a Data supplied by Textron Aerospace Fasteners.  
b Loads developed from tests with hole diameters of 0.144, 0.178, and 0.207, +/-0.001 inch.  
c The values in the table above the horizontal line in each column are for knife-edge conditions, and the use of fasteners in this condition is undesirable. The use of knife-edge conditions in the design of military aircraft requires the specific approval of the procuring activity.  
d Yield value is less than 2/3 of indicated ultimate strength value.  
e Rivet shear strength is documented on CR3242 standards drawing.  
f Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

Table 8.1.3.2.2(aa). Static Joint Strength of Blind Flush Head Locked Spindle Aluminum Alloy Rivets in Machine-Countersunk Aluminum Alloy Sheet

| Rivet Type .....                                                      |             | HC3242 (F <sub>su</sub> = 51 ksi approx.) <sup>a</sup> |                    |                  |
|-----------------------------------------------------------------------|-------------|--------------------------------------------------------|--------------------|------------------|
| Sheet Material .....                                                  |             | Clad 2024-T3                                           |                    |                  |
| Rivet Diameter, in.<br>(Nominal Hole Diameter, in. <sup>b</sup> ..... |             | 1/8<br>(0.144)                                         | 5/32<br>(0.178)    | 3/16<br>(0.207)  |
|                                                                       |             | Ultimate Strength, lbs.                                |                    |                  |
| Sheet Thickness, in.:                                                 | 0.032 ..... | 267 <sup>c,d</sup>                                     | ---                | ---              |
|                                                                       | 0.040 ..... | 310                                                    | 411 <sup>c,d</sup> | ---              |
|                                                                       | 0.050 ..... | 363                                                    | 477                | ---              |
|                                                                       | 0.063 ..... | 433                                                    | 563                | 682 <sup>c</sup> |
|                                                                       | 0.071 ..... | 475                                                    | 616                | 744              |
|                                                                       | 0.080 ..... | 522                                                    | 675                | 813              |
|                                                                       | 0.090 ..... | 560                                                    | 741                | 889              |
|                                                                       | 0.100 ..... | 597                                                    | 803                | 966              |
|                                                                       | 0.125 ..... | 690                                                    | 918                | 1130             |
|                                                                       | 0.160 ..... | 814                                                    | 1075               | 1320             |
|                                                                       | 0.190 ..... | ---                                                    | 1215               | 1480             |
|                                                                       | 0.250 ..... | ---                                                    | ---                | 1685             |

THIS FASTENER HAS ONLY BEEN TESTED IN THE SHEET GAGES SHOWN IN THIS TABLE. DESIGN DATA FOR SHEET GAGES OR DIAMETERS OTHER THAN THOSE SHOWN HERE CANNOT BE EXTRAPOLATED.

| Rivet Shear Strength <sup>e</sup> ..... |             | 814                              | 1245  | 1685  |
|-----------------------------------------|-------------|----------------------------------|-------|-------|
|                                         |             | Yield Strength, lbs <sup>f</sup> |       |       |
| Sheet Thickness, in.:                   | 0.032 ..... | 138                              | ---   | ---   |
|                                         | 0.040 ..... | 218                              | 217   | ---   |
|                                         | 0.050 ..... | 317                              | 340   | ---   |
|                                         | 0.063 ..... | 433                              | 500   | 529   |
|                                         | 0.071 ..... | 475                              | 598   | 643   |
|                                         | 0.080 ..... | 510                              | 675   | 772   |
|                                         | 0.090 ..... | 527                              | 741   | 889   |
|                                         | 0.100 ..... | 543                              | 781   | 966   |
|                                         | 0.125 ..... | 585                              | 833   | 1075  |
|                                         | 0.160 ..... | 644                              | 906   | 1160  |
|                                         | 0.190 ..... | ---                              | 968   | 1235  |
|                                         | 0.250 ..... | ---                              | ---   | 1375  |
| Head Height (ref.), in. ....            |             | 0.035                            | 0.047 | 0.063 |

a Data supplied by Huck International Inc.  
b Loads developed from tests with hole diameters of 0.144, 0.178, and 0.207, +/-0.001 inch.  
c The values in the table above the horizontal line in each column are for knife-edge conditions, and the use of fasteners in this condition is undesirable. The use of knife-edge conditions in the design of military aircraft requires the specific approval of the procuring activity.  
d Yield value is less than 2/3 of indicated ultimate strength value.  
e Rivet shear strength is documented on HC3242 standards drawing.  
f Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

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**Table 8.1.3.2.2(bb). Static Joint Strength of Blind Flush Head Locked Spindle Aluminum Alloy Rivets in Aluminum Alloy Sheet**

|                                                                                                                                                                                            |                                                        |                  |                  |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|------------------|------------------|
| Rivet Type .....                                                                                                                                                                           | AF3222 (F <sub>su</sub> = 50 ksi approx.) <sup>a</sup> |                  |                  |
| Sheet Material .....                                                                                                                                                                       | Clad 2024-T3                                           |                  |                  |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) <sup>b</sup> .....                                                                                                                | 1/8<br>(0.130)                                         | 5/32<br>(0.162)  | 3/16<br>(0.194)  |
| Sheet thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 ..... | Ultimate Strength, lbs.                                |                  |                  |
|                                                                                                                                                                                            | 202 <sup>c</sup>                                       | ...              | ...              |
|                                                                                                                                                                                            | 287                                                    | 316 <sup>c</sup> | ...              |
|                                                                                                                                                                                            | 388                                                    | 452              | 492 <sup>c</sup> |
|                                                                                                                                                                                            | 412                                                    | 536              | 593              |
|                                                                                                                                                                                            | 439                                                    | 608              | 706              |
|                                                                                                                                                                                            | 469                                                    | 645              | 832              |
|                                                                                                                                                                                            | 498                                                    | 683              | 891              |
|                                                                                                                                                                                            | 573                                                    | 775              | 1000             |
|                                                                                                                                                                                            | 664                                                    | 905              | 1155             |
|                                                                                                                                                                                            | ...                                                    | 1015             | 1290             |
|                                                                                                                                                                                            | ...                                                    | 1030             | 1480             |
|                                                                                                                                                                                            | 664                                                    | 1030             | 1480             |
| Rivet shear strength <sup>d</sup> .....                                                                                                                                                    | 664                                                    | 1030             | 1480             |
| Sheet thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 ..... | Yield Strength <sup>e</sup> , lbs.                     |                  |                  |
|                                                                                                                                                                                            | 160                                                    | ...              | ...              |
|                                                                                                                                                                                            | 216                                                    | 249              | ...              |
|                                                                                                                                                                                            | 290                                                    | 341              | 383              |
|                                                                                                                                                                                            | 335                                                    | 397              | 451              |
|                                                                                                                                                                                            | 379                                                    | 460              | 527              |
|                                                                                                                                                                                            | 421                                                    | 531              | 611              |
|                                                                                                                                                                                            | 462                                                    | 591              | 696              |
|                                                                                                                                                                                            | 566                                                    | 720              | 880              |
|                                                                                                                                                                                            | 664                                                    | 901              | 1095             |
|                                                                                                                                                                                            | ...                                                    | 1015             | 1280             |
|                                                                                                                                                                                            | ...                                                    | 1030             | 1480             |
| Head height (ref.), in. ....                                                                                                                                                               | 0.042                                                  | 0.055            | 0.070            |

a Data supplied by Allfast Fastening Systems Inc.  
b Loads developed from tests with hole diameters of 0.130, 0.162, and 0.194, +/- 0.001 inch.  
c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in the design of military aircraft requires specific approval of the procuring agency.  
d Rivet shear strength as documented in Allfast Fastening Systems Inc. P-127.  
e Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

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Table 8.1.3.2.2(cc). Static Joint Strength of Flush Head 5056 Aluminum Alloy Rivets in Clad Aluminum Alloy Sheet

|                                                                                                                                                                                            |                                                        |                    |                    |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|--------------------|--------------------|
| Rivet Type .....                                                                                                                                                                           | CR3222 (F <sub>su</sub> = 50 ksi approx.) <sup>a</sup> |                    |                    |
| Sheet Material .....                                                                                                                                                                       | Clad 2024-T3                                           |                    |                    |
| Rivet Diameter, in. ....<br>(Nominal Hole Diameter, in.) <sup>b</sup> .....                                                                                                                | 1/8<br>(0.130)                                         | 5/32<br>(0.162)    | 3/16<br>(0.194)    |
| Sheet thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 ..... | Ultimate Strength, lbs.                                |                    |                    |
|                                                                                                                                                                                            | 286 <sup>c,d</sup>                                     | ...                | ...                |
|                                                                                                                                                                                            | 328 <sup>d</sup>                                       | 445 <sup>c,d</sup> | ...                |
|                                                                                                                                                                                            | 382 <sup>d</sup>                                       | 513 <sup>d</sup>   | 658 <sup>c,d</sup> |
|                                                                                                                                                                                            | 416                                                    | 555 <sup>d</sup>   | 708 <sup>d</sup>   |
|                                                                                                                                                                                            | 454                                                    | 602 <sup>d</sup>   | 764 <sup>d</sup>   |
|                                                                                                                                                                                            | 496                                                    | 654                | 827 <sup>d</sup>   |
|                                                                                                                                                                                            | 528                                                    | 706                | 889                |
|                                                                                                                                                                                            | 589                                                    | 821                | 1045               |
|                                                                                                                                                                                            | 664                                                    | 928                | 1215               |
|                                                                                                                                                                                            | ...                                                    | 1020               | 1325               |
|                                                                                                                                                                                            | ...                                                    | 1030               | 1480               |
| Rivet shear strength <sup>e</sup> .....                                                                                                                                                    | 664                                                    | 1030               | 1480               |
| Sheet thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 ..... | Yield Strength <sup>f</sup> , lbs.                     |                    |                    |
|                                                                                                                                                                                            | 158                                                    | ...                | ...                |
|                                                                                                                                                                                            | 199                                                    | 247                | ...                |
|                                                                                                                                                                                            | 252                                                    | 313                | 373                |
|                                                                                                                                                                                            | 285                                                    | 354                | 422                |
|                                                                                                                                                                                            | 322                                                    | 399                | 476                |
|                                                                                                                                                                                            | 362                                                    | 450                | 537                |
|                                                                                                                                                                                            | 384                                                    | 501                | 598                |
|                                                                                                                                                                                            | 425                                                    | 597                | 750                |
|                                                                                                                                                                                            | 483                                                    | 669                | 881                |
|                                                                                                                                                                                            | ...                                                    | 731                | 955                |
|                                                                                                                                                                                            | ...                                                    | 854                | 1100               |
| Head height (ref.), in. ....                                                                                                                                                               | 0.041                                                  | 0.054              | 0.069              |

a Data supplied by Textron Aerospace Fasteners.  
b Loads developed from tests with hole diameters of 0.130, 0.162, and 0.194, +/- 0.0005 inch.  
c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in the design of military aircraft requires the specific approval of the procuring agency.  
d Yield values is less than 2/3 of indicated ultimate strength value.  
e Rivet shear strength as documented in Textron Aerospace Fasteners PS-CMR-3000.  
f Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

Table 8.1.3.2.3(a). Static Joint Strength of Blind 100° Flush Head A-286 Bolts in Machine-Countersunk Aluminum Alloy Sheet and Plate

|                                                                 |                                           |                                |                   |                                |                                |
|-----------------------------------------------------------------|-------------------------------------------|--------------------------------|-------------------|--------------------------------|--------------------------------|
| Fastener Type . . . . .                                         | MS21140 <sup>a</sup> ( $F_{su}$ = 95 ksi) |                                |                   |                                |                                |
| Sheet and Plate Material . . . . .                              | Clad 7075-T6 and T651                     |                                |                   |                                |                                |
| Fastener Diameter, in. . . . .<br>(Nominal Shank Diameter, in.) | 5/32<br>(0.163)                           | 3/16<br>(0.198)                | 1/4<br>(0.259)    | 5/16<br>(0.311)                | 3/8<br>(0.373)                 |
| Ultimate Strength, lbs                                          |                                           |                                |                   |                                |                                |
| Sheet or plate thickness, in.:                                  |                                           |                                |                   |                                |                                |
| 0.071 . . . . .                                                 | 1165 <sup>b</sup>                         | ...                            | ...               | ...                            | ...                            |
| 0.080 . . . . .                                                 | 1330 <sup>b</sup>                         | <sup>c</sup> 1600 <sup>b</sup> | ...               | ...                            | ...                            |
| 0.090 . . . . .                                                 | 1515 <sup>b</sup>                         | 1805 <sup>b</sup>              | <sup>c</sup> ...  | ...                            | ...                            |
| 0.100 . . . . .                                                 | 1700 <sup>b</sup>                         | 2020 <sup>b</sup>              | 2615 <sup>b</sup> | ...                            | ...                            |
| 0.125 . . . . .                                                 | 1980 <sup>b</sup>                         | 2595 <sup>b</sup>              | 3295 <sup>b</sup> | <sup>c</sup> 3935 <sup>b</sup> | ...                            |
| 0.160 . . . . .                                                 | ...                                       | 2925 <sup>b</sup>              | 4335 <sup>b</sup> | 5080 <sup>b</sup>              | <sup>c</sup> 6010 <sup>b</sup> |
| 0.190 . . . . .                                                 | ...                                       | ...                            | 5005 <sup>b</sup> | 6150 <sup>b</sup>              | <sup>c</sup> 7205 <sup>b</sup> |
| 0.200 . . . . .                                                 | ...                                       | ...                            | ...               | 6520 <sup>b</sup>              | 6580 <sup>b</sup>              |
| 0.250 . . . . .                                                 | ...                                       | ...                            | ...               | 7215 <sup>b</sup>              | 9810 <sup>b</sup>              |
| 0.312 . . . . .                                                 | ...                                       | ...                            | ...               | ...                            | 10380 <sup>b</sup>             |
| Fastener shear strength <sup>d</sup> . . . . .                  | 1980                                      | 2925                           | 5005              | 7215                           | 10380                          |
| Yield Strength <sup>e</sup> , lbs                               |                                           |                                |                   |                                |                                |
| Sheet or plate thickness, in.:                                  |                                           |                                |                   |                                |                                |
| 0.071 . . . . .                                                 | 478                                       | ...                            | ...               | ...                            | ...                            |
| 0.080 . . . . .                                                 | 584                                       | 627                            | ...               | ...                            | ...                            |
| 0.090 . . . . .                                                 | 702                                       | 730                            | ...               | ...                            | ...                            |
| 0.100 . . . . .                                                 | 819                                       | 901                            | 1025              | ...                            | ...                            |
| 0.125 . . . . .                                                 | 1115                                      | 1260                           | 1435              | 1540                           | ...                            |
| 0.160 . . . . .                                                 | ...                                       | 1760                           | 2090              | 2285                           | 2430                           |
| 0.190 . . . . .                                                 | ...                                       | ...                            | 2655              | 2965                           | 3235                           |
| 0.200 . . . . .                                                 | ...                                       | ...                            | ...               | 3190                           | 3510                           |
| 0.250 . . . . .                                                 | ...                                       | ...                            | ...               | 4320                           | 4860                           |
| 0.312 . . . . .                                                 | ...                                       | ...                            | ...               | ...                            | 6460                           |
| Head height (ref.), in. . . . .                                 | 0.074                                     | 0.082                          | 0.108             | 0.140                          | 0.168                          |

a Data supplied by Huck Manufacturing Company.  
b Yield value is less than 2/3 of the indicated ultimate strength value.  
c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
d Fastener shear strength is documented in MIL-F-8975.  
e Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3) (revised May 1, 1986, from the greater of 0.012 inch or 4% of nominal diameter).

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**Table 8.1.3.2.3(b<sub>1</sub>). Static Joint Strength of Blind 100° Flush Head Alloy Steel Fasteners in Machine-Countersunk Aluminum Alloy Sheet and Plate**

|                                                                                                                                                                                                                              |                                                                    |                     |                     |                     |                     |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------|---------------------|---------------------|---------------------|---------------------|
| Fastener Type . . . . .                                                                                                                                                                                                      | MS90353, MS90353S, and MS90353U <sup>a</sup> ( $F_{su} = 112$ ksi) |                     |                     |                     |                     |
| Sheet and Plate Material . . . . .                                                                                                                                                                                           | Clad 2024-T3 and T351                                              |                     |                     |                     |                     |
| Fastener Diameter, in. . . . .<br>(Nominal Shank Diameter, in.) .                                                                                                                                                            | 5/32<br>(0.163)                                                    | 3/16<br>(0.198)     | 1/4<br>(0.259)      | 5/16<br>(0.311)     | 3/8<br>(0.373)      |
| Sheet or plate thickness, in.:<br>0.071 . . . . .<br>0.080 . . . . .<br>0.090 . . . . .<br>0.100 . . . . .<br>0.125 . . . . .<br>0.160 . . . . .<br>0.190 . . . . .<br>0.250 . . . . .<br>0.312 . . . . .<br>0.375 . . . . . | Ultimate Strength, lbs                                             |                     |                     |                     |                     |
|                                                                                                                                                                                                                              | 1120 <sup>b,c</sup>                                                | ...                 | ...                 | ...                 | ...                 |
|                                                                                                                                                                                                                              | 1305 <sup>b</sup>                                                  | 1480 <sup>b,c</sup> | ...                 | ...                 | ...                 |
|                                                                                                                                                                                                                              | 1510 <sup>b</sup>                                                  | 1735 <sup>b</sup>   | ...                 | ...                 | ...                 |
|                                                                                                                                                                                                                              | 1740 <sup>b</sup>                                                  | 2000 <sup>b</sup>   | 2380 <sup>b,c</sup> | ...                 | ...                 |
|                                                                                                                                                                                                                              | 2080 <sup>b</sup>                                                  | 2670 <sup>b</sup>   | 3210 <sup>b</sup>   | 3625 <sup>b,c</sup> | ...                 |
|                                                                                                                                                                                                                              | 2340 <sup>b</sup>                                                  | 3195 <sup>b</sup>   | 4440 <sup>b</sup>   | 5060 <sup>b</sup>   | 5700 <sup>b,c</sup> |
|                                                                                                                                                                                                                              | ...                                                                | 3450 <sup>b</sup>   | 5090 <sup>b</sup>   | 6310 <sup>b</sup>   | 7180 <sup>b</sup>   |
|                                                                                                                                                                                                                              | ...                                                                | ...                 | 5900 <sup>b</sup>   | 7860 <sup>b</sup>   | 9890 <sup>b</sup>   |
|                                                                                                                                                                                                                              | ...                                                                | ...                 | ...                 | 8500 <sup>b</sup>   | 11600 <sup>b</sup>  |
|                                                                                                                                                                                                                              | ...                                                                | ...                 | ...                 | ...                 | 12200 <sup>b</sup>  |
|                                                                                                                                                                                                                              | 2340                                                               | 3450                | 5900                | 8500                | 12200               |
| Sheet or plate thickness, in.:<br>0.071 . . . . .<br>0.080 . . . . .<br>0.090 . . . . .<br>0.100 . . . . .<br>0.125 . . . . .<br>0.160 . . . . .<br>0.190 . . . . .<br>0.250 . . . . .<br>0.312 . . . . .<br>0.375 . . . . . | Yield Strength <sup>e</sup> , lbs                                  |                     |                     |                     |                     |
|                                                                                                                                                                                                                              | 403                                                                | ...                 | ...                 | ...                 | ...                 |
|                                                                                                                                                                                                                              | 513                                                                | 501                 | ...                 | ...                 | ...                 |
|                                                                                                                                                                                                                              | 636                                                                | 652                 | ...                 | ...                 | ...                 |
|                                                                                                                                                                                                                              | 759                                                                | 799                 | 1045                | ...                 | ...                 |
|                                                                                                                                                                                                                              | 989                                                                | 1170                | 1525                | 1620                | ...                 |
|                                                                                                                                                                                                                              | 1170                                                               | 1510                | 2200                | 2430                | 2610                |
|                                                                                                                                                                                                                              | ...                                                                | 1700                | 2700                | 3120                | 3440                |
|                                                                                                                                                                                                                              | ...                                                                | ...                 | 3330                | 4170                | 5095                |
|                                                                                                                                                                                                                              | ...                                                                | ...                 | ...                 | 4955                | 6175                |
|                                                                                                                                                                                                                              | ...                                                                | ...                 | ...                 | ...                 | 7135                |
| Head height (ref.), in. . . . .                                                                                                                                                                                              | 0.072                                                              | 0.080               | 0.105               | 0.137               | 0.165               |

a Data supplied by Huck Manufacturing Company.  
b Yield strength value is less than 2/3 of indicated ultimate strength value.  
c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
d Fastener shear strength is documented in MIL-F-81177.  
e Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

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**1 December 1998**

**Table 8.1.3.2.2(b<sub>2</sub>). Static Joint Strength of Blind 100° Flush Head Alloy Steel Fasteners in Machine-Countersunk Aluminum Alloy Sheet and Plate**

|                                                                  |                                            |                   |                   |                   |                    |
|------------------------------------------------------------------|--------------------------------------------|-------------------|-------------------|-------------------|--------------------|
| Rivet Type . . . . .                                             | MS90353 <sup>a</sup> ( $F_{su} = 112$ ksi) |                   |                   |                   |                    |
| Sheet and Plate Material . . . . .                               | Clad or Bare 7075-T6 and T651              |                   |                   |                   |                    |
| Fastener Diameter, in. . . . .<br>(Nominal Hole Diameter, in.) . | 5/32<br>(0.163)                            | 3/16<br>(0.198)   | 1/4<br>(0.259)    | 5/16<br>(0.311)   | 3/8<br>(0.373)     |
| Ultimate Strength, lbs                                           |                                            |                   |                   |                   |                    |
| Sheet or plate thickness, in.:                                   |                                            |                   |                   |                   |                    |
| 0.071 . . . . .                                                  | 1360 <sup>c</sup>                          | ...               | ...               | ...               | ...                |
| 0.080 . . . . .                                                  | 1535 <sup>c</sup>                          | 1830 <sup>c</sup> | ...               | ...               | ...                |
| 0.090 . . . . .                                                  | 1710 <sup>c</sup>                          | 2090 <sup>c</sup> | ...               | ...               | ...                |
| 0.100 . . . . .                                                  | 1880 <sup>c</sup>                          | 2330 <sup>c</sup> | 2970 <sup>c</sup> | ...               | ...                |
| 0.125 . . . . .                                                  | 2200 <sup>c</sup>                          | 2825 <sup>c</sup> | 3805 <sup>c</sup> | 4490 <sup>c</sup> | ...                |
| 0.160 . . . . .                                                  | 2340                                       | 3365              | 4760 <sup>c</sup> | 5850 <sup>c</sup> | 6960 <sup>c</sup>  |
| 0.190 . . . . .                                                  | ...                                        | 3450              | 5370 <sup>c</sup> | 6790 <sup>c</sup> | 8310 <sup>c</sup>  |
| 0.250 . . . . .                                                  | ...                                        | ...               | 5900              | 8290 <sup>c</sup> | 10450 <sup>c</sup> |
| 0.312 . . . . .                                                  | ...                                        | ...               | ...               | 8500              | 12200              |
| 0.375 . . . . .                                                  | ...                                        | ...               | ...               | ...               | 12200              |
| Fastener shear strength <sup>d</sup> . . . . .                   | 2340                                       | 3450              | 5900              | 8500              | 12200              |
| Yield Strength <sup>e</sup> , lbs                                |                                            |                   |                   |                   |                    |
| Sheet or plate thickness, in.:                                   |                                            |                   |                   |                   |                    |
| 0.071 . . . . .                                                  | 557                                        | ...               | ...               | ...               | ...                |
| 0.080 . . . . .                                                  | 666                                        | 757               | ...               | ...               | ...                |
| 0.090 . . . . .                                                  | 787                                        | 875               | ...               | ...               | ...                |
| 0.100 . . . . .                                                  | 909                                        | 1025              | 1240              | ...               | ...                |
| 0.125 . . . . .                                                  | 1215                                       | 1395              | 1640              | 1860              | ...                |
| 0.160 . . . . .                                                  | 1640                                       | 1910              | 2315              | 2590              | 2850               |
| 0.190 . . . . .                                                  | ...                                        | 2355              | 2895              | 3290              | 3675               |
| 0.250 . . . . .                                                  | ...                                        | ...               | 4055              | 4680              | 5345               |
| 0.312 . . . . .                                                  | ...                                        | ...               | ...               | 6125              | 7075               |
| 0.375 . . . . .                                                  | ...                                        | ...               | ...               | ...               | 8830               |
| Head height (ref.), in. . . . .                                  | 0.072                                      | 0.080             | 0.105             | 0.137             | 0.165              |

a Data supplied by Huck Manufacturing Company.

b Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.

c Yield value is less than 2/3 of indicated ultimate strength value.

d Fastener shear strength is documented in MIL-F-81177.

e Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3) revised May 1, 1986, from the greater of 0.012 inch or 4% of nominal diameters.



**Table 8.1.3.2.3(c). Static Joint Strength of Blind 100° Flush Head Alloy Steel Fasteners in Machine-Countersunk Aluminum Alloy Sheet and Plate**

| Fastener Type . . . . .                                                                                                                                                                                                                           | FF-200 <sup>a</sup>               |                   | FF-260 <sup>a</sup> |                   | FF-312 <sup>a</sup> |                   |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|-------------------|---------------------|-------------------|---------------------|-------------------|
| Sheet and Plate Material . . . . .                                                                                                                                                                                                                | Clad<br>2024-T42                  | Clad<br>7075-T6   | Clad<br>2024-T42    | Clad<br>7075-T6   | Clad<br>2024-T42    | Clad<br>7075-T6   |
| Fastener Diameter, in. . . . .<br>(Nominal Shank Diameter, in.)                                                                                                                                                                                   | 3/16<br>(0.198)                   | 3/16<br>(0.198)   | 1/4<br>(0.259)      | 1/4<br>(0.259)    | 5/16<br>(0.311)     | 5/16<br>(0.311)   |
| Sheet or plate thickness, in.:<br>0.071 . . . . .<br>0.080 . . . . .<br>0.090 . . . . .<br>0.100 . . . . .<br>0.125 . . . . .<br>0.160 . . . . .<br>0.190 . . . . .<br>0.250 . . . . .<br>0.312 . . . . .<br>Fastener shear strength <sup>d</sup> | Ultimate Strength, lbs            |                   |                     |                   |                     |                   |
|                                                                                                                                                                                                                                                   | 1220 <sup>b</sup>                 | 1360 <sup>b</sup> | ...                 | ...               | ...                 | ...               |
|                                                                                                                                                                                                                                                   | 1380 <sup>b</sup>                 | 1500 <sup>b</sup> | ...                 | ...               | ...                 | ...               |
|                                                                                                                                                                                                                                                   | 1520 <sup>b</sup>                 | 1620 <sup>b</sup> | ...                 | ...               | ...                 | ...               |
|                                                                                                                                                                                                                                                   | 1650 <sup>b</sup>                 | 1740 <sup>b</sup> | 2250 <sup>b</sup>   | 2700 <sup>b</sup> | ...                 | ...               |
|                                                                                                                                                                                                                                                   | 1890 <sup>b</sup>                 | 1960              | 2940 <sup>b</sup>   | 3220 <sup>b</sup> | 2720                | 3080 <sup>b</sup> |
|                                                                                                                                                                                                                                                   | 2160                              | 2200              | 3390 <sup>b</sup>   | 3570 <sup>b</sup> | 3600 <sup>b</sup>   | 3940 <sup>b</sup> |
|                                                                                                                                                                                                                                                   | 2400                              | 2420              | 3730 <sup>b</sup>   | 2860 <sup>b</sup> | 4490 <sup>b</sup>   | 4810 <sup>b</sup> |
|                                                                                                                                                                                                                                                   | 2620                              | 2620              | 4260 <sup>b</sup>   | 4320              | 5550 <sup>b</sup>   | 6000 <sup>b</sup> |
|                                                                                                                                                                                                                                                   | ...                               | ...               | 4500                | 4500              | 6000 <sup>b</sup>   | ...               |
| Sheet or plate thickness, in.:<br>0.071 . . . . .<br>0.080 . . . . .<br>0.090 . . . . .<br>0.100 . . . . .<br>0.125 . . . . .<br>0.160 . . . . .<br>0.190 . . . . .<br>0.250 . . . . .<br>0.312 . . . . .                                         | Yield Strength <sup>e</sup> , lbs |                   |                     |                   |                     |                   |
|                                                                                                                                                                                                                                                   | 685                               | 850               | ...                 | ...               | ...                 | ...               |
|                                                                                                                                                                                                                                                   | 770                               | 930               | ...                 | ...               | ...                 | ...               |
|                                                                                                                                                                                                                                                   | 870                               | 1025              | ...                 | ...               | ...                 | ...               |
|                                                                                                                                                                                                                                                   | 980                               | 1130              | 1120                | 1280              | ...                 | ...               |
|                                                                                                                                                                                                                                                   | 1200                              | 1350              | 1380                | 1600              | 1440                | 1540              |
|                                                                                                                                                                                                                                                   | 1500                              | 1640              | 1700                | 2050              | 1820                | 1980              |
|                                                                                                                                                                                                                                                   | 1800                              | 1960              | 2010                | 2470              | 2200                | 2520              |
|                                                                                                                                                                                                                                                   | 2400                              | 2550              | 2600                | 3190              | 2950                | 3710              |
|                                                                                                                                                                                                                                                   | ...                               | ...               | 3200                | 3880              | 3690                | ...               |
| Head height (ref.), in. . . . .                                                                                                                                                                                                                   | 0.077                             |                   | 0.102               |                   | 0.134               |                   |

a Data supplied by Monogram Aerospace Fasteners.

b Yield value is less than 2/3 of indicated ultimate strength value.

c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.

d Fastener shear strength is documented in NAS1675.

e Permanent set at yield load: the greater of 0.012 inch or 4% of nominal diameter.

**Table 8.1.3.2.3(d). Static Joint Strength of Blind 100° Flush Head Alloy Steel Fasteners in Machine-Countersunk Aluminum Alloy Sheet**

|                                                                 |                                   |                                |                   |
|-----------------------------------------------------------------|-----------------------------------|--------------------------------|-------------------|
| Fastener Type . . . . .                                         | NS 100 <sup>a</sup>               |                                |                   |
| Sheet Material . . . . .                                        | Clad 7075-T6                      |                                |                   |
| Fastener Diameter, in. . . . .<br>(Nominal Shank Diameter, in.) | 5/32<br>(0.163)                   | 3/16<br>(0.198)                | 1/4<br>(0.259)    |
| Sheet thickness, in.:                                           | Ultimate Strength, lbs            |                                |                   |
|                                                                 | 1085 <sup>b</sup>                 | ...                            | ...               |
|                                                                 | 1295 <sup>b</sup>                 | <sup>c</sup> 1400 <sup>b</sup> | ...               |
|                                                                 | 1525 <sup>b</sup>                 | 1710 <sup>b</sup>              | ...               |
|                                                                 | 1695 <sup>b</sup>                 | 2020 <sup>b</sup>              | ...               |
|                                                                 | 1830 <sup>b</sup>                 | 2335 <sup>b</sup>              | 2715 <sup>b</sup> |
|                                                                 | 2170 <sup>b</sup>                 | 2745 <sup>b</sup>              | 3765 <sup>b</sup> |
|                                                                 | 2190                              | 3325 <sup>b</sup>              | 4615 <sup>b</sup> |
|                                                                 | ...                               | 3325 <sup>b</sup>              | 5280 <sup>b</sup> |
|                                                                 | ...                               | ...                            | 5690 <sup>b</sup> |
|                                                                 | 2190                              | 3325                           | 5690              |
| Sheet thickness, in.:                                           | Yield Strength <sup>e</sup> , lbs |                                |                   |
|                                                                 | 516                               | ...                            | ...               |
|                                                                 | 602                               | 690                            | ...               |
|                                                                 | 698                               | 805                            | ...               |
|                                                                 | 804                               | 936                            | ...               |
|                                                                 | 911                               | 1065                           | 1300              |
|                                                                 | 1180                              | 1390                           | 1725              |
|                                                                 | 1500                              | 1835                           | 2320              |
|                                                                 | ...                               | 2165                           | 2830              |
|                                                                 | ...                               | ...                            | 3725              |
| Head height (ref.), in. . . . .                                 | 0.069                             | 0.077                          | 0.102             |

- a Data supplied by Monogram Aerospace Fasteners.  
b Yield value is less than 2/3 of the indicated ultimate strength value.  
c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
d Fastener shear strength values are A basis from analysis of test data.  
e Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3) (revised May 1, 1985, from the greater of 0.012 inch or 4% of nominal diameter).

**Table 8.1.3.2.3(e). Static Joint Strength of Blind 100° Flush Head Aluminum Alloy Fasteners in Machine-Countersunk Aluminum Alloy Sheet**

| Fastener Type .....                                                | SSHFA-200 <sup>a</sup> ( $F_{su} = 50$ ksi) |                 | SSHFA-260 <sup>a</sup> ( $F_{su} = 50$ ksi) |                   |
|--------------------------------------------------------------------|---------------------------------------------|-----------------|---------------------------------------------|-------------------|
| Sheet Material .....                                               | Clad 2024-T42                               | Clad 7075-T6    | Clad 2024-T42                               | Clad 7075-T6      |
| Fastener Diameter, in. ....<br>(Nominal Shank Diameter, in.) ..... | 3/16<br>(0.198)                             | 3/16<br>(0.198) | 1/4<br>(0.259)                              | 1/4<br>(0.259)    |
| Ultimate Strength, lbs                                             |                                             |                 |                                             |                   |
| Sheet thickness, in.:                                              |                                             |                 |                                             |                   |
| 0.050 .....                                                        | 500                                         | 590             | ...                                         | ...               |
| 0.063 .....                                                        | 640                                         | 750             | <sup>b</sup> ...                            | ...               |
| 0.071 .....                                                        | 790                                         | 880             | ...                                         | ...               |
| 0.080 .....                                                        | 1040                                        | 1060            | 1310                                        | 1480              |
| 0.090 .....                                                        | 1270                                        | 1270            | 1480                                        | 1650 <sup>b</sup> |
| 0.100 .....                                                        | 1450                                        | 1450            | 1680                                        | 1850              |
| 0.125 .....                                                        | 1550                                        | 1550            | 2010                                        | 2250              |
| 0.160 .....                                                        | ...                                         | ...             | 2300                                        | 2650              |
| 0.190 .....                                                        | ...                                         | ...             | 2520                                        | ...               |
| 0.250 .....                                                        | ...                                         | ...             | 2650                                        | ...               |
| Fastener shear strength <sup>c</sup> .....                         | 1550                                        | 1550            | 2650                                        | 2650              |
| Yield Strength <sup>d</sup> , lbs                                  |                                             |                 |                                             |                   |
| Sheet thickness, in.:                                              |                                             |                 |                                             |                   |
| 0.050 .....                                                        | 500                                         | 520             | ...                                         | ...               |
| 0.063 .....                                                        | 630                                         | 700             | ...                                         | ...               |
| 0.071 .....                                                        | 740                                         | 800             | ...                                         | ...               |
| 0.080 .....                                                        | 860                                         | 915             | 940                                         | 1160              |
| 0.090 .....                                                        | 990                                         | 1040            | 1080                                        | 1300              |
| 0.100 .....                                                        | 1130                                        | 1180            | 1230                                        | 1460              |
| 0.125 .....                                                        | 1340                                        | 1420            | 1550                                        | 1790              |
| 0.160 .....                                                        | ...                                         | ...             | 1980                                        | 2240              |
| 0.190 .....                                                        | ...                                         | ...             | 2420                                        | ...               |
| 0.250 .....                                                        | ...                                         | ...             | 2650                                        | ...               |
| Head height (ref.), in. ....                                       | 0.061                                       | 0.061           | 0.088                                       | 0.088             |

a Data supplied by Monogram Aerospace Fasteners.

b Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.

c Fastener shear strength is documented in NAS1675.

d Permanent set at yield load: the greater of 0.012 inch or 4% of nominal diameter.

**Table 8.1.3.2.3(f). Static Joint Strength of Blind 100° Flush Head Alloy Steel Fasteners in Machine-Countersunk Aluminum Alloy Sheet and Plate**

|                                                                                                                                                                                      |                                                                                                   |                     |                   |                     |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|---------------------|-------------------|---------------------|
| Fastener Type .....                                                                                                                                                                  | PLT-150 <sup>a</sup> ( $F_{su} = 112$ ksi)<br>(H-11 Nut and screw, Inconel X-750 or A-286 Sleeve) |                     |                   |                     |
| Sheet or Plate Material .....                                                                                                                                                        | Clad 7075-T6 and T651                                                                             |                     |                   |                     |
| Fastener Diameter, in. ....<br>(Nominal Shank Diameter, in.) .....                                                                                                                   | 5/32<br>(0.163)                                                                                   | 3/16<br>(0.198)     | 1/4<br>(0.259)    | 3/8<br>(0.373)      |
| Sheet or plate thickness, in.:<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 .....<br>0.312 ..... | Ultimate Strength, lbs                                                                            |                     |                   |                     |
|                                                                                                                                                                                      | 1120 <sup>b</sup>                                                                                 | ...                 | ...               | ...                 |
|                                                                                                                                                                                      | 1320 <sup>b</sup>                                                                                 | c 1470 <sup>b</sup> | ...               | ...                 |
|                                                                                                                                                                                      | 1550 <sup>b</sup>                                                                                 |                     | ...               | ...                 |
|                                                                                                                                                                                      | 1730 <sup>b</sup>                                                                                 | 2060 <sup>b</sup>   | ...               | ...                 |
|                                                                                                                                                                                      | 1885 <sup>b</sup>                                                                                 | 2350 <sup>b</sup>   | 2820 <sup>b</sup> | ...                 |
|                                                                                                                                                                                      | 2300 <sup>b</sup>                                                                                 | 2850 <sup>b</sup>   | 3825 <sup>b</sup> | c 6695 <sup>b</sup> |
|                                                                                                                                                                                      | 2340 <sup>b</sup>                                                                                 | 3450 <sup>b</sup>   | 4790 <sup>b</sup> |                     |
|                                                                                                                                                                                      | ...                                                                                               | ...                 | 5570 <sup>b</sup> | 8440 <sup>b</sup> c |
|                                                                                                                                                                                      | ...                                                                                               | ...                 | 5900 <sup>b</sup> | 10700 <sup>b</sup>  |
|                                                                                                                                                                                      | ...                                                                                               | ...                 | ...               | 12250 <sup>b</sup>  |
|                                                                                                                                                                                      | Fastener shear strength <sup>d</sup> .....                                                        | 2340                | 3450              | 5900                |
| Sheet or plate thickness, in.:<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 .....<br>0.312 ..... | Yield Strength <sup>e</sup> , lbs                                                                 |                     |                   |                     |
|                                                                                                                                                                                      | 534                                                                                               | ...                 | ...               | ...                 |
|                                                                                                                                                                                      | 615                                                                                               | 730                 | ...               | ...                 |
|                                                                                                                                                                                      | 705                                                                                               | 830                 | ...               | ...                 |
|                                                                                                                                                                                      | 805                                                                                               | 953                 | ...               | ...                 |
|                                                                                                                                                                                      | 906                                                                                               | 1075                | 1345              | ...                 |
|                                                                                                                                                                                      | 1235                                                                                              | 1390                | 1750              | ...                 |
|                                                                                                                                                                                      | 1545                                                                                              | 1910                | 2310              | 3160                |
|                                                                                                                                                                                      | ...                                                                                               | ...                 | 2965              | 3850                |
|                                                                                                                                                                                      | ...                                                                                               | ...                 | 3840              | 5395                |
|                                                                                                                                                                                      | ...                                                                                               | ...                 | ...               | 6985                |
|                                                                                                                                                                                      | Head height (ref.), in. ....                                                                      | 0.069               | 0.077             | 0.102               |
|                                                                                                                                                                                      |                                                                                                   |                     |                   | 0.160               |

a Data supplied by Voi-Shan Industries (Inconel X-750 Sleeve) and Monogram Aerospace Fasteners (A-286 Sleeve).

b Yield value is less than 2/3 of the indicated ultimate strength value.

c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.

d Fastener shear strength based on area computed from nominal shank diameter in Table 9.4.1.2(a) and  $F_{su} = 112$  ksi.

e Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3) (revised May 1, 1985, from the greater of 0.012 inch or 4% of nominal diameter).

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**Table 8.1.3.2.3(g). Static Joint Strength of Blind 100° Flush Head Alloy Steel Fasteners in Machine-Countersunk Aluminum Alloy Sheet and Plate**

| Fastener Type . . . . .                                                        | NAS1670-L <sup>a</sup> |                                |                   |                                |                                |
|--------------------------------------------------------------------------------|------------------------|--------------------------------|-------------------|--------------------------------|--------------------------------|
| Sheet and Plate Material . . . . .                                             | Clad 7075-T6 and T651  |                                |                   |                                |                                |
| Fastener Diameter, in. <sup>b</sup> . . . . .<br>(Nominal Shank Diameter, in.) | 5/32<br>(0.163)        | 3/16<br>(0.198)                | 1/4<br>(0.259)    | 5/16<br>(0.311)                | 3/8<br>(0.373)                 |
| Ultimate Strength, lbs                                                         |                        |                                |                   |                                |                                |
| Sheet or plate thickness, in.:                                                 |                        |                                |                   |                                |                                |
| 0.063 . . . . .                                                                | 1110 <sup>c</sup>      | ...                            | ...               | ...                            | ...                            |
| 0.071 . . . . .                                                                | 1230 <sup>c</sup>      | <sup>d</sup> 1530 <sup>c</sup> | ...               | ...                            | ...                            |
| 0.080 . . . . .                                                                | 1365 <sup>c</sup>      | 1700 <sup>c</sup>              | <sup>d</sup> ...  | ...                            | ...                            |
| 0.090 . . . . .                                                                | 1525 <sup>c</sup>      | 1885 <sup>c</sup>              | ...               | ...                            | ...                            |
| 0.100 . . . . .                                                                | 1678 <sup>c</sup>      | 2065 <sup>c</sup>              | 2800 <sup>c</sup> | ...                            | ...                            |
| 0.125 . . . . .                                                                | 1678                   | 2530 <sup>c</sup>              | 3400 <sup>c</sup> | <sup>d</sup> 4165 <sup>c</sup> | ...                            |
| 0.160 . . . . .                                                                | 1678                   | 2620 <sup>c</sup>              | 4255 <sup>c</sup> | 5190 <sup>c</sup>              | <sup>d</sup> 6350 <sup>c</sup> |
| 0.190 . . . . .                                                                | ...                    | 2620                           | 4500 <sup>c</sup> | 6000 <sup>c</sup>              | <sup>d</sup> 7395 <sup>c</sup> |
| 0.250 . . . . .                                                                | ...                    | ...                            | 4500              | 6000                           | 9625 <sup>c</sup>              |
| 0.312 . . . . .                                                                | ...                    | ...                            | ...               | ...                            | 9750                           |
| 0.375 . . . . .                                                                | ...                    | ...                            | ...               | ...                            | 9750                           |
| Fastener shear strength <sup>e</sup> . . . . .                                 | 1678                   | 2620                           | 4500              | 6000                           | 9750                           |
| Yield Strength <sup>f</sup> , lbs                                              |                        |                                |                   |                                |                                |
| Sheet or plate thickness, in.:                                                 |                        |                                |                   |                                |                                |
| 0.063 . . . . .                                                                | 500                    | ...                            | ...               | ...                            | ...                            |
| 0.071 . . . . .                                                                | 601                    | 647                            | ...               | ...                            | ...                            |
| 0.080 . . . . .                                                                | 711                    | 788                            | ...               | ...                            | ...                            |
| 0.090 . . . . .                                                                | 802                    | 941                            | ...               | ...                            | ...                            |
| 0.100 . . . . .                                                                | 887                    | 1085                           | 1255              | ...                            | ...                            |
| 0.125 . . . . .                                                                | 1105                   | 1340                           | 1770              | 1930                           | ...                            |
| 0.160 . . . . .                                                                | 1405                   | 1700                           | 2250              | 2720                           | 3055                           |
| 0.190 . . . . .                                                                | ...                    | 2020                           | 2655              | 3200                           | 3890                           |
| 0.250 . . . . .                                                                | ...                    | ...                            | 3480              | 4185                           | 5020                           |
| 0.312 . . . . .                                                                | ...                    | ...                            | ...               | ...                            | 6280                           |
| 0.375 . . . . .                                                                | ...                    | ...                            | ...               | ...                            | 7520                           |
| Head height (ref.), in. . . . .                                                | 0.069                  | 0.077                          | 0.102             | 0.134                          | 0.160                          |

- a Data supplied by Monogram Aerospace Fasteners.
- b Fasteners installed in 0.165/0.166, 0.200/0.201, 0.261/0.262, 0.312/0.313, 0.375/0.376 inch holes.
- c Yield value is less than 2/3 of the indicated ultimate strength value.
- d Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.
- e Fastener shear strength is documented in NAS1675.
- f Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

**Table 8.1.3.2.3(h). Static Joint Strength of Blind 100° Flush Head Aluminum Alloy Fasteners in Machine-Countersunk Aluminum Alloy Sheet**

|                                                                                                                                               |                                   |                 |                |
|-----------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|-----------------|----------------|
| Fastener Type .....                                                                                                                           | NAS1674-L <sup>a</sup>            |                 |                |
| Sheet Material .....                                                                                                                          | Clad 7075-T6                      |                 |                |
| Fastener Diameter, in. ....<br>(Nominal Shank Diameter, in.) <sup>b</sup>                                                                     | 5/32<br>(0.163)                   | 3/16<br>(0.198) | 1/4<br>(0.259) |
| Sheet thickness, in.:<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 ..... | Ultimate Strength, lbs            |                 |                |
|                                                                                                                                               | 548 <sup>c</sup>                  | ...             | ...            |
|                                                                                                                                               | 756 <sup>c</sup>                  | 853             | ...            |
|                                                                                                                                               | 882 <sup>c</sup>                  | 1010            | ...            |
|                                                                                                                                               | 960                               | 1185            | ...            |
|                                                                                                                                               | ...                               | 1375            | 1645           |
|                                                                                                                                               | ...                               | 1550            | 1900           |
|                                                                                                                                               | ...                               | ...             | 2535           |
|                                                                                                                                               | ...                               | ...             | 2650           |
|                                                                                                                                               | 960                               | 1550            | 2650           |
| Sheet thickness, in.:<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 ..... | Yield Strength <sup>e</sup> , lbs |                 |                |
|                                                                                                                                               | 356                               | ...             | ...            |
|                                                                                                                                               | 481                               | 666             | ...            |
|                                                                                                                                               | 561                               | 774             | ...            |
|                                                                                                                                               | 650                               | 892             | ...            |
|                                                                                                                                               | ...                               | 1025            | 1275           |
|                                                                                                                                               | ...                               | 1155            | 1450           |
|                                                                                                                                               | ...                               | ...             | 1880           |
|                                                                                                                                               | ...                               | ...             | 2480           |
| Head height (ref.), in. ....                                                                                                                  | 0.049                             | 0.061           | 0.088          |

a Data supplied by Monogram Aerospace Fasteners.  
b Fasteners installed in 0.165/0.166, 0.199/0.200, 0.260/0.261 inch holes.  
c Yield value is less than 2/3 of the indicated ultimate strength value.  
d Fastener shear strength is documented in NAS1675.  
e Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

**8.1.4 SWAGED COLLAR/UPSET-PIN FASTENERS** — The strengths shown in the following tables are applicable only when grip lengths and hole tolerances are as recommended by respective fastener manufacturers. For some fastener systems, permanent set at yield load may be increased if hole sizes greater than those listed in the applicable table are used. This condition may exist even though the test hole size lies within the manufacturer's recommended hole size range (refer to Section 9.4.1.3.3).

The ultimate allowable shear load for lockbolts and lockbolt stumps may be obtained from Table 8.1.4 for the appropriate shear stress level. Tensile strengths of lockbolts and lockbolt stumps also are contained in Table 8.1.4.

For lockbolts under combined loading of shear and tension installed in material having a thickness large enough to make the shear cutoff strength critical for shear loading, the following interaction equations are applicable:

$$\begin{aligned}\text{Steel lockbolts, } R_t + R_s^{10} &= 1.0 \\ 7075\text{-T6 lockbolts, } R_t + R_s^5 &= 1.0\end{aligned}$$

where  $R_t$  and  $R_s$  are the ratios of applied load to allowable load in tension and shear, respectively.

Unless otherwise specified, yield load is defined in Section 9.4.1.3.3 as the load which results in a joint permanent set equal to 4% D, where D is the decimal equivalent of the fastener shank diameter, as defined in 9.4.1.2(a).

**8.1.4.1 Protruding-Head Swaged Collar Fastener Joints** — Tables 8.1.4.1(a) and (b) contain joint allowables for various protruding-head swaged collar fastener/sheet material combinations. It has been shown that protruding shear head (representative configurations are NAS 2406 to NAS 2412 and M43859/1) fastener joints may not develop the full bearing strength of joint material. Therefore, static allowable loads for protruding shear head fasteners must be established from test data using the criteria specified in Section 9.4.1. For shear joints with protruding tension head fasteners, the load per fastener at which shear or bearing type of failure occurs is calculated separately and the lower of the two governs the design. Allowable shear loads are obtained from Table 8.1.4.

The design bearing stresses for various materials at room and other temperatures are given in strength properties stated for each alloy or group of alloys, and are applicable to joints with pins in cylindrical holes and where  $t/D \geq 0.18$ . Where  $t/D < 0.18$ , tests to substantiate yield and ultimate bearing strengths must be performed. These bearing stresses are applicable only for design of rigid joints where there is no possibility of relative motion of the parts joined without deformation of such parts.

For convenience, "unit" sheet bearing strengths for pins, based on bearing stress of 100 ksi and nominal fastener diameters, are given in Table 8.1.5.1. The strength for a specific combination of fastener, sheet thickness, and sheet material is obtained by multiplying the proper "unit" strength by the ratio of material allowable bearing stress (ksi) to 100.

**8.1.4.2 Flush-Head Swaged Collar Fastener Joints** — Tables 8.1.4.2(a) through (j) contain joint allowables for various flush-head swaged collar fastener/sheet material combinations. The allowable loads for flush-head swaged collar fasteners were established from test data using the following criteria, unless otherwise noted in the footnotes of individual tables.

*Ultimate Load* — Average ultimate test load divided by a factor of 1.14, as defined in Section 9.4. This factor is not applicable to shear strength cutoff values which may be either the procurement specification shear strength (S value) of the fastener or, if no specification exists, a statistical value determined from test results as described in Section 9.4.

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The allowable loads shown for flush-head swaged collar fasteners are applicable to joints having  $e/D$  equal to or greater than 2.0.

For machine countersunk joints, the sheet gage specified in the tables is that of countersunk sheet. When the noncountersunk sheet is thinner than the countersunk sheet, the bearing allowable for the noncountersunk sheet-fastener combination should be computed, compared to the table value, and the lower of the two values selected.



**Table 8.1.4. Ultimate Single-Shear and Tensile Strengths of Lockbolts and Lockbolt Stumps<sup>a</sup>**

| Nominal Diameter<br>(inches) | Heat Treated Alloy Steel <sup>b</sup> (160 ksi) |                           |                         | 7075-T6 <sup>c</sup>           |                           |                           |
|------------------------------|-------------------------------------------------|---------------------------|-------------------------|--------------------------------|---------------------------|---------------------------|
|                              | Single-Shear<br>Strength, lbs.                  | Tensile Strength, lbs.    |                         | Single-Shear<br>Strength, lbs. | Tensile<br>Strength, lbs. |                           |
|                              |                                                 | Tensile Type <sup>d</sup> | Shear Type <sup>e</sup> |                                |                           | Tensile Type <sup>d</sup> |
|                              |                                                 | NAS 1456 thru 1462        | NAS 1414 thru 1422      |                                |                           | NAS 1516 thru 1522        |
|                              |                                                 | NAS 1465 thru 1472        | NAS 1424 thru 1432      |                                |                           | NAS 1525 thru 1532        |
| NAS 1475 thru 1482           | NAS 1436 thru 1442                              | NAS 1535 thru 1542        |                         |                                |                           |                           |
| NAS 1486 thru 1492           | NAS 1446 thru 1452                              | NAS 1546 thru 1552        |                         |                                |                           |                           |
| NAS 1496 thru 1502           |                                                 | NAS 1556 thru 1562        |                         |                                |                           |                           |
| 5/32 .....                   | 2007 <sup>f</sup> /1822 <sup>g</sup>            | 1100 <sup>f</sup>         | 705 <sup>g</sup>        | 960 <sup>f</sup>               | 740 <sup>f</sup>          |                           |
| 3/16 .....                   | 2623                                            | 2210                      | 1105                    | 1260                           | 1195                      |                           |
| 1/4 .....                    | 4660                                            | 4080                      | 2040                    | 2185                           | 2200                      |                           |
| 5/16 .....                   | 7290                                            | 6500 <sup>d</sup>         | 3250                    | 3450                           | 3500                      |                           |
| 3/8 .....                    | 10490                                           | 10100 <sup>h</sup>        | 5050                    | 4970                           | 5455                      |                           |

a Lockbolts are pull-gun driven; lockbolt stumps are hammer or squeeze driven.

b Used with 2024-T4 aluminum alloy collar, NAS 1080.

c Used with 6061-T6 aluminum alloy collar.

d Tensile type have a higher head and more grooves than the shear type and can be either protruding or 100° flush head.  
Strength value listed refers to lowest strength fastener configuration within this type.

e Shear type have shorter head and less grooves than the tensile type and can be either protruding or 100° flush head.  
Strength values listed refer to lowest strength fastener configuration within this type.

f Available as lockbolt only (0.164 dia. for #8 lockbolts).

g Available as lockbolt stump only (0.156 dia. for 5/32 stumps).

h Five groove design on lockbolts.

**Table 8.1.4.1(a). Static Joint Strength of Protruding Shear Head Ti-6Al-4V Cherrybuck Fasteners in Aluminum Alloy Sheet**

|                                                                               |                                           |                 |                |
|-------------------------------------------------------------------------------|-------------------------------------------|-----------------|----------------|
| Fastener Type .....                                                           | CSR 925 <sup>a</sup> ( $F_{su} = 95$ ksi) |                 |                |
| Sheet Material .....                                                          | Clad 7075-T6                              |                 |                |
| Fastener Diameter, in. ....<br>(Nominal Shank Diameter, in.) <sup>b</sup> ... | 5/32<br>(0.164)                           | 3/16<br>(0.190) | 1/4<br>(0.250) |
| Ultimate Strength, lbs.                                                       |                                           |                 |                |
| Sheet thickness, in.:                                                         |                                           |                 |                |
| 0.050 .....                                                                   | 995                                       | ...             | ...            |
| 0.063 .....                                                                   | 1227                                      | 1442            | ...            |
| 0.071 .....                                                                   | 1371                                      | 1607            | ...            |
| 0.080 .....                                                                   | 1532                                      | 1792            | 2415           |
| 0.090 .....                                                                   | 1711                                      | 2001            | 2688           |
| 0.100 .....                                                                   | 1890                                      | 2205            | 2960           |
| 0.125 .....                                                                   | 2007                                      | 2694            | 3641           |
| 0.160 .....                                                                   | ...                                       | ...             | 4595           |
| 0.190 .....                                                                   | ...                                       | ...             | 4660           |
| Fastener shear strength <sup>c</sup> .....                                    | 2007                                      | 2694            | 4660           |
| Yield Strength <sup>d</sup> , lbs.                                            |                                           |                 |                |
| Sheet thickness, in.:                                                         |                                           |                 |                |
| 0.050 .....                                                                   | 861                                       | ...             | ...            |
| 0.063 .....                                                                   | 1013                                      | 1225            | ...            |
| 0.071 .....                                                                   | 1107                                      | 1334            | ...            |
| 0.080 .....                                                                   | 1213                                      | 1455            | 2067           |
| 0.090 .....                                                                   | 1331                                      | 1592            | 2246           |
| 0.100 .....                                                                   | 1448                                      | 1727            | 2425           |
| 0.125 .....                                                                   | 1741                                      | 2068            | 2873           |
| 0.160 .....                                                                   | ...                                       | ...             | 3499           |
| 0.190 .....                                                                   | ...                                       | ...             | 4036           |

a Data supplied by Cherry Fasteners.

b Fasteners installed in clearance holes (0.0005" - 0.002") (Ref. Section 8.1.4).

c Fastener shear strength based on area computed from nominal shank diameters in Table 9.4.1.2(a) and  $F_{su} = 95$  ksi.

d Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

**Table 8.1.4.1(b). Static Joint Strength of Protruding Shear Head Ti-6Al-4V Cherrybuck Fasteners in Aluminum Alloy Sheet**

|                                                                                                                                                                                                            |                                           |                 |                |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|-----------------|----------------|
| Fastener Type .....                                                                                                                                                                                        | CSR 925 <sup>a</sup> ( $F_{su} = 95$ ksi) |                 |                |
| Sheet Material .....                                                                                                                                                                                       | Clad 2024-T3                              |                 |                |
| Fastener Diameter, in. ....<br>(Nominal Shank Diameter, in.) <sup>b</sup> ..                                                                                                                               | 5/32<br>(0.164)                           | 3/16<br>(0.190) | 1/4<br>(0.250) |
| Sheet thickness, in.:<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>Fastener shear strength <sup>c</sup> ..... | Ultimate Strength, lbs.                   |                 |                |
|                                                                                                                                                                                                            | 807                                       | ...             | ...            |
|                                                                                                                                                                                                            | 1020                                      | 1180            | ...            |
|                                                                                                                                                                                                            | 1150                                      | 1335            | ...            |
|                                                                                                                                                                                                            | 1300                                      | 1505            | 1970           |
|                                                                                                                                                                                                            | 1465                                      | 1695            | 2220           |
|                                                                                                                                                                                                            | 1630                                      | 1885            | 2470           |
|                                                                                                                                                                                                            | 2007                                      | 2360            | 3095           |
|                                                                                                                                                                                                            | ...                                       | 2694            | 3975           |
|                                                                                                                                                                                                            | ...                                       | ...             | 4660           |
|                                                                                                                                                                                                            | 2007                                      | 2694            | 4660           |
| Sheet thickness, in.:<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....                                               | Yield Strength <sup>d</sup> , lbs.        |                 |                |
|                                                                                                                                                                                                            | 619                                       | ...             | ...            |
|                                                                                                                                                                                                            | 747                                       | 889             | ...            |
|                                                                                                                                                                                                            | 827                                       | 981             | ...            |
|                                                                                                                                                                                                            | 916                                       | 1085            | 1495           |
|                                                                                                                                                                                                            | 1015                                      | 1200            | 1645           |
|                                                                                                                                                                                                            | 1115                                      | 1315            | 1795           |
|                                                                                                                                                                                                            | 1360                                      | 1600            | 2175           |
|                                                                                                                                                                                                            | ...                                       | 2000            | 2705           |
|                                                                                                                                                                                                            | ...                                       | ...             | 3155           |

a Data supplied by Cherry Fasteners.  
b Fasteners installed in clearance holes (0.0005" - 0.002") (Ref. Section 8.1.4).  
c Fastener shear strength based on area computed from nominal diameters in Table 9.4.1.2(a) and  $F_{su} = 95$  ksi.  
d Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

**Table 8.1.4.2(a). Static Joint Strength of 100° Flush Shear Head Alloy Steel Lockbolt Fasteners in Machine-Countersunk Aluminum Alloy Sheet and Plate**

|                                                                                                                                                                       |                                                 |                |                   |                |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|----------------|-------------------|----------------|
| Fastener Type .....                                                                                                                                                   | NAS 1436-1442 <sup>a</sup> ( $F_{su} = 95$ ksi) |                |                   |                |
| Sheet and Plate Material .....                                                                                                                                        | Clad 7075-T6 and T651                           |                |                   |                |
| Fastener Diameter, in. ....<br>(Nominal Shank Diameter, in.) ..                                                                                                       | 3/16<br>(0.190)                                 | 1/4<br>(0.250) | 5/16<br>(0.312)   | 3/8<br>(0.375) |
| Sheet or plate thickness, in.:<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 .....<br>0.312 ..... | Ultimate Strength, lbs                          |                |                   |                |
|                                                                                                                                                                       | 1684                                            | ...            | ...               | ...            |
|                                                                                                                                                                       | 1875                                            | ...            | ...               | ...            |
|                                                                                                                                                                       | 2077                                            | ...            | ...               | ...            |
|                                                                                                                                                                       | 2286                                            | 3075           | ...               | ...            |
|                                                                                                                                                                       | 2620                                            | 3750           | 4811              | ...            |
|                                                                                                                                                                       | ...                                             | 4625           | 5994 <sup>b</sup> | 7350           |
|                                                                                                                                                                       | ...                                             | 4650           | 6993              | 8554           |
|                                                                                                                                                                       | ...                                             | ...            | 7300              | 10435          |
|                                                                                                                                                                       | ...                                             | ...            | ...               | 10500          |
|                                                                                                                                                                       | 2620                                            | 4650           | 7300              | 10500          |
| Sheet or plate thickness, in.:<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 .....<br>0.312 ..... | Yield Strength <sup>d</sup> , lbs               |                |                   |                |
|                                                                                                                                                                       | 1405                                            | ...            | ...               | ...            |
|                                                                                                                                                                       | 1598                                            | ...            | ...               | ...            |
|                                                                                                                                                                       | 1717                                            | ...            | ...               | ...            |
|                                                                                                                                                                       | 1850                                            | 2395           | ...               | ...            |
|                                                                                                                                                                       | 2232                                            | 2790           | 3327              | ...            |
|                                                                                                                                                                       | ...                                             | 3415           | 3851              | 5656           |
|                                                                                                                                                                       | ...                                             | 3765           | 4666              | 6342           |
|                                                                                                                                                                       | ...                                             | ...            | 5248              | 7910           |
|                                                                                                                                                                       | ...                                             | ...            | ...               | 8946           |
| Head height (max.), in. ....                                                                                                                                          | 0.049                                           | 0.063          | 0.071             | 0.081          |

a Data supplied by Huck Manufacturing Company.  
b Yield value is less than 2/3 of the indicated ultimate strength value.  
c Fastener shear strength is documented in NAS 1413.  
d Permanent set at yield load: the greater of 0.012 inch or 4% of nominal diameter.

**Table 8.1.4.2(b). Static Joint Strength of 100° Flush Shear/Tension Head Alloy Steel Lockbolt Fasteners in Machine-Countersunk Aluminum Alloy Sheet and Plate**

| Fastener Type . . . . .                                           | NAS 7024-7032 <sup>a,b</sup> ( $F_{su} = 108$ ksi) |                   |                   |                   |                   |                   |
|-------------------------------------------------------------------|----------------------------------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
|                                                                   | Clad 7075-T6 and T651                              |                   |                   |                   |                   |                   |
| Sheet and Plate Material . . . . .                                | 1/8                                                | 5/32              | 3/16              | 1/4               | 5/16              | 3/8               |
| Fastener Diameter, in. . . . .<br>(Nominal Shank Diameter, in.) . | (0.125)                                            | (0.156)           | (0.190)           | (0.250)           | (0.312)           | (0.375)           |
| Sheet or plate thickness, in.:                                    | Ultimate Strength, lbs                             |                   |                   |                   |                   |                   |
|                                                                   |                                                    |                   |                   |                   |                   |                   |
| 0.040 . . . . .                                                   | 563                                                | ...               | ...               | ...               | ...               | ...               |
| 0.050 . . . . .                                                   | 846 <sup>d</sup>                                   | <sup>c</sup> 881  | 1071              | ...               | ...               | ...               |
| 0.063 . . . . .                                                   | 1040 <sup>d</sup>                                  | 1341 <sup>d</sup> | 1398              | ...               | ...               | ...               |
| 0.071 . . . . .                                                   | 1147                                               | 1494 <sup>d</sup> | 1743 <sup>d</sup> | 2001              | ...               | ...               |
| 0.080 . . . . .                                                   | 1231                                               | 1645 <sup>d</sup> | 2083 <sup>d</sup> | 2256              | ...               | ...               |
| 0.090 . . . . .                                                   | 1289                                               | 1813              | 2288 <sup>d</sup> | 2823              | 3071              | ...               |
| 0.100 . . . . .                                                   | 1325                                               | 1921              | 2493 <sup>d</sup> | 3390 <sup>d</sup> | 3425              | <sup>c</sup> 4225 |
| 0.125 . . . . .                                                   | ...                                                | 2070              | 2878              | 4140 <sup>d</sup> | 5200 <sup>d</sup> | <sup>c</sup> 5500 |
| 0.160 . . . . .                                                   | ...                                                | ...               | 3060              | 4930              | 6490              | 8080 <sup>d</sup> |
| 0.190 . . . . .                                                   | ...                                                | ...               | ...               | 5280              | 7530              | 8725 <sup>d</sup> |
| 0.250 . . . . .                                                   | ...                                                | ...               | ...               | 5300              | 7870              | 10010             |
| 0.312 . . . . .                                                   | ...                                                | ...               | ...               | ...               | 8220              | 11270             |
| 0.324 . . . . .                                                   | ...                                                | ...               | ...               | ...               | 8280              | 11340             |
| 0.375 . . . . .                                                   | ...                                                | ...               | ...               | ...               | ...               | 11620             |
| 0.433 . . . . .                                                   | ...                                                | ...               | ...               | ...               | ...               | 11930             |
| Fastener shear strength <sup>e</sup> . . . . .                    | 1325                                               | 2070              | 3060              | 5300              | 8280              | 11930             |
| Sheet or plate thickness, in.:                                    | Yield Strength <sup>f</sup> , lbs                  |                   |                   |                   |                   |                   |
|                                                                   |                                                    |                   |                   |                   |                   |                   |
| 0.040 . . . . .                                                   | 426                                                | ...               | ...               | ...               | ...               | ...               |
| 0.050 . . . . .                                                   | 537                                                | 666               | 804               | ...               | ...               | ...               |
| 0.063 . . . . .                                                   | 682                                                | 846               | 1024              | ...               | ...               | ...               |
| 0.071 . . . . .                                                   | 770                                                | 957               | 1159              | 1508              | ...               | ...               |
| 0.080 . . . . .                                                   | 870                                                | 1082              | 1311              | 1708              | ...               | ...               |
| 0.090 . . . . .                                                   | 981                                                | 1221              | 1430              | 1931              | 2392              | ...               |
| 0.100 . . . . .                                                   | 1092                                               | 1360              | 1649              | 2152              | 2669              | 3177              |
| 0.125 . . . . .                                                   | ...                                                | 1705              | 2071              | 2709              | 3363              | 4010              |
| 0.160 . . . . .                                                   | ...                                                | ...               | 2595              | 3486              | 4340              | 4975              |
| 0.190 . . . . .                                                   | ...                                                | ...               | ...               | 4050              | 5170              | 5760              |
| 0.250 . . . . .                                                   | ...                                                | ...               | ...               | 4140              | 6210              | 7340              |
| 0.312 . . . . .                                                   | ...                                                | ...               | ...               | ...               | 7040              | 8730              |
| 0.324 . . . . .                                                   | ...                                                | ...               | ...               | ...               | 7200              | 8810              |
| 0.375 . . . . .                                                   | ...                                                | ...               | ...               | ...               | ...               | 9160              |
| 0.433 . . . . .                                                   | ...                                                | ...               | ...               | ...               | ...               | 9560              |
| Head height (ref.), in. . . . .                                   | 0.042                                              | 0.050             | 0.060             | 0.077             | 0.094             | 0.111             |

- a Data supplied by Huck Manufacturing Company.  
b Used with NAS1080K aluminum alloy collar.  
c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
d Yield value is less than 2/3 of indicated ultimate strength value.  
e Fastener shear strength is documented in NAS1413.  
f Permanent set at yield load: the greater of 0.012 inch or 4% of nominal diameter.

Table 8.1.4.2(c). Static Joint Strength of 100° Flush Shear Head Ti-6Al-4V Cherrybuck Fasteners in Machine-Countersunk Aluminum Alloy Sheet

|                                                                                                                                                                                                                           |                                           |                 |                |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|-----------------|----------------|
| Fastener Type .....                                                                                                                                                                                                       | CSR 924 <sup>a</sup> ( $F_{su}$ = 95 ksi) |                 |                |
| Sheet Material .....                                                                                                                                                                                                      | Clad 7075-T6                              |                 |                |
| Fastener Diameter, in. ....<br>(Nominal Shank Diameter, in.) <sup>b</sup> ..                                                                                                                                              | 5/32<br>(0.164)                           | 3/16<br>(0.190) | 1/4<br>(0.250) |
| Sheet thickness, in.:<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 .....<br>Fastener shear strength <sup>b</sup> ..... | Ultimate Strength, lbs.                   |                 |                |
|                                                                                                                                                                                                                           | 941                                       | ...             | ...            |
|                                                                                                                                                                                                                           | 1207                                      | 1383            | ...            |
|                                                                                                                                                                                                                           | 1385                                      | 1588            | ...            |
|                                                                                                                                                                                                                           | 1557                                      | 1779            | 2281           |
|                                                                                                                                                                                                                           | 1775                                      | 2050            | 2594           |
|                                                                                                                                                                                                                           | 1876                                      | 2263            | 2919           |
|                                                                                                                                                                                                                           | 1950                                      | 2542            | 3765           |
|                                                                                                                                                                                                                           | 2007                                      | 2660            | 4387           |
|                                                                                                                                                                                                                           | ...                                       | 2694            | 4525           |
|                                                                                                                                                                                                                           | ...                                       | ...             | 4660           |
|                                                                                                                                                                                                                           | 2007                                      | 2694            | 4660           |
| Sheet thickness, in.:<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 .....                                               | Yield Strength <sup>c</sup> , lbs.        |                 |                |
|                                                                                                                                                                                                                           | 659                                       | ...             | ...            |
|                                                                                                                                                                                                                           | 887                                       | 985             | ...            |
|                                                                                                                                                                                                                           | 1022                                      | 1148            | ...            |
|                                                                                                                                                                                                                           | 1116                                      | 1325            | 1625           |
|                                                                                                                                                                                                                           | 1189                                      | 1480            | 1894           |
|                                                                                                                                                                                                                           | 1257                                      | 1545            | 2162           |
|                                                                                                                                                                                                                           | 1393                                      | 1733            | 2619           |
|                                                                                                                                                                                                                           | 1608                                      | 1978            | 2950           |
|                                                                                                                                                                                                                           | ...                                       | 2191            | 3231           |
|                                                                                                                                                                                                                           | ...                                       | ...             | 3794           |
| Head height (ref.), in. ....                                                                                                                                                                                              | 0.034                                     | 0.046           | 0.060          |

a Data supplied by Cherry Fasteners.  
b Fastener shear strength based on area computed from nominal shank diameter in Table 9.4.1.2(a) and  $F_{su}$  = 95 ksi.  
c Permanent set at yield load; 4% of nominal diameter (Ref. 9.4.1.3.3).

Table 8.1.4.2(d). Static Joint Strength of 100° Flush Shear Head Ti-6Al-4V Cherrybuck Fasteners in Machine-Countersunk Aluminum Alloy Sheet

|                                                                                                                                                                                                                           |                                           |                   |                   |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|-------------------|-------------------|
| Fastener Type .....                                                                                                                                                                                                       | CSR 924 <sup>a</sup> ( $F_{su} = 95$ ksi) |                   |                   |
| Sheet Material .....                                                                                                                                                                                                      | Clad 2024-T3                              |                   |                   |
| Fastener Diameter, in. ....<br>(Nominal Shank Diameter, in.) <sup>b</sup> ..                                                                                                                                              | 5/32<br>(0.164)                           | 3/16<br>(0.190)   | 1/4<br>(0.250)    |
| Sheet thickness, in.:<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 .....<br>Fastener shear strength <sup>d</sup> ..... | Ultimate Strength, lbs.                   |                   |                   |
|                                                                                                                                                                                                                           | 737                                       | ...               | ...               |
|                                                                                                                                                                                                                           | 1019                                      | 1118              | ...               |
|                                                                                                                                                                                                                           | 1152                                      | 1319              | ...               |
|                                                                                                                                                                                                                           | 1279 <sup>c</sup>                         | 1509              | 1837              |
|                                                                                                                                                                                                                           | 1419 <sup>c</sup>                         | 1673 <sup>c</sup> | 2168              |
|                                                                                                                                                                                                                           | 1560 <sup>c</sup>                         | 1834 <sup>c</sup> | 2500              |
|                                                                                                                                                                                                                           | 1898 <sup>c</sup>                         | 2242 <sup>c</sup> | 3036 <sup>c</sup> |
|                                                                                                                                                                                                                           | 2007 <sup>c</sup>                         | 2680 <sup>c</sup> | 3786 <sup>c</sup> |
|                                                                                                                                                                                                                           | ...                                       | 2694              | 4404 <sup>c</sup> |
|                                                                                                                                                                                                                           | ...                                       | ...               | 4660              |
|                                                                                                                                                                                                                           | 2007                                      | 2694              | 4660              |
| Sheet thickness, in.:<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 .....                                               | Yield Strength <sup>e</sup> , lbs.        |                   |                   |
|                                                                                                                                                                                                                           | 511                                       | ...               | ...               |
|                                                                                                                                                                                                                           | 712                                       | 778               | ...               |
|                                                                                                                                                                                                                           | 786                                       | 922               | ...               |
|                                                                                                                                                                                                                           | 840                                       | 1039              | 1276              |
|                                                                                                                                                                                                                           | 900                                       | 1109              | 1513              |
|                                                                                                                                                                                                                           | 960                                       | 1178              | 1750              |
|                                                                                                                                                                                                                           | 1110                                      | 1352              | 1979              |
|                                                                                                                                                                                                                           | 1321                                      | 1596              | 2300              |
|                                                                                                                                                                                                                           | ...                                       | 1805              | 2575              |
|                                                                                                                                                                                                                           | ...                                       | ...               | 3125              |
| Head height (ref.), in. ....                                                                                                                                                                                              | 0.034                                     | 0.046             | 0.060             |

a Data supplied by Cherry Fasteners.  
b Fasteners installed in clearance holes (0.0005 - 0.002) (Ref. Section 8.1.4).  
c Yield load is less than 2/3 of indicated ultimate.  
d Fastener shear strength based on area computed from nominal shank diameter in Table 9.4.1.2(a) and  $F_{su} = 95$  ksi.  
e Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

Table 8.1.4.2(e). Static Joint Strength of 100° Flush Shear Head A-286 Rivets in Machine-Countersunk Aluminum Alloy Sheet

|                                                                                                                                                                                             |                                          |                 |                |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------|-----------------|----------------|
| Fastener Type .....                                                                                                                                                                         | HSR201 <sup>a</sup> ( $F_{su}$ = 95 ksi) |                 |                |
| Sheet Material .....                                                                                                                                                                        | 7075-T6                                  |                 |                |
| Fastener Diameter, in. ....<br>(Nominal Shank Diameter, in.) <sup>b</sup> ..                                                                                                                | 5/32<br>(0.164)                          | 3/16<br>(0.190) | 1/4<br>(0.250) |
| Sheet thickness, in.:<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>Fastener shear strength <sup>c</sup> ..... | Ultimate Strength, lbs.                  |                 |                |
|                                                                                                                                                                                             | 1055                                     | 1095            | ...            |
|                                                                                                                                                                                             | 1330                                     | 1545            | 2030           |
|                                                                                                                                                                                             | 1500                                     | 1740            | 2285           |
|                                                                                                                                                                                             | 1690                                     | 1955            | 2575           |
|                                                                                                                                                                                             | 1900                                     | 2200            | 2895           |
|                                                                                                                                                                                             | 2007                                     | 2445            | 3220           |
|                                                                                                                                                                                             | ...                                      | 2694            | 4025           |
|                                                                                                                                                                                             | ...                                      | ...             | 4660           |
|                                                                                                                                                                                             | 2007                                     | 2694            | 4660           |
| Sheet thickness, in.:<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>Head height (nom.), in. ....               | Yield Strength <sup>d</sup> , lbs.       |                 |                |
|                                                                                                                                                                                             | 835                                      | 870             | ...            |
|                                                                                                                                                                                             | 1055                                     | 1225            | 1605           |
|                                                                                                                                                                                             | 1185                                     | 1380            | 1810           |
|                                                                                                                                                                                             | 1340                                     | 1550            | 2040           |
|                                                                                                                                                                                             | 1505                                     | 1745            | 2295           |
|                                                                                                                                                                                             | 1675                                     | 1940            | 2550           |
|                                                                                                                                                                                             | ...                                      | 2420            | 3190           |
|                                                                                                                                                                                             | ...                                      | ...             | 4180           |
|                                                                                                                                                                                             | 0.040                                    | 0.046           | 0.060          |

a Data supplied by Hi-Shear Corporation.  
b Hole Size: Fastener installed in 0.000 interference to 0.005 clearance (Ref. Section 8.1.4).  
c Fastener shear strength based on area computed from nominal shank diameter in Table 9.4.1.2(a) and  $F_{su}$  = 95 ksi.  
d Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).



**Table 8.1.4.2(f). Static Joint Strength of 100° Flush Shear Head Ti-8Mo-8V-2Fe-3Al Rivets in Machine-Countersunk Aluminum Alloy Sheet**

|                                                                           |                                          |                 |                |
|---------------------------------------------------------------------------|------------------------------------------|-----------------|----------------|
| Rivet Type .....                                                          | HSR101 <sup>a</sup> ( $F_{su} = 95$ ksi) |                 |                |
| Sheet Material .....                                                      | 7075-T6                                  |                 |                |
| Rivet Diameter, in. ....<br>(Nominal Shank Diameter, in.) <sup>b</sup> .. | 5/32<br>(0.164)                          | 3/16<br>(0.190) | 1/4<br>(0.250) |
| Ultimate Strength, lbs.                                                   |                                          |                 |                |
| Sheet thickness, in.:                                                     |                                          |                 |                |
| 0.050 .....                                                               | 1040                                     | 1205            | ...            |
| 0.063 .....                                                               | 1310                                     | 1520            | 2000           |
| 0.071 .....                                                               | 1480                                     | 1715            | 2255           |
| 0.080 .....                                                               | 1665                                     | 1930            | 2540           |
| 0.090 .....                                                               | 1875                                     | 2170            | 2855           |
| 0.100 .....                                                               | 2007                                     | 2410            | 3175           |
| 0.125 .....                                                               | ...                                      | 2694            | 3965           |
| 0.160 .....                                                               | ...                                      | ...             | 4660           |
| Rivet shear strength <sup>c</sup> .....                                   | 2007                                     | 2694            | 4660           |
| Yield Strength <sup>d</sup> , lbs.                                        |                                          |                 |                |
| Sheet thickness, in.:                                                     |                                          |                 |                |
| 0.050 .....                                                               | 797                                      | 921             | ...            |
| 0.063 .....                                                               | 1005                                     | 1165            | 1530           |
| 0.071 .....                                                               | 1130                                     | 1310            | 1725           |
| 0.080 .....                                                               | 1275                                     | 1475            | 1945           |
| 0.090 .....                                                               | 1435                                     | 1660            | 2185           |
| 0.100 .....                                                               | 1595                                     | 1845            | 2430           |
| 0.125 .....                                                               | ...                                      | 2310            | 3035           |
| 0.160 .....                                                               | ...                                      | ...             | 3885           |
| Head height (nom.), in. ....                                              | 0.040                                    | 0.046           | 0.060          |

a Data supplied by Hi-Shear Corporation.

b Hole Size: Fastener installed in 0.000 interference to 0.005 clearance (Ref. Section 8.1.4).

c Fastener shear strength based on area computed from nominal shank diameter in Table 9.4.1.2(a) and  $1/4 = 0.250$  and  $F_{su} = 95$  ksi.

d Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

Table 8.1.4.2(g). Static Joint Strength of 100° Flush Shear Head Ti-6Al-4V Lockbolt Fasteners in Machine-Countersunk Aluminum Alloy Sheet

|                                                                                                                                                                                                                                                                    |                                                                 |                |                   |                   |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|----------------|-------------------|-------------------|
| Rivet Type . . . . .                                                                                                                                                                                                                                               | GPL3SC-V Pin <sup>a,b</sup> ( $F_{su}$ = 95 ksi), 2SC-3C Collar |                |                   |                   |
| Sheet Material . . . . .                                                                                                                                                                                                                                           | Clad 7075-T6                                                    |                |                   |                   |
| Rivet Diameter, in. . . . .<br>(Nominal Shank Diameter, in) <sup>c</sup> . . .                                                                                                                                                                                     | 3/16<br>(0.190)                                                 | 1/4<br>(0.250) | 5/16<br>(0.312)   | 3/8<br>(0.375)    |
| Sheet thickness, in.:<br>0.050 . . . . .<br>0.063 . . . . .<br>0.071 . . . . .<br>0.080 . . . . .<br>0.090 . . . . .<br>0.100 . . . . .<br>0.125 . . . . .<br>0.160 . . . . .<br>0.190 . . . . .<br>0.250 . . . . .<br>Rivet shear strength <sup>d</sup> . . . . . | Ultimate Strength, lbs.                                         |                |                   |                   |
|                                                                                                                                                                                                                                                                    | 1105                                                            | ...            | ...               | ...               |
|                                                                                                                                                                                                                                                                    | 1500                                                            | 1800           | ...               | ...               |
|                                                                                                                                                                                                                                                                    | 1740                                                            | 2125           | <sup>e</sup> 2430 | ...               |
|                                                                                                                                                                                                                                                                    | 2020                                                            | 2485           | 2865              | 3170              |
|                                                                                                                                                                                                                                                                    | 2200                                                            | 2885           | 3365              | 3780 <sup>e</sup> |
|                                                                                                                                                                                                                                                                    | 2355                                                            | 3310           | 3865              | 4390              |
|                                                                                                                                                                                                                                                                    | 2694                                                            | 3945           | 5135              | 5880              |
|                                                                                                                                                                                                                                                                    | ...                                                             | 4660           | 6245              | 8005              |
|                                                                                                                                                                                                                                                                    | ...                                                             | ...            | 7010              | 8955              |
|                                                                                                                                                                                                                                                                    | ...                                                             | ...            | 7290              | 10490             |
|                                                                                                                                                                                                                                                                    | 2694                                                            | 4660           | 7290              | 10490             |
| Sheet thickness, in.:<br>0.050 . . . . .<br>0.063 . . . . .<br>0.071 . . . . .<br>0.080 . . . . .<br>0.090 . . . . .<br>0.100 . . . . .<br>0.125 . . . . .<br>0.160 . . . . .<br>0.190 . . . . .<br>0.250 . . . . .                                                | Yield Strength <sup>f</sup> , lbs.                              |                |                   |                   |
|                                                                                                                                                                                                                                                                    | 948                                                             | ...            | ...               | ...               |
|                                                                                                                                                                                                                                                                    | 1160                                                            | 1585           | ...               | ...               |
|                                                                                                                                                                                                                                                                    | 1290                                                            | 1755           | 2265              | ...               |
|                                                                                                                                                                                                                                                                    | 1435                                                            | 1945           | 2500              | 3090              |
|                                                                                                                                                                                                                                                                    | 1600                                                            | 2160           | 2765              | 3415              |
|                                                                                                                                                                                                                                                                    | 1760                                                            | 2375           | 3030              | 3740              |
|                                                                                                                                                                                                                                                                    | 2095                                                            | 2910           | 3705              | 4535              |
|                                                                                                                                                                                                                                                                    | ...                                                             | 3585           | 4640              | 5670              |
|                                                                                                                                                                                                                                                                    | ...                                                             | ...            | 5440              | 6635              |
|                                                                                                                                                                                                                                                                    | ...                                                             | ...            | 6270              | 8230              |
| Head height (ref.), in. . . . .                                                                                                                                                                                                                                    | 0.048                                                           | 0.063          | 0.070             | 0.081             |

a Data supplied by Huck Manufacturing Company and Voi-Shan Industries.  
b Aluminum coated per NAS 4006.  
c Hole Size: Fastener installed in 0.005" interference to 0.0005" clearance (Ref. Section 8.1.4).  
d Fastener shear strength based on area computed from nominal shank diameter in Table 9.4.1.2(a) and 1/4 = 0.250 and  $F_{su}$  = 95 ksi.  
e Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
f Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

Table 8.1.4.2(h). Static Joint Strength of 100° Flush Shear Head Ti-6Al-4V Lockbolt Fasteners in Machine-Countersunk Aluminum Alloy Sheet and Plate

|                                                                             |                                                                 |                   |                   |                   |
|-----------------------------------------------------------------------------|-----------------------------------------------------------------|-------------------|-------------------|-------------------|
| Rivet Type . . . . .                                                        | GPL3SC-V Pin <sup>a,b</sup> ( $F_{su} = 95$ ksi), 2SC-3C Collar |                   |                   |                   |
| Sheet Material . . . . .                                                    | Clad 2024-T3                                                    |                   |                   |                   |
| Rivet Diameter, in. . . . .<br>(Nominal Shank Diameter, in.) <sup>c</sup> . | 3/16<br>(0.190)                                                 | 1/4<br>(0.250)    | 5/16<br>(0.312)   | 3/8<br>(0.375)    |
| Sheet thickness, in.:                                                       | Ultimate Strength, lbs.                                         |                   |                   |                   |
| 0.050 . . . . .                                                             | 938                                                             | ...               | ...               | ...               |
| 0.063 . . . . .                                                             | 1255                                                            | 1535              | ...               | ...               |
| 0.071 . . . . .                                                             | 1455                                                            | 1795              | <sup>f</sup> 2085 | ...               |
| 0.080 . . . . .                                                             | 1680                                                            | 2085              |                   | 2740              |
| 0.090 . . . . .                                                             | 1920 <sup>e</sup>                                               | 2410              | 2845              | 3230 <sup>f</sup> |
| 0.100 . . . . .                                                             | 2080 <sup>e</sup>                                               | 2735              | 3245              | 3725              |
| 0.125 . . . . .                                                             | 2460 <sup>e</sup>                                               | 3470 <sup>e</sup> | 4270              | 4930              |
| 0.160 . . . . .                                                             | 2694                                                            | 4175 <sup>e</sup> | 5505 <sup>e</sup> | 6645              |
| 0.190 . . . . .                                                             | ...                                                             | 4590 <sup>e</sup> | 6260 <sup>e</sup> | 7885 <sup>e</sup> |
| 0.250 . . . . .                                                             | ...                                                             | 4660              | 7230              | 9705 <sup>e</sup> |
| 0.312 . . . . .                                                             | ...                                                             | ...               | 7290              | 10490             |
| 0.375 . . . . .                                                             | ...                                                             | ...               | ...               | ...               |
| Rivet shear strength <sup>d</sup> . . . . .                                 | 2694                                                            | 4660              | 7290              | 10490             |
| Sheet thickness, in.:                                                       | Yield Strength <sup>g</sup> , lbs.                              |                   |                   |                   |
| 0.050 . . . . .                                                             | 777                                                             | ...               | ...               | ...               |
| 0.063 . . . . .                                                             | 945                                                             | 1285              | ...               | ...               |
| 0.071 . . . . .                                                             | 1050                                                            | 1435              | 1810              | ...               |
| 0.080 . . . . .                                                             | 1140                                                            | 1590              | 2030              | 2440              |
| 0.090 . . . . .                                                             | 1230                                                            | 1760              | 2260              | 2750              |
| 0.100 . . . . .                                                             | 1320                                                            | 1910              | 2475              | 3065              |
| 0.125 . . . . .                                                             | 1545                                                            | 2205              | 2975              | 3705              |
| 0.160 . . . . .                                                             | 1860                                                            | 2620              | 3495              | 4475              |
| 0.190 . . . . .                                                             | ...                                                             | 2975              | 3935              | 5010              |
| 0.250 . . . . .                                                             | ...                                                             | 3685              | 4820              | 6075              |
| 0.312 . . . . .                                                             | ...                                                             | ...               | 5740              | 7175              |
| Head height (ref.), in. . . . .                                             | 0.048                                                           | 0.063             | 0.070             | 0.081             |

a Data supplied by Huck Manufacturing Company and Voi-Shan Industries.  
b Aluminum coated per NAS 4006.  
c Hole size: Fasteners installed in 0.005" interference to 0.0005" clearance (Ref. Section 8.1.4).  
d Fastener shear strength based on area computed from nominal shank diameter in Table 9.4.1.2(a) and  $F_{su} = 95$  ksi.  
e Yield load is less than 2/3 of indicated ultimate.  
f Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
g Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

**Table 8.1.4.2(i). Static Joint Strength of 100° Flush Shear Head Ti-6Al-4V Lockbolt Fasteners in Machine-Countersunk Aluminum Alloy Sheet and Plate**

|                                                                          |                                                                  |                |                   |                   |
|--------------------------------------------------------------------------|------------------------------------------------------------------|----------------|-------------------|-------------------|
| Rivet Type .....                                                         | LGPL2SC-V Pin <sup>a,b</sup> ( $F_{su} = 95$ ksi), 3SLC-C Collar |                |                   |                   |
| Sheet Material .....                                                     | Clad 7075-T6                                                     |                |                   |                   |
| Rivet Diameter, in. ....<br>(Nominal Shank Diameter, in.) <sup>c</sup> . | 3/16<br>(0.190)                                                  | 1/4<br>(0.250) | 5/16<br>(0.312)   | 3/8<br>(0.375)    |
| Sheet thickness, in.:                                                    | Ultimate Strength, lbs.                                          |                |                   |                   |
| 0.050 .....                                                              | 1040                                                             | ...            | ...               | ...               |
| 0.063 .....                                                              | 1370                                                             | 1710           | ...               | ...               |
| 0.071 .....                                                              | 1575                                                             | 1980           | <sup>e</sup> 2345 | ...               |
| 0.080 .....                                                              | 1805                                                             | 2280           | 2715              | 3105              |
| 0.090 .....                                                              | 2060                                                             | 2615           | 3130              | 3620 <sup>e</sup> |
| 0.100 .....                                                              | 2315                                                             | 2950           | 3550              | 4130              |
| 0.125 .....                                                              | 2590                                                             | 3790           | 4605              | 5375              |
| 0.160 .....                                                              | 2694                                                             | 4430           | 6070              | 7150              |
| 0.190 .....                                                              | ...                                                              | 4660           | 6750              | 8660              |
| 0.250 .....                                                              | ...                                                              | ...            | 7290              | 10154             |
| 0.312 .....                                                              | ...                                                              | ...            | ...               | 10490             |
| Rivet shear strength <sup>d</sup> .....                                  | 2694                                                             | 4660           | 7290              | 10490             |
| Sheet thickness, in.:                                                    | Yield Strength <sup>f</sup> , lbs.                               |                |                   |                   |
| 0.050 .....                                                              | 948                                                              | ...            | ...               | ...               |
| 0.063 .....                                                              | 1160                                                             | 1585           | ...               | ...               |
| 0.071 .....                                                              | 1290                                                             | 1755           | 2265              | ...               |
| 0.080 .....                                                              | 1435                                                             | 1945           | 2500              | 3090              |
| 0.090 .....                                                              | 1600                                                             | 2160           | 2765              | 3415              |
| 0.100 .....                                                              | 1760                                                             | 2375           | 3030              | 3740              |
| 0.125 .....                                                              | 2095                                                             | 2910           | 3705              | 4535              |
| 0.160 .....                                                              | 2395                                                             | 3585           | 4640              | 5670              |
| 0.190 .....                                                              | ...                                                              | 3900           | 5440              | 6635              |
| 0.250 .....                                                              | ...                                                              | ...            | 6270              | 8230              |
| 0.312 .....                                                              | ...                                                              | ...            | ...               | 9255              |
| Head height (ref.), in. ....                                             | 0.048                                                            | 0.063          | 0.070             | 0.081             |

a Data supplied by Huck Manufacturing Company and Voi-Shan Industries.  
b Aluminum coated per NAS 4006.  
c Hole size: Fasteners installed in 0.005" interference to 0.0005" clearance (Ref. Section 8.1.4).  
d Fastener shear strength based on area computed from nominal shank diameter in Table 9.4.1.2(a) and  $F_{su} = 95$  ksi.  
e Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
f Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

Table 8.1.4.2(j). Static Joint Strength of 100° Flush Shear Head Ti-6Al-4V Lockbolt Fasteners in Machine-Countersunk Aluminum Alloy Sheet and Plate

|                                                                          |                                                                  |                   |                   |                   |
|--------------------------------------------------------------------------|------------------------------------------------------------------|-------------------|-------------------|-------------------|
| Rivet Type .....                                                         | LGPL2SC-V Pin <sup>a,b</sup> ( $F_{su}$ = 95 ksi), 3SLC-C Collar |                   |                   |                   |
| Sheet Material .....                                                     | Clad 2024-T3                                                     |                   |                   |                   |
| Rivet Diameter, in. ....<br>(Nominal Shank Diameter, in.) <sup>c</sup> . | 3/16<br>(0.190)                                                  | 1/4<br>(0.250)    | 5/16<br>(0.312)   | 3/8<br>(0.375)    |
| Sheet thickness, in.:                                                    | Ultimate Strength, lbs.                                          |                   |                   |                   |
| 0.050 .....                                                              | 836                                                              | ...               | ...               | ...               |
| 0.063 .....                                                              | 1180                                                             | 1350              | ...               | ...               |
| 0.071 .....                                                              | 1395                                                             | 1630              | <sup>f</sup> 1775 | ...               |
| 0.080 .....                                                              | 1640                                                             | 1950              |                   | 2270              |
| 0.090 .....                                                              | 1900 <sup>e</sup>                                                | 2300              | 2595              | 2800 <sup>f</sup> |
| 0.100 .....                                                              | 2115 <sup>e</sup>                                                | 2650              | 3035              | 3335              |
| 0.125 .....                                                              | 2340                                                             | 3530 <sup>e</sup> | 4140              | 4640              |
| 0.160 .....                                                              | 2655                                                             | 4000              | 5645 <sup>e</sup> | 6500              |
| 0.190 .....                                                              | 2694                                                             | 4355              | 6085              | 8080 <sup>e</sup> |
| 0.250 .....                                                              | ...                                                              | 4660              | 6965              | 9180              |
| 0.312 .....                                                              | ...                                                              | ...               | 7290              | 10270             |
| 0.375 .....                                                              | ...                                                              | ...               | ...               | 10490             |
| Rivet shear strength <sup>d</sup> .....                                  | 2694                                                             | 4660              | 7290              | 10490             |
| Sheet thickness, in.:                                                    | Yield Strength <sup>g</sup> , lbs.                               |                   |                   |                   |
| 0.050 .....                                                              | 733                                                              | ...               | ...               | ...               |
| 0.063 .....                                                              | 901                                                              | 1220              | ...               | ...               |
| 0.071 .....                                                              | 1005                                                             | 1360              | 1745              | ...               |
| 0.080 .....                                                              | 1125                                                             | 1515              | 1930              | 2270              |
| 0.090 .....                                                              | 1250                                                             | 1685              | 2140              | 2635              |
| 0.100 .....                                                              | 1380                                                             | 1855              | 2355              | 2895              |
| 0.125 .....                                                              | 1640                                                             | 2280              | 2895              | 3530              |
| 0.160 .....                                                              | 1910                                                             | 2795              | 3640              | 4430              |
| 0.190 .....                                                              | 2140                                                             | 3100              | 4230              | 5200              |
| 0.250 .....                                                              | ...                                                              | 3700              | 4985              | 6440              |
| 0.312 .....                                                              | ...                                                              | ...               | 5760              | 7375              |
| 0.375 .....                                                              | ...                                                              | ...               | ...               | 8325              |
| Head height (ref.), in. ....                                             | 0.048                                                            | 0.063             | 0.070             | 0.081             |

a Data supplied by Huck Manufacturing Company and Voi-Shan Industries.  
b Aluminum coated per NAS 4006.  
c Hole size: Fasteners installed in 0.0005" interference to 0.0005" clearance (Ref. Section 8.1.4).  
d Fastener shear strength based on area computed from nominal shank diameter in Table 9.4.1.2(a) and  $F_{su}$  = 95 ksi.  
e Yield load is less than 2/3 of indicated ultimate.  
f Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
g Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

**8.1.5 THREADED FASTENERS** — The strengths shown in the following tables are applicable only when grip lengths and hole tolerances are as recommended by the respective fastener manufacturers. For some fastener systems, permanent set at yield load may be increased if hole sizes greater than those listed in the applicable table are used. This condition may exist even though the test hole size lies within the manufacturer's recommended hole size range (refer to Section 9.4.1.3.3).

The ultimate single shear strength of threaded fasteners at full diameter is shown in Table 8.1.5(a). The ultimate tensile strength of threaded fasteners is shown in Tables 8.1.5(b<sub>1</sub>) and (b<sub>2</sub>). In both tables values shown are a product of the indicated strength and area, with the area based on the following:

*Shear* — Based on basic shank diameter.

*Tension* — Based on the nominal minor diameter of the thread as published in Table 2.21 of Handbook H-28.

For any given threaded fastener the allowable load shall be chosen using an appropriate category corresponding to minimum tensile strength, shear strength, or other requirements of the pertinent procurement specification.

It is recognized that some procurement specifications may provide higher tensile strengths than those reported in Tables 8.1.5(b<sub>1</sub>) and (b<sub>2</sub>), since they may be based on a larger effective area than shown in the table. The values listed herein have been judged acceptable for design, acknowledging that they may be slightly conservative since they are based on the nominal minor diameter area.

Unless otherwise specified, the yield load is defined in Section 9.4.1.3.3 for threaded fasteners as the load at which the joint permanent is set equal to 0.04D, where D is the decimal equivalent of the fastener shank diameter as defined in Table 9.4.1.2(a).

**8.1.5.1 Protruding-Head Threaded Fastener Joints** — It has been shown that protruding shear head (representative configuration is NAS 1982) fastener joints may not develop the full bearing strength of the joint material. Therefore, static allowable loads for protruding shear head fasteners must be established from test data using the criteria specified in Section 9.4.1. For shear joints with protruding tension head fasteners, the load per fastener at which shear or bearing type of failure occurs is separately calculated, and the lower of the two values so determined governs the design. Allowable shear loads may be obtained from Table 8.1.5(a).

The design bearing stresses for various materials at room and other temperatures are given in the properties for each alloy or group of alloys, and are applicable to joints with fasteners in cylindrical holds and where  $t/D \geq 0.18$ . Where  $t/D < 0.18$ , tests to substantiate yield and ultimate bearing strengths must be performed. These bearing stresses are applicable only for design of rigid joints where there is no possibility of relative motion of the parts joined without deformation of such parts.

For convenience, "unit" sheet bearing strengths for threaded fasteners, based on a strength of 100 ksi and nominal fastener diameters, are given in Table 8.1.5.1. The strength for a specific combination of fasteners, sheet thickness, and sheet material is obtained by multiplying the proper "unit" strength by the ratio of material allowable bearing stress (ksi) to 100.

The following interaction formula is applicable to AN3 series bolts under combined shear and tension loading:  $R_s^3 + R_t^2 = 1.0$ , where  $R_s$  and  $R_t$  are ratios of applied load to allowable load in shear and tension, respectively.

**8.1.5.2 Flush-Head Threaded Fastener Joints** — Tables 8.1.5.2(a) through (o) contain joint allowables for various flush-head threaded fastener/sheet material combinations. Unless otherwise noted, the allowable loads for flush-head threaded fasteners were established from test data using the following criteria;

*Ultimate Load* — Average ultimate test load divided by a factor of 1.15, as defined in Chapter 9. This factor is not applicable to shear strength cutoff values which may be either procurement specification shear strength (S value) of the fastener or, if no specification exists, a statistical value determined from test results. It should coincide with shear values from Table 8.1.5(a).

The allowables shown for flush-head threaded fasteners are applicable to joints having  $e/D$  equal to or greater than 2.0.

For machine countersunk joints, the sheet gage specified in the tables is that of the countersunk sheet. When the noncountersunk sheet is thinner than the countersunk sheet, the bearing allowable for the noncountersunk sheet-fastener combination should be computed, compared to the table value, and the lower of the two values selected.

Table 8.1.5(a). Ultimate Single Shear Strength of Threaded Fasteners

| Shear Stress of Fastener, ksi |                   |             | 35                                   | 38    | 75     | 90     | 95     | 108    | 125    | 132    | 145    | 156    |
|-------------------------------|-------------------|-------------|--------------------------------------|-------|--------|--------|--------|--------|--------|--------|--------|--------|
| Fastener Diameter             |                   | Basic Shank |                                      |       |        |        |        |        |        |        |        |        |
| in.                           | Size <sup>a</sup> | Area        | Ultimate Single Shear Strength, lbs. |       |        |        |        |        |        |        |        |        |
| 0.112                         | #4                | 0.0098520   | 345                                  | 374   | 739    | 887    | 936    | 1060   | 1230   | 1300   | 1425   | 1535   |
| 0.125                         | 1/8               | 0.012272    | 430                                  | 466   | 920    | 1105   | 1165   | 1325   | 1530   | 1620   | 1775   | 1910   |
| 0.138                         | #6                | 0.014957    | 523                                  | 568   | 1120   | 1345   | 1420   | 1615   | 1870   | 1970   | 2165   | 2330   |
| 0.156                         | 5/32              | 0.019175    | 671                                  | 729   | 1435   | 1725   | 1820   | 2070   | 2395   | 2530   | 2780   | 2990   |
| 0.164                         | #8                | 0.021124    | 739                                  | 803   | 1580   | 1900   | 2005   | 2280   | 2640   | 2785   | 3060   | 3295   |
| 0.188                         | 3/16              | 0.027612    | 966                                  | 1045  | 2070   | 2485   | 2620   | 2980   | 3450   | 3645   | 4005   | 4310   |
| 0.190                         | #10               | 0.028353    | 992                                  | 1075  | 2125   | 2550   | 2690   | 3060   | 3540   | 3740   | 4110   | 4420   |
| 0.216                         | #12               | 0.036644    | 1280                                 | 1390  | 2745   | 3295   | 3480   | 3955   | 4580   | 4840   | 5315   | 5720   |
| 0.219                         | 7/32              | 0.037582    | 1315                                 | 1425  | 2815   | 3380   | 3570   | 4060   | 4700   | 4960   | 5445   | 5860   |
| 0.250                         | 1/4               | 0.049087    | 1715                                 | 1865  | 3680   | 4420   | 4660   | 5300   | 6140   | 6480   | 7115   | 7660   |
| 0.312                         | 5/16              | 0.076699    | 2680                                 | 2915  | 5750   | 6900   | 7290   | 8280   | 9590   | 10100  | 11100  | 11950  |
| 0.375                         | 3/8               | 0.11045     | 3865                                 | 4200  | 8280   | 9935   | 10450  | 11900  | 13800  | 14550  | 16000  | 17200  |
| 0.438                         | 7/16              | 0.15033     | 5260                                 | 5710  | 11250  | 13500  | 14250  | 16200  | 18750  | 19800  | 21750  | 23450  |
| 0.500                         | 1/2               | 0.19635     | 6870                                 | 7460  | 14700  | 17650  | 18650  | 21200  | 24500  | 25900  | 28450  | 30600  |
| 0.562                         | 9/16              | 0.24850     | 8700                                 | 9440  | 18600  | 22350  | 23600  | 26800  | 31050  | 32800  | 36000  | 38750  |
| 0.625                         | 5/8               | 0.30680     | 10700                                | 11650 | 23000  | 27600  | 29150  | 33100  | 38350  | 40500  | 44500  | 47900  |
| 0.750                         | 3/4               | 0.44179     | 15450                                | 16750 | 33100  | 39750  | 42000  | 47700  | 55200  | 58300  | 64000  | 68900  |
| 0.875                         | 7/8               | 0.60132     | 21050                                | 22850 | 45100  | 54100  | 57100  | 64900  | 75200  | 79400  | 87200  | 93800  |
| 1.000                         | 1                 | 0.78540     | 27450                                | 29850 | 58900  | 70700  | 74600  | 84800  | 98200  | 103500 | 113500 | 122500 |
| 1.125                         | 1-1/8             | 0.99402     | 34750                                | 37750 | 74600  | 89500  | 94400  | 107000 | 124000 | 131000 | 144000 | 155000 |
| 1.250                         | 1-1/4             | 1.2272      | 43000                                | 46600 | 92000  | 110000 | 116500 | 132500 | 153000 | 162000 | 177500 | 191000 |
| 1.375                         | 1-3/8             | 1.4849      | 52000                                | 56400 | 111000 | 133500 | 141000 | 160000 | 185500 | 196000 | 215000 | 231500 |
| 1.500                         | 1-1/2             | 1.7671      | 61800                                | 67100 | 132500 | 159000 | 167500 | 190500 | 220500 | 233000 | 256000 | 275500 |

a Fractional equivalent or screw number.



**Table 8.1.5(b<sub>1</sub>). Ultimate Tensile Strength of Threaded Fasteners**

| Tensile Stress of Fastener, ksi |          |                                       | 55                                             | 62    | 62.5  | 125    | 140    | 160    | 180    |
|---------------------------------|----------|---------------------------------------|------------------------------------------------|-------|-------|--------|--------|--------|--------|
| Fastener Diameter               |          | Nominal<br>Minor<br>Area <sup>d</sup> | MIL-S-7742                                     |       |       |        |        |        |        |
|                                 |          |                                       | Ultimate Tensile Strength, lbs. <sup>a,b</sup> |       |       |        |        |        |        |
| in.                             | c        |                                       |                                                |       |       |        |        |        |        |
| 0.112                           | 4-40     | 0.0050896                             | 280                                            | 316   | 318   | 636    | 713    | 814    | 916    |
| 0.138                           | 6-32     | 0.0076821                             | 423                                            | 476   | 480   | 960    | 1075   | 1225   | 1380   |
| 0.164                           | 8-32     | 0.012233                              | 673                                            | 758   | 765   | 1525   | 1710   | 1955   | 2200   |
| 0.190                           | 10-32    | 0.018074                              | 994                                            | 1120  | 1130  | 2255   | 2530   | 2890   | 3250   |
| 0.250                           | 1/4-28   | 0.033394                              | 1835                                           | 2070  | 2085  | 4170   | 4680   | 5340   | 6010   |
| 0.312                           | 5/16-24  | 0.053666                              | 2950                                           | 3325  | 3350  | 6710   | 7510   | 8590   | 9660   |
| 0.375                           | 3/8-24   | 0.082397                              | 4530                                           | 5110  | 5150  | 10300  | 11500  | 13150  | 14800  |
| 0.438                           | 7/16-20  | 0.11115                               | 6110                                           | 6890  | 6950  | 13850  | 15550  | 17750  | 20000  |
| 0.500                           | 1/2-20   | 0.15116                               | 8310                                           | 9370  | 9450  | 18900  | 21150  | 24150  | 27200  |
| 0.562                           | 9/16-18  | 0.19190                               | 10550                                          | 11900 | 11950 | 23950  | 26850  | 30700  | 34500  |
| 0.625                           | 5/8-18   | 0.24349                               | 13350                                          | 15100 | 15200 | 30400  | 34050  | 38950  | 43800  |
| 0.750                           | 3/4-16   | 0.35605                               | 19550                                          | 22050 | 22250 | 44500  | 49800  | 57000  | 64100  |
| 0.875                           | 7/8-14   | 0.48695                               | 26750                                          | 30150 | 30400 | 60900  | 68200  | 77900  | 87700  |
| 1.000                           | 1-12     | 0.63307                               | 34800                                          | 39250 | 39550 | 79100  | 88600  | 101000 | 114000 |
| 1.125                           | 1-1/8-12 | 0.82162                               | 45200                                          | 50900 | 51400 | 102500 | 115000 | 131500 | 147500 |
| 1.250                           | 1-1/4-12 | 1.0347                                | 56900                                          | 64200 | 64700 | 129000 | 144500 | 165500 | 186000 |
| 1.375                           | 1-3/8-12 | 1.2724                                | 70000                                          | 78900 | 79500 | 159000 | 178000 | 203500 | 229000 |
| 1.500                           | 1-1/2-12 | 1.5345                                | 84400                                          | 95100 | 95900 | 191500 | 214500 | 245500 | 276000 |

a Values shown above heavy line are for 2A threads, all other values are for 3A threads.

b Nuts and fastener heads designed to develop the ultimate tensile strength of the fastener are required to develop the tabulated tension loads.

c Fractional equivalent or number and threads per inch.

d The tension fastener allowables above are based on the nominal minor diameter thread area for MIL-S-7742 threads from Table 2.2.1 of Handbook H-28.

**Table 8.1.5(b<sub>2</sub>). Ultimate Tensile Strength of Threaded Fasteners (Continued)**

| Tensile Stress of Fastener, ksi |          |                                       | 160                                            | 180    | 220    | 260    |
|---------------------------------|----------|---------------------------------------|------------------------------------------------|--------|--------|--------|
| Fastener Diameter               |          | Maximum<br>Minor<br>Area <sup>d</sup> | MIL-S-8879                                     |        |        |        |
| in.                             | c        |                                       | Ultimate Tensile Strength, lbs. <sup>a,b</sup> |        |        |        |
| 0.112                           | 4-40     | 0.0054367                             | 869                                            | 979    | 1195   | 1410   |
| 0.138                           | 6-32     | 0.0081553                             | 1305                                           | 1465   | 1790   | 2120   |
| 0.164                           | 8-32     | 0.012848                              | 2055                                           | 2310   | 2825   | 3340   |
| 0.190                           | 10-32    | 0.018602                              | 2975                                           | 3345   | 4090   | 4840   |
| 0.250                           | 1/4-28   | 0.034241                              | 5480                                           | 6160   | 7530   | 8900   |
| 0.312                           | 5/16-24  | 0.054905                              | 8780                                           | 9880   | 12050  | 14250  |
| 0.375                           | 3/8-24   | 0.083879                              | 13400                                          | 15100  | 18450  | 21800  |
| 0.438                           | 7/16-20  | 0.11323                               | 18100                                          | 20350  | 24900  | 29400  |
| 0.500                           | 1/2-20   | 0.15358                               | 24550                                          | 27600  | 33750  | 39900  |
| 0.562                           | 9/16-18  | 0.19502                               | 31200                                          | 35100  | 42900  | 50700  |
| 0.625                           | 5/8-18   | 0.24700                               | 39500                                          | 44500  | 54300  | 64200  |
| 0.750                           | 3/4-16   | 0.36082                               | 57700                                          | 64900  | 79400  | 93800  |
| 0.875                           | 7/8-14   | 0.49327                               | 78900                                          | 88800  | 108500 | 128000 |
| 1.000                           | 1-12     | 0.64156                               | 102500                                         | 115500 | 141000 | 166500 |
| 1.125                           | 1-1/8-12 | 0.83129                               | 133000                                         | 149500 | 182500 | 216000 |
| 1.250                           | 1-1/4-12 | 1.0456                                | 167000                                         | 188000 | 230000 | 271500 |
| 1.375                           | 1-3/8-12 | 1.2844                                | 205500                                         | 231000 | 282500 | 333500 |
| 1.500                           | 1-1/2-12 | 1.5477                                | 247500                                         | 278500 | 340500 | 402000 |

a Values are for 3A threads.

b Nuts and fastener heads designed to develop the ultimate tensile strength of the fastener are required to develop the tabulated tension loads.

c Fractional equivalent or number and threads per inch.

d The tension fastener allowables above are based on the maximum minor diameter thread area for MIL-S-8879 threads from Tables II and III of MIL-S-8879.

**Table 8.1.5.1. Unit Bearing Strength of Sheet and Plate in Joints With Threaded Fasteners or Pins;  $F_{br}$  = ksi**

| Fastener, Diameter, in. | Unit Bearing Strength of Sheet for Fastener Diameter Indicated, lbs. <sup>a</sup> |       |       |       |       |       |       |       |       |       |       |       |       |        |
|-------------------------|-----------------------------------------------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
|                         | 0.156                                                                             | 0.164 | 0.188 | 0.190 | 0.250 | 0.312 | 0.375 | 0.438 | 0.500 | 0.562 | 0.625 | 0.750 | 0.875 | 1.000  |
| Thickness, in.          |                                                                                   |       |       |       |       |       |       |       |       |       |       |       |       |        |
| 0.032 .....             | 500                                                                               | 525   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    |
| 0.036 .....             | 563                                                                               | 590   | 675   | 684   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    |
| 0.040 .....             | 625                                                                               | 656   | 750   | 760   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    |
| 0.045 .....             | 704                                                                               | 738   | 845   | 855   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    |
| 0.050 .....             | 781                                                                               | 820   | 940   | 950   | 1250  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    |
| 0.063 .....             | 985                                                                               | 1033  | 1180  | 1197  | 1575  | 1969  | ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...    |
| 0.071 .....             | 1110                                                                              | 1164  | 1330  | 1349  | 1775  | 2219  | 2662  | ...   | ...   | ...   | ...   | ...   | ...   | ...    |
| 0.080 .....             | 1250                                                                              | 1312  | 1500  | 1520  | 2000  | 2500  | 3000  | 3500  | ...   | ...   | ...   | ...   | ...   | ...    |
| 0.090 .....             | 1407                                                                              | 1476  | 1690  | 1710  | 2250  | 2812  | 3375  | 3938  | 4500  | ...   | ...   | ...   | ...   | ...    |
| 0.100 .....             | 1562                                                                              | 1640  | 1875  | 1900  | 2500  | 3125  | 3750  | 4375  | 5000  | ...   | ...   | ...   | ...   | ...    |
| 0.125 .....             | 1953                                                                              | 2050  | 2340  | 2375  | 3125  | 3906  | 4688  | 5469  | 6250  | 7030  | 7812  | ...   | ...   | ...    |
| 0.160 .....             | 2500                                                                              | 2624  | 3000  | 3040  | 4000  | 5000  | 6000  | 7000  | 8000  | 9000  | 10000 | 12000 | ...   | ...    |
| 0.200 .....             | 3125                                                                              | 3280  | 3750  | 3800  | 5000  | 6250  | 7500  | 8750  | 10000 | 11250 | 12500 | 15000 | 17500 | 20000  |
| 0.250 .....             | 3916                                                                              | 4100  | 4688  | 4750  | 6250  | 7812  | 9375  | 10940 | 12500 | 14060 | 15625 | 18750 | 21875 | 25000  |
| 0.312 .....             | 4867                                                                              | 5117  | 5866  | 5928  | 7800  | 9734  | 11700 | 13670 | 15600 | 17530 | 19500 | 23400 | 27300 | 31200  |
| 0.375 .....             | 5850                                                                              | 6150  | 7050  | 7125  | 9375  | 11700 | 14063 | 16425 | 18750 | 21075 | 23400 | 28125 | 32810 | 37500  |
| 0.500 .....             | 7800                                                                              | 8200  | 9400  | 9500  | 12500 | 15600 | 18750 | 21900 | 25000 | 28100 | 31250 | 37500 | 43750 | 50000  |
| 0.625 .....             | 9750                                                                              | 10250 | 11750 | 11875 | 15625 | 19500 | 23440 | 27375 | 31250 | 35125 | 39062 | 46875 | 54690 | 62500  |
| 0.750 .....             | 11700                                                                             | 12300 | 14100 | 14250 | 18750 | 23400 | 28125 | 32850 | 37500 | 42150 | 46875 | 56250 | 65625 | 75000  |
| 0.875 .....             | 13650                                                                             | 14350 | 16450 | 16625 | 21875 | 27300 | 32810 | 38325 | 43750 | 49175 | 56690 | 65625 | 76560 | 87500  |
| 1.000 .....             | 15600                                                                             | 16400 | 18800 | 19000 | 25000 | 31200 | 37600 | 43800 | 50000 | 56200 | 62500 | 75000 | 87500 | 100000 |

<sup>a</sup> Bearing strengths shown are based on nominal fastener diameter.

Table 8.1.5.2(a<sub>1</sub>). Static Joint Strength of 100° Flush Head Alloy Steel Screws in Machine-Countersunk Aluminum Alloy Sheet and Plate

|                                                                                                                                                                                                           |                                                                                   |                   |                                |                   |                                 |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------------------|--------------------------------|-------------------|---------------------------------|
| Fastener Type . . . . .                                                                                                                                                                                   | AN509 <sup>b</sup> steel screw ( $F_{su} = 75$ ksi) w/MS20365 or equiv. steel nut |                   |                                |                   |                                 |
| Sheet and Plate Material . . . . .                                                                                                                                                                        | Clad 2024-T3 and T351                                                             |                   |                                |                   |                                 |
| Fastener Diameter, in. . . . .<br>(Nominal Shank Diameter, in.) .                                                                                                                                         | 3/16<br>(0.190)                                                                   | 1/4<br>(0.250)    | 5/16<br>(0.312)                | 3/8<br>(0.375)    | ½<br>(0.500)                    |
| Sheet or plate thickness, in.:<br>0.080 . . . . .<br>0.090 . . . . .<br>0.100 . . . . .<br>0.125 . . . . .<br>0.160 . . . . .<br>0.190 . . . . .<br>0.250 . . . . .<br>0.312 . . . . .<br>0.375 . . . . . | Ultimate Strength <sup>a</sup> , lbs                                              |                   |                                |                   |                                 |
|                                                                                                                                                                                                           | 1576 <sup>c</sup>                                                                 | ...               | ...                            | ...               | ...                             |
|                                                                                                                                                                                                           | 1726 <sup>c</sup>                                                                 | <sup>d</sup> ...  | ...                            | ...               | ...                             |
|                                                                                                                                                                                                           | 1877 <sup>c</sup>                                                                 | 2567 <sup>c</sup> | ...                            | ...               | ...                             |
|                                                                                                                                                                                                           | 2126 <sup>c</sup>                                                                 | 3054 <sup>c</sup> | <sup>d</sup> 3922 <sup>c</sup> | 4579 <sup>c</sup> | ...                             |
|                                                                                                                                                                                                           | ...                                                                               | 3536 <sup>c</sup> | 4722 <sup>c</sup>              | 5878 <sup>c</sup> | <sup>d</sup> ...                |
|                                                                                                                                                                                                           | ...                                                                               | 3682              | 5405 <sup>c</sup>              | 6872 <sup>c</sup> | 9408 <sup>c</sup>               |
|                                                                                                                                                                                                           | ...                                                                               | ...               | 5750                           | 8280 <sup>c</sup> | <sup>d</sup> 12201 <sup>c</sup> |
|                                                                                                                                                                                                           | ...                                                                               | ...               | ...                            | 8280 <sup>c</sup> | 14141 <sup>c</sup>              |
|                                                                                                                                                                                                           | ...                                                                               | ...               | ...                            | ...               | 14730                           |
| Fastener shear strength <sup>e</sup> . . . . .                                                                                                                                                            | 2126                                                                              | 3682              | 5750                           | 8280              | 14730                           |
| Sheet or plate thickness, in.:<br>0.080 . . . . .<br>0.090 . . . . .<br>0.100 . . . . .<br>0.125 . . . . .<br>0.160 . . . . .<br>0.190 . . . . .<br>0.250 . . . . .<br>0.312 . . . . .<br>0.375 . . . . . | Yield Strength <sup>a,f</sup> , lbs                                               |                   |                                |                   |                                 |
|                                                                                                                                                                                                           | 903                                                                               | ...               | ...                            | ...               | ...                             |
|                                                                                                                                                                                                           | 989                                                                               | ...               | ...                            | ...               | ...                             |
|                                                                                                                                                                                                           | 1084                                                                              | 1490              | ...                            | ...               | ...                             |
|                                                                                                                                                                                                           | 1296                                                                              | 1748              | 2001                           | 2559              | ...                             |
|                                                                                                                                                                                                           | 1615                                                                              | 2116              | 2334                           | 2939              | ...                             |
|                                                                                                                                                                                                           | ...                                                                               | 2484              | 2702                           | 3361              | 6012                            |
|                                                                                                                                                                                                           | ...                                                                               | ...               | 3404                           | 4197              | 7306                            |
|                                                                                                                                                                                                           | ...                                                                               | ...               | ...                            | 5092              | 8452                            |
|                                                                                                                                                                                                           | ...                                                                               | ...               | ...                            | ...               | 9996                            |
| Head height (ref.), in. . . . .                                                                                                                                                                           | 0.080                                                                             | 0.106             | 0.133                          | 0.159             | 0.213                           |

a Test data from which the yield and ultimate strengths were derived can be found in Reference 8.1.5.2.  
b This fastener is no longer manufactured; do not specify for new designs.  
c Yield value is less than 2/3 of the indicated ultimate strength value.  
d Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
e Fastener shear strength based on area computed from nominal shank diameters in Table 9.4.1.2(a) and  $F_{su} = 75$  ksi.  
f Permanent set at yield load: the greater of 0.012 inch or 4% of nominal diameter.

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**Table 8.1.5.2(a<sub>2</sub>). Static Joint Strength of 100° Flush Head Alloy Steel Screws in Machine-Countersunk Aluminum Alloy Sheet and Plate**

|                                                                   |                                                                                   |                   |                                |                   |                    |
|-------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------------------|--------------------------------|-------------------|--------------------|
| Fastener Type . . . . .                                           | AN509 <sup>b</sup> steel screw ( $F_{su} = 75$ ksi) w/MS20365 or equiv. steel nut |                   |                                |                   |                    |
| Sheet and Plate Material . . . . .                                | Clad 7075-T6 and T651                                                             |                   |                                |                   |                    |
| Fastener Diameter, in. . . . .<br>(Nominal Shank Diameter, in.) . | 3/16<br>(0.190)                                                                   | 1/4<br>(0.250)    | 5/16<br>(0.312)                | 3/8<br>(0.375)    | 1/2<br>(0.500)     |
| Ultimate Strength <sup>a</sup> , lbs                              |                                                                                   |                   |                                |                   |                    |
| Sheet or plate thickness, in.:                                    |                                                                                   |                   |                                |                   |                    |
| 0.080 . . . . .                                                   | 1632 <sup>c</sup>                                                                 | ...               | ...                            | ...               | ...                |
| 0.090 . . . . .                                                   | 1762 <sup>c</sup>                                                                 | <sup>d</sup> ...  | ...                            | ...               | ...                |
| 0.100 . . . . .                                                   | 1892                                                                              | 2723 <sup>c</sup> | ...                            | ...               | ...                |
| 0.125 . . . . .                                                   | 2126                                                                              | 3109 <sup>c</sup> | <sup>d</sup> 4180 <sup>c</sup> | 5216 <sup>c</sup> | ...                |
| 0.160 . . . . .                                                   | ...                                                                               | 3551 <sup>c</sup> | 4858 <sup>c</sup>              | 6193 <sup>c</sup> | <sup>d</sup> ...   |
| 0.190 . . . . .                                                   | ...                                                                               | 3682              | 5433 <sup>c</sup>              | 6996 <sup>c</sup> | ...                |
| 0.250 . . . . .                                                   | ...                                                                               | ...               | 5750                           | 8280 <sup>c</sup> | 12421 <sup>c</sup> |
| 0.312 . . . . .                                                   | ...                                                                               | ...               | ...                            | 8280              | 14185 <sup>c</sup> |
| 0.375 . . . . .                                                   | ...                                                                               | ...               | ...                            | ...               | 14730              |
| Fastener shear strength <sup>e</sup> . . . . .                    | 2126                                                                              | 3682              | 5750                           | 8280              | 14730              |
| Yield Strength <sup>a,f</sup> , lbs                               |                                                                                   |                   |                                |                   |                    |
| Sheet or plate thickness, in.:                                    |                                                                                   |                   |                                |                   |                    |
| 0.080 . . . . .                                                   | 965                                                                               | ...               | ...                            | ...               | ...                |
| 0.090 . . . . .                                                   | 1063                                                                              | ...               | ...                            | ...               | ...                |
| 0.100 . . . . .                                                   | 1179                                                                              | 1600              | ...                            | ...               | ...                |
| 0.125 . . . . .                                                   | 1462                                                                              | 1895              | 2098                           | 2699              | ...                |
| 0.160 . . . . .                                                   | ...                                                                               | 2363              | 2501                           | 3088              | ...                |
| 0.190 . . . . .                                                   | ...                                                                               | 2926              | 3018                           | 3601              | ...                |
| 0.250 . . . . .                                                   | ...                                                                               | ...               | 4312                           | 4868              | 8041               |
| 0.312 . . . . .                                                   | ...                                                                               | ...               | ...                            | 6624              | 9437               |
| 0.375 . . . . .                                                   | ...                                                                               | ...               | ...                            | ...               | 11686              |
| Head height (ref.), in. . . . .                                   | 0.080                                                                             | 0.106             | 0.133                          | 0.159             | 0.213              |

a Test data from which the yield and ultimate strengths were derived can be found in Reference 8.1.5.2.  
b This fastener is no longer manufactured; do not specify for new designs.  
c Yield value is less than 2/3 of the indicated ultimate strength value.  
d Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
e Fastener shear strength based on area computed from nominal shank diameters in Table 9.4.1.2(a) and  $F_{su} = 75$  ksi.  
f Permanent set at yield load: the greater of 0.012 inch or 4% of nominal diameter.

**Table 8.1.5.2(b). Static Joint Strength of 100° Flush Head Stainless Steel (PH13-8Mo-H1000) Fasteners in Machine-Countersunk Titanium Alloy Sheet and Plate**

| Fastener Type .....                                                        | PBF 11 <sup>a</sup> ( $F_{su} = 125$ ksi) |                |                |                |
|----------------------------------------------------------------------------|-------------------------------------------|----------------|----------------|----------------|
| Sheet and Plate Material .....                                             | Annealed Ti-6Al-4V                        |                |                |                |
| Rivet Diameter, in. ....<br>(Nominal Shank Diameter, in.) <sup>b</sup> ... | 5/32<br>(0.164)                           | 1/4<br>(0.250) | 3/8<br>(0.375) | 1/2<br>(0.500) |
| Ultimate Strength, lbs                                                     |                                           |                |                |                |
| Sheet or plate thickness, in.:                                             |                                           |                |                |                |
| 0.040 .....                                                                | 1535                                      | ...            | ...            | ...            |
| 0.050 .....                                                                | 1963                                      | ...            | ...            | ...            |
| 0.063 .....                                                                | 2528                                      | 3656           | ...            | ...            |
| 0.071 .....                                                                | 2640                                      | 4213           | ...            | ...            |
| 0.080 .....                                                                | ...                                       | 4813           | 6820           | ...            |
| 0.090 .....                                                                | ...                                       | 5438           | 7818           | ...            |
| 0.100 .....                                                                | ...                                       | 6140           | 8775           | 11250          |
| 0.125 .....                                                                | ...                                       | ...            | 11264          | 14575          |
| 0.160 .....                                                                | ...                                       | ...            | 13810          | 19250          |
| 0.190 .....                                                                | ...                                       | ...            | ...            | 23200          |
| 0.200 .....                                                                | ...                                       | ...            | ...            | 24540          |
| Fastener shear strength <sup>d</sup> .....                                 | 2640                                      | 6140           | 13810          | 24540          |
| Yield Strength <sup>e</sup> , lbs                                          |                                           |                |                |                |
| Sheet or plate thickness, in.:                                             |                                           |                |                |                |
| 0.040 .....                                                                | 1237                                      | ...            | ...            | ...            |
| 0.050 .....                                                                | 1543                                      | ...            | ...            | ...            |
| 0.063 .....                                                                | 1947                                      | 2969           | ...            | ...            |
| 0.071 .....                                                                | 2049                                      | 3350           | ...            | ...            |
| 0.080 .....                                                                | ...                                       | 3756           | 5667           | ...            |
| 0.090 .....                                                                | ...                                       | 4219           | 6370           | ...            |
| 0.100 .....                                                                | ...                                       | 4600           | 7101           | 9500           |
| 0.125 .....                                                                | ...                                       | ...            | 8789           | 11825          |
| 0.160 .....                                                                | ...                                       | ...            | 10645          | 15025          |
| 0.190 .....                                                                | ...                                       | ...            | ...            | 17825          |
| 0.200 .....                                                                | ...                                       | ...            | ...            | 18400          |
| Head height (nom.), in. ....                                               | 0.040                                     | 0.060          | 0.077          | 0.101          |

- a Data supplied by Huck Manufacturing Company and PB Fasteners.  
b Fasteners installed in clearance holes (0.0025-0.0030) (Ref. Section 8.1.5).  
c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
d Fastener shear strength based on areas computed from indicated nominal shank diameter  $F_{su} = 125$  ksi.  
e Permanent set at yield load: 4% of nominal diameter (Ref. 9.4.1.3.3).

**Table 8.1.5.2(c). Static Joint Strength of 100° Flush Head Tapered Alloy Steel Fasteners in Machine-Countersunk Aluminum Alloy Sheet and Plate**

|                                                                                                                                                                                      |                                           |                 |                  |                 |                  |                 |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|-----------------|------------------|-----------------|------------------|-----------------|
| Fastener Type .....                                                                                                                                                                  | TL 100 <sup>a</sup> ( $F_{su}$ = 108 ksi) |                 |                  |                 |                  |                 |
| Sheet and Plate Material .....                                                                                                                                                       | Clad 7075-T6 and T651                     |                 |                  |                 |                  |                 |
| Fastener Diameter, in. ....<br>(Nominal Shank Diameter, in.) ..                                                                                                                      | 3/16<br>(0.1969)                          | 1/4<br>(0.2585) | 5/16<br>(0.3214) | 3/8<br>(0.3860) | 7/16<br>(0.4490) | 1/2<br>(0.5122) |
| Sheet or plate thickness, in.:<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 .....<br>0.285 .....<br>0.312 .....<br>0.344 .....<br>0.375 .....<br>0.500 ..... | Ultimate Strength, lbs                    |                 |                  |                 |                  |                 |
|                                                                                                                                                                                      | 2435                                      | ...             | ...              | ...             | ...              | ...             |
|                                                                                                                                                                                      | 2913                                      | 3745            | 4443             | ...             | ...              | ...             |
|                                                                                                                                                                                      | 3290                                      | 4831            | 6017             | 7016            | 7993             | ...             |
|                                                                                                                                                                                      | ...                                       | 5269            | 7017             | 8511            | 9737             | 10900           |
|                                                                                                                                                                                      | ...                                       | 5670            | 8148             | 11120           | 13220            | 14890           |
|                                                                                                                                                                                      | ...                                       | ...             | 8760             | 11360           | 15000            | 17240           |
|                                                                                                                                                                                      | ...                                       | ...             | ...              | 11570           | 15280            | 19000           |
|                                                                                                                                                                                      | ...                                       | ...             | ...              | 11800           | 15560            | 19800           |
|                                                                                                                                                                                      | ...                                       | ...             | ...              | 12030           | 15820            | 20110           |
|                                                                                                                                                                                      | ...                                       | ...             | ...              | 12640           | 16870            | 21320           |
|                                                                                                                                                                                      | 3290                                      | 5670            | 8760             | 12640           | 17100            | 22250           |
| Fastener shear strength <sup>b</sup> .....                                                                                                                                           | 3290                                      | 5670            | 8760             | 12640           | 17100            | 22250           |
| Sheet or plate thickness, in.:<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 .....<br>0.285 .....<br>0.312 .....<br>0.344 .....<br>0.375 .....<br>0.500 ..... | Yield Strength <sup>c</sup> , lbs         |                 |                  |                 |                  |                 |
|                                                                                                                                                                                      | 1960                                      | ...             | ...              | ...             | ...              | ...             |
|                                                                                                                                                                                      | 2350                                      | 2990            | 3818             | ...             | ...              | ...             |
|                                                                                                                                                                                      | 2840                                      | 3550            | 4650             | 5650            | 6703             | ...             |
|                                                                                                                                                                                      | ...                                       | 3970            | 5308             | 6596            | 7806             | 9045            |
|                                                                                                                                                                                      | ...                                       | 4830            | 6450             | 8209            | 9903             | 11560           |
|                                                                                                                                                                                      | ...                                       | ...             | 7060             | 9090            | 10930            | 12840           |
|                                                                                                                                                                                      | ...                                       | ...             | ...              | 9680            | 11780            | 13930           |
|                                                                                                                                                                                      | ...                                       | ...             | ...              | 10010           | 12710            | 14930           |
|                                                                                                                                                                                      | ...                                       | ...             | ...              | 10430           | 13200            | 16000           |
|                                                                                                                                                                                      | ...                                       | ...             | ...              | ...             | 15160            | 18490           |
|                                                                                                                                                                                      | ...                                       | ...             | ...              | ...             | 15160            | 18490           |
| Head height (max.), in. ....                                                                                                                                                         | 0.048                                     | 0.063           | 0.070            | 0.081           | 0.100            | 0.110           |

a Data supplied by Briles Manufacturing Company.  
b Fastener shear strength based on areas computed from indicated nominal shank diameter and  $F_{su}$  = 108 ksi.  
c Permanent set at yield load: the greater of 0.012 inch or 4% of nominal diameter.

**Table 8.1.5.2(d). Static Joint Strength of 100° Flush Head Tapered STA Ti-6Al-4V Fasteners in Machine-Countersunk Aluminum Alloy Sheet**

| Fastener Type . . . . .                                                 | TLV 10 <sup>a</sup> ( $F_{su} = 95$ ksi) |                  |                  |                   |
|-------------------------------------------------------------------------|------------------------------------------|------------------|------------------|-------------------|
|                                                                         | Clad 7075-T6                             |                  |                  |                   |
| Sheet Material . . . . .                                                |                                          |                  |                  |                   |
| Fastener Diameter, in. . . . .<br>(Nominal Shank Diameter, in.) . . . . | 1/8<br>(0.1437)                          | 5/32<br>(0.1688) | 3/16<br>(0.1965) | 1/4<br>(0.2583)   |
| Ultimate Strength, lbs                                                  |                                          |                  |                  |                   |
| Sheet thickness, in.:                                                   |                                          |                  |                  |                   |
| 0.032 . . . . .                                                         | 488                                      | ...              | ...              | ...               |
| 0.040 . . . . .                                                         | 610                                      | <sup>b</sup> 713 | 826              | ...               |
| 0.050 . . . . .                                                         | 768                                      | 896              | 1050             | <sup>b</sup> ...  |
| 0.063 . . . . .                                                         | 967                                      | 1145             | 1312             | 1730              |
| 0.071 . . . . .                                                         | 1120                                     | 1290             | 1491             | 1960 <sup>b</sup> |
| 0.080 . . . . .                                                         | 1260                                     | 1470             | 1690             | 2223              |
| 0.090 . . . . .                                                         | 1377                                     | 1670             | 1910             | 2505              |
| 0.100 . . . . .                                                         | 1441                                     | 1845             | 2130             | 2800              |
| 0.125 . . . . .                                                         | 1530                                     | 2010             | 2580             | 3540              |
| 0.160 . . . . .                                                         | 1540                                     | 2125             | 2800             | 4410              |
| 0.190 . . . . .                                                         | ...                                      | ...              | 2880             | 4750              |
| 0.250 . . . . .                                                         | ...                                      | ...              | ...              | 4980              |
| Fastener shear strength <sup>c</sup> . . . . .                          | 1540                                     | 2125             | 2880             | 4980              |
| Yield Strength <sup>d</sup> , lbs                                       |                                          |                  |                  |                   |
| Sheet thickness, in.:                                                   |                                          |                  |                  |                   |
| 0.032 . . . . .                                                         | 488                                      | ...              | ...              | ...               |
| 0.040 . . . . .                                                         | 610                                      | 713              | 826              | ...               |
| 0.050 . . . . .                                                         | 753                                      | 890              | 1050             | ...               |
| 0.063 . . . . .                                                         | 925                                      | 1118             | 1301             | 1730              |
| 0.071 . . . . .                                                         | 1035                                     | 1240             | 1467             | 1960              |
| 0.080 . . . . .                                                         | 1138                                     | 1377             | 1637             | 2192              |
| 0.090 . . . . .                                                         | 1238                                     | 1522             | 1806             | 2455              |
| 0.100 . . . . .                                                         | 1321                                     | 1639             | 1976             | 2711              |
| 0.125 . . . . .                                                         | 1480                                     | 1880             | 2331             | 3304              |
| 0.160 . . . . .                                                         | 1540                                     | 2111             | 2683             | 3986              |
| 0.190 . . . . .                                                         | ...                                      | ...              | 2880             | 4437              |
| 0.250 . . . . .                                                         | ...                                      | ...              | ...              | 4980              |
| Head height (max.), in. . . . .                                         | 0.033                                    | 0.041            | 0.048            | 0.063             |

- a Data supplied by Lockheed Georgia Company.
- b Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.
- c Fastener shear strength based on areas computed from indicated nominal shank diameter and  $F_{su} = 95$  ksi.
- d Permanent set at yield load: the greater of 0.012 inch or 4% of fractional diameter.



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**Table 8.1.5.2(e). Static Joint Strength of 70° Flush Head Tapered Ti-6Al-4V Fasteners in Non-Matching Machine-Countersunk Aluminum Alloy Sheet and Plate**

| Fastener Type .....                              | HPB-V <sup>a</sup> ( $F_{su} = 95$ ksi) |          |          |          |
|--------------------------------------------------|-----------------------------------------|----------|----------|----------|
| Sheet and Plate Material .....                   | Clad 7075-T6 and T651                   |          |          |          |
| Fastener Diameter .....                          | 3/16                                    | 1/4      | 5/16     | 3/8      |
| (Nominal Shank Diameter, in.) <sup>b</sup> ..... | (0.1976)                                | (0.2587) | (0.3211) | (0.3850) |
| Sheet Countersink Angle .....                    | 82°                                     | 82°      | 82°      | 75°      |
| Ultimate Strength, lbs                           |                                         |          |          |          |
| Sheet or plate thickness, in.:                   |                                         |          |          |          |
| 0.063 .....                                      | 1355                                    | ...      | ...      | ...      |
| 0.071 .....                                      | 1554                                    | 2041     | ...      | ...      |
| 0.080 .....                                      | 1710                                    | 2296     | ...      | ...      |
| 0.090 .....                                      | 1847                                    | 2583     | 3207     | ...      |
| 0.100 .....                                      | 1984                                    | 2864     | 3567     | 4269     |
| 0.125 .....                                      | 2319                                    | 3293     | 4454     | 5336     |
| 0.160 .....                                      | 2792                                    | 3908     | 5176     | 6611     |
| 0.190 .....                                      | 2913                                    | 4444     | 5836     | 7396     |
| 0.250 .....                                      | ...                                     | 4993     | 7155     | 8968     |
| 0.312 .....                                      | ...                                     | ...      | 7692     | 10613    |
| 0.375 .....                                      | ...                                     | ...      | ...      | 11058    |
| 0.500 .....                                      | ...                                     | ...      | ...      | 11058    |
| Fastener shear strength <sup>c</sup> .....       | 2913                                    | 4993     | 7692     | 11058    |
| Yield Strength <sup>d</sup> , lbs                |                                         |          |          |          |
| Sheet or plate thickness, in.:                   |                                         |          |          |          |
| 0.063 .....                                      | 1269                                    | ...      | ...      | ...      |
| 0.071 .....                                      | 1429                                    | 1874     | ...      | ...      |
| 0.080 .....                                      | 1613                                    | 2108     | ...      | ...      |
| 0.090 .....                                      | 1812                                    | 2376     | 2949     | ...      |
| 0.100 .....                                      | 1984                                    | 2637     | 3279     | 3928     |
| 0.125 .....                                      | 2319                                    | 3299     | 4093     | 4906     |
| 0.160 .....                                      | 2718                                    | 3908     | 5176     | 6285     |
| 0.190 .....                                      | 2913                                    | 4397     | 5836     | 7396     |
| 0.250 .....                                      | ...                                     | 4993     | 6980     | 8968     |
| 0.312 .....                                      | ...                                     | ...      | 7692     | 10257    |
| 0.375 .....                                      | ...                                     | ...      | ...      | 11058    |
| 0.500 .....                                      | ...                                     | ...      | ...      | 11058    |
| Head height (max.), in. ....                     | 0.057                                   | 0.067    | 0.076    | 0.086    |

a Data supplied by PB Fasteners.

b Fasteners installed in interference holes (0.0015-0.0048) (Ref. Section 8.1.5).

c Fastener shear strength based on areas computed from the indicated nominal shank diameter and  $F_{su} = 95$  ksi.

d Permanent set at yield load: the greater of 0.012 inch or 4% of nominal diameter.

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**Table 8.1.5.2(f). Static Joint Strength of 100° Flush Shear Head Ti-6Al-4V Fasteners in Machine-Countersunk Aluminum Alloy Sheet**

| Fastener Type .....                                                         | KLBHV Pin ( $F_{su} = 95$ ksi), KFN 600 Nut <sup>a</sup> |                   |                |                  |                |
|-----------------------------------------------------------------------------|----------------------------------------------------------|-------------------|----------------|------------------|----------------|
| Sheet Material .....                                                        | Clad 7075-T6                                             |                   |                |                  |                |
| Fastener Diameter, in. ....<br>(Nominal Shank Diameter, in.) <sup>b</sup> . | 5/32<br>(0.164)                                          | 3/16<br>(0.190)   | 1/4<br>(0.250) | 5/16<br>(0.3125) | 3/8<br>(0.375) |
| Sheet thickness, in.:                                                       | Ultimate Strength, lbs                                   |                   |                |                  |                |
|                                                                             |                                                          |                   |                |                  |                |
| 0.040 .....                                                                 | 748                                                      | ...               | ...            | ...              | ...            |
| 0.050 .....                                                                 | 987                                                      | <sup>c</sup> 1112 | ...            | ...              | ...            |
| 0.063 .....                                                                 | 1291                                                     | 1462              | 1813           | ...              | ...            |
| 0.071 .....                                                                 | 1428                                                     | 1679              | 2100           | <sup>c</sup> ... | ...            |
| 0.080 .....                                                                 | 1571                                                     | 1888              | 2438           | 2902             | ...            |
| 0.090 .....                                                                 | 1722                                                     | 2058              | 2794           | 3322             | 3867           |
| 0.100 .....                                                                 | 1883                                                     | 2231              | 3150           | 3810             | 4402           |
| 0.125 .....                                                                 | 2007                                                     | 2694              | 3725           | 4924             | 5724           |
| 0.160 .....                                                                 | ...                                                      | ...               | 4531           | 4901             | 7397           |
| 0.190 .....                                                                 | ...                                                      | ...               | 4660           | 6790             | 8452           |
| 0.200 .....                                                                 | ...                                                      | ...               | ...            | 7083             | 8789           |
| 0.250 .....                                                                 | ...                                                      | ...               | ...            | 7290             | 10490          |
| Fastener shear strength <sup>d</sup> .....                                  | 2007                                                     | 2694              | 4660           | 7290             | 10490          |
| Sheet thickness, in.:                                                       | Yield Strength <sup>e</sup> , lbs                        |                   |                |                  |                |
|                                                                             |                                                          |                   |                |                  |                |
| 0.040 .....                                                                 | 594                                                      | ...               | ...            | ...              | ...            |
| 0.050 .....                                                                 | 740                                                      | 859               | ...            | ...              | ...            |
| 0.063 .....                                                                 | 931                                                      | 1079              | 1419           | ...              | ...            |
| 0.071 .....                                                                 | 1049                                                     | 1213              | 1600           | ...              | ...            |
| 0.080 .....                                                                 | 1176                                                     | 1368              | 1806           | 2267             | ...            |
| 0.090 .....                                                                 | 1283                                                     | 1534              | 2031           | 2540             | 3052           |
| 0.100 .....                                                                 | 1375                                                     | 1675              | 2250           | 2824             | 3375           |
| 0.125 .....                                                                 | 1606                                                     | 1942              | 2813           | 3517             | 4219           |
| 0.160 .....                                                                 | ...                                                      | ...               | 3306           | 4455             | 5386           |
| 0.190 .....                                                                 | ...                                                      | ...               | 3725           | 4983             | 6385           |
| 0.200 .....                                                                 | ...                                                      | ...               | ...            | 5168             | 6581           |
| 0.250 .....                                                                 | ...                                                      | ...               | ...            | 6038             | 7636           |
| Head height (ref.), in. ....                                                | 0.043                                                    | 0.048             | 0.063          | 0.070            | 0.081          |

a Data supplied by Kaynar Manufacturing Co., Inc.

b Fasteners installed in interference holes (0.003-0.055) (Ref. 8.1.5).

c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.

d Fastener shear strength based on areas computed from indicated nominal shank diameter and  $F_{su} = 95$  ksi.

e Permanent set at yield load: 4% of the nominal diameter (Ref. 9.4.1.3.3).

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**Table 8.1.5.2(g). Static Joint Strength of 100° Flush Shear AISI 431a Hi-Lok Fasteners in Aluminum Alloy Sheet and Plate**

| Rivet Type .....                           | HL 61 Pin ( $F_{su} = 125$ ksi), HL 70 Collar <sup>b</sup> |         |                   |         |
|--------------------------------------------|------------------------------------------------------------|---------|-------------------|---------|
| Sheet and Plate Material .....             | Clad 7075-T6 and T651                                      |         |                   |         |
| Rivet Diameter .....                       | 3/16                                                       | 1/4     | 5/16              | 3/8     |
| (Nominal Shank Diameter, in.) ..           | (0.190)                                                    | (0.250) | (0.312)           | (0.375) |
| Ultimate Strength, lbs                     |                                                            |         |                   |         |
| Sheet or plate thickness, in.:             |                                                            |         |                   |         |
| 0.090 .....                                | 2327                                                       | ...     | ...               | ...     |
| 0.100 .....                                | 2430                                                       | 3740    | ...               | ...     |
| 0.125 .....                                | 2695                                                       | 4080    | ...               | ...     |
| 0.160 .....                                | 3070                                                       | 4560    | 6500 <sup>c</sup> | ...     |
| 0.190 .....                                | 3390                                                       | 4970    | 7160              | 9100    |
| 0.250 .....                                | 3544                                                       | 5800    | 8320              | 10230   |
| 0.312 .....                                | ...                                                        | 6140    | 9590              | 11390   |
| 0.375 .....                                | ...                                                        | ...     | ...               | 12580   |
| 0.500 .....                                | ...                                                        | ...     | ...               | 13810   |
| Fastener shear strength <sup>d</sup> ..... | 3544                                                       | 6140    | 9590              | 13810   |
| Yield Strength <sup>e</sup> , lbs          |                                                            |         |                   |         |
| Sheet or plate thickness, in.:             |                                                            |         |                   |         |
| 0.090 .....                                | 1840                                                       | ...     | ...               | ...     |
| 0.100 .....                                | 1943                                                       | 2900    | ...               | ...     |
| 0.125 .....                                | 2195                                                       | 3240    | ...               | ...     |
| 0.160 .....                                | 2540                                                       | 3700    | 4030              | ...     |
| 0.190 .....                                | 2840                                                       | 4020    | 5430              | 7120    |
| 0.250 .....                                | 3110                                                       | 4870    | 6590              | 8500    |
| 0.312 .....                                | ...                                                        | 5350    | 7580              | 9700    |
| 0.375 .....                                | ...                                                        | ...     | 7890              | 10410   |
| 0.500 .....                                | ...                                                        | ...     | ...               | 12070   |
| Head height (max.), in. ....               | 0.049                                                      | 0.063   | 0.077             | 0.051   |

- a AISI 431 is prohibited from use in Air Force and Navy structure by MIL-STD-1568 and SD-24, respectively, because of its sensitivity to heat treatment. Use of fasteners made of this material in design of military aerospace structures requires the specific approval of the procuring agency.
- b Data supplied by Hi-Shear Corporation.
- c Yield value is less than 2/3 of the indicated ultimate strength value.
- d Fastener shear strength based on areas computed from the indicated nominal shank diameter and  $F_{su} = 125$  ksi.
- e Permanent set at yield load: the greater of 0.012 inch or 4% of nominal diameter.

**Table 8.1.5.2(h). Static Joint Strength of 100° Flush Shear Head Alloy Steel Hi-Lok Fasteners in Machine-Countersunk Aluminum Alloy Sheet and Plate**

| Fastener Type . . . . .                                                                | HL 719 Pin ( $F_{su} = 108$ ksi), HL 79 Collar <sup>a</sup> |                   |                |                 |                |
|----------------------------------------------------------------------------------------|-------------------------------------------------------------|-------------------|----------------|-----------------|----------------|
| Sheet and Plate Material . . . . .                                                     | 7075-T6 and T651                                            |                   |                |                 |                |
| Fastener Diameter, in. . . . .<br>(Nominal Shank Diameter, in.) <sup>b</sup> . . . . . | 5/32<br>(0.164)                                             | 3/16<br>(0.190)   | 1/4<br>(0.250) | 5/16<br>(0.312) | 3/8<br>(0.375) |
| Sheet or plate thickness, in.:                                                         | Ultimate Strength, lbs                                      |                   |                |                 |                |
|                                                                                        |                                                             |                   |                |                 |                |
| 0.040 . . . . .                                                                        | 734                                                         | ...               | ...            | ...             | ...            |
| 0.050 . . . . .                                                                        | 1044                                                        | <sup>c</sup> 1131 | ...            | ...             | ...            |
| 0.063 . . . . .                                                                        | 1384                                                        | 1565              | 1813           | ...             | ...            |
| 0.071 . . . . .                                                                        | 1518                                                        | 1820              | 2216           | ...             | ...            |
| 0.080 . . . . .                                                                        | 1668                                                        | 1998              | 2594           | 2916            | ...            |
| 0.090 . . . . .                                                                        | 1764                                                        | 2193              | 3015           | 3532            | 3724           |
| 0.100 . . . . .                                                                        | 1825                                                        | 2345              | 3338           | 4059            | 4516           |
| 0.125 . . . . .                                                                        | 1979                                                        | 2524              | 3980           | 5229            | 6167           |
| 0.160 . . . . .                                                                        | 2195                                                        | 2774              | 4350           | 6347            | 7928           |
| 0.190 . . . . .                                                                        | ...                                                         | 2989              | 4634           | 6702            | 9087           |
| 0.250 . . . . .                                                                        | ...                                                         | 3062              | 5200           | 7512            | 9985           |
| 0.312 . . . . .                                                                        | ...                                                         | ...               | 5300           | 8146            | 10870          |
| 0.375 . . . . .                                                                        | ...                                                         | ...               | ...            | 8280            | 11760          |
| Fastener shear strength <sup>d</sup> . . . . .                                         | 2281                                                        | 3062              | 5300           | 8280            | 11930          |
| Sheet or plate thickness, in.:                                                         | Yield Strength <sup>e</sup> , lbs                           |                   |                |                 |                |
|                                                                                        |                                                             |                   |                |                 |                |
| 0.040 . . . . .                                                                        | 690                                                         | ...               | ...            | ...             | ...            |
| 0.050 . . . . .                                                                        | 861                                                         | 1000              | ...            | ...             | ...            |
| 0.063 . . . . .                                                                        | 1086                                                        | 1261              | 1664           | ...             | ...            |
| 0.071 . . . . .                                                                        | 1224                                                        | 1421              | 1876           | ...             | ...            |
| 0.080 . . . . .                                                                        | 1346                                                        | 1601              | 2114           | 2647            | ...            |
| 0.090 . . . . .                                                                        | 1478                                                        | 1771              | 2378           | 2978            | 3578           |
| 0.100 . . . . .                                                                        | 1610                                                        | 1924              | 2642           | 3309            | 3976           |
| 0.125 . . . . .                                                                        | 1845                                                        | 2308              | 3210           | 4136            | 4970           |
| 0.160 . . . . .                                                                        | 2022                                                        | 2583              | 3920           | 5124            | 6362           |
| 0.190 . . . . .                                                                        | ...                                                         | 2750              | 4344           | 5886            | 7330           |
| 0.250 . . . . .                                                                        | ...                                                         | 3062              | 4785           | 6925            | 9160           |
| 0.312 . . . . .                                                                        | ...                                                         | ...               | ...            | 7496            | 10130          |
| 0.375 . . . . .                                                                        | ...                                                         | ...               | ...            | 8158            | 10820          |
| Head height (nom.), in. . . . .                                                        | 0.040                                                       | 0.046             | 0.060          | 0.067           | 0.077          |

a Data supplied by Hi-Shear Corporation.

b Fasteners installed in interference holes (0.001-0.002) (Ref. Section 8.1.5).

c Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.

d Fastener shear strength based on areas computed from indicated nominal shank diameter and  $F_{su} = 108$  ksi.

e Permanent set at yield load: the greater of 0.012 inch or 4% of nominal diameter.

**Table 8.1.5.2(i). Static Joint Strength of 100° Flush Shear Head Ti-6Al-4V Fasteners in Machine-Countersunk Aluminum Alloy Sheet and Plate**

|                                                                                                                                                                                                                                   |                                                           |                 |                   |                   |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|-----------------|-------------------|-------------------|
| Fastener Type .....                                                                                                                                                                                                               | HL 11 Pin ( $F_{su} = 95$ ksi), HL 70 Collar <sup>a</sup> |                 |                   |                   |
| Sheet and Plate Material .....                                                                                                                                                                                                    | Clad 7075-T6 and T651                                     |                 |                   |                   |
| Fastener Diameter, in. ....<br>(Nominal Shank Diameter, in.) ....                                                                                                                                                                 | 5/32<br>(0.164)                                           | 3/16<br>(0.190) | 1/4<br>(0.250)    | 5/16<br>(0.312)   |
| Sheet or plate thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 .....<br>0.312 .....<br>0.375 ..... | Ultimate Strength, lbs                                    |                 |                   |                   |
|                                                                                                                                                                                                                                   | 734                                                       | 837             | ...               | ...               |
|                                                                                                                                                                                                                                   | 941                                                       | 1083            | <sup>b</sup> 1343 | ...               |
|                                                                                                                                                                                                                                   | 1207                                                      | 1393            | 1762              | <sup>b</sup> 2170 |
|                                                                                                                                                                                                                                   | 1385                                                      | 1588            | 2012              | 2463              |
|                                                                                                                                                                                                                                   | 1557                                                      | 1779            | 2281              | 2823              |
|                                                                                                                                                                                                                                   | 1775                                                      | 2050            | 2594              | 3193              |
|                                                                                                                                                                                                                                   | 1876                                                      | 2263            | 2919              | 3631              |
|                                                                                                                                                                                                                                   | 1950                                                      | 2542            | 3765              | 4594              |
|                                                                                                                                                                                                                                   | 2007                                                      | 2660            | 3970              | 5890              |
|                                                                                                                                                                                                                                   | ...                                                       | 2694            | 4165              | 6105              |
|                                                                                                                                                                                                                                   | ...                                                       | ...             | 4530              | 6580              |
|                                                                                                                                                                                                                                   | ...                                                       | ...             | 4660              | 7050              |
|                                                                                                                                                                                                                                   | ...                                                       | ...             | ...               | 7290              |
|                                                                                                                                                                                                                                   | 2007                                                      | 2694            | 4660              | 7290              |
| Sheet or plate thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 .....<br>0.312 .....<br>0.375 ..... | Yield Strength <sup>d</sup> , lbs                         |                 |                   |                   |
|                                                                                                                                                                                                                                   | 674                                                       | 794             | ...               | ...               |
|                                                                                                                                                                                                                                   | 835                                                       | 982             | 1325              | ...               |
|                                                                                                                                                                                                                                   | 1038                                                      | 1230            | 1655              | 2141              |
|                                                                                                                                                                                                                                   | 1130                                                      | 1355            | 1813              | 2338              |
|                                                                                                                                                                                                                                   | 1230                                                      | 1480            | 2062              | 2620              |
|                                                                                                                                                                                                                                   | 1342                                                      | 1625            | 2250              | 2880              |
|                                                                                                                                                                                                                                   | 1440                                                      | 1750            | 2470              | 3420              |
|                                                                                                                                                                                                                                   | 1670                                                      | 2020            | 2930              | 3860              |
|                                                                                                                                                                                                                                   | 1891                                                      | 2360            | 3480              | 4620              |
|                                                                                                                                                                                                                                   | ...                                                       | 2560            | 3840              | 5150              |
|                                                                                                                                                                                                                                   | ...                                                       | ...             | 4440              | 6170              |
|                                                                                                                                                                                                                                   | ...                                                       | ...             | 4660              | 6900              |
|                                                                                                                                                                                                                                   | ...                                                       | ...             | ...               | 7290              |
| Head height (nom.), in. ....                                                                                                                                                                                                      | 0.040                                                     | 0.046           | 0.060             | 0.067             |

a Data supplied by Hi-Shear Corporation.

b Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.

c Fastener shear strength based on areas computed from indicated nominal shank diameter and  $F_{su} = 95$  ksi.

d Permanent set at yield load: the greater of 0.012 inch or 4% of nominal diameter.

**Table 8.1.5.2(j). Static Joint Strength of 100° Flush Shear Head Ti-6Al-6V-2Sn Fasteners in Machine-Countersunk Aluminum Alloy Sheet and Plate**

| Fastener Type . . . . .                                                   | HL 911 Pin ( $F_{su} = 108$ ksi), HL 70 Collar <sup>a</sup> |                   |                |                   |                   |
|---------------------------------------------------------------------------|-------------------------------------------------------------|-------------------|----------------|-------------------|-------------------|
| Sheet and Plate Material . . . . .                                        | Clad 7075-T6 and T651                                       |                   |                |                   |                   |
| Fastener Diameter, in. . . . .<br>(Nominal Shank Diameter, in.) . . . . . | 5/32<br>(0.164)                                             | 3/16<br>(0.190)   | 1/4<br>(0.250) | 5/16<br>(0.312)   | 3/8<br>(0.375)    |
| Sheet or plate thickness, in.:                                            | Ultimate Strength, lbs                                      |                   |                |                   |                   |
|                                                                           | 780                                                         | ...               | ...            | ...               | ...               |
| 0.040 . . . . .                                                           | 982                                                         | <sup>b</sup> 1137 | 1456           | ...               | ...               |
| 0.050 . . . . .                                                           | 1264                                                        | 1458              | 1863           | <sup>b</sup> 2287 | ...               |
| 0.063 . . . . .                                                           | 1426                                                        | 1642              | 2094           | 2570              | <sup>b</sup> 3096 |
| 0.071 . . . . .                                                           | 1622                                                        | 1866              | 2425           | 2920              | 3473 <sup>b</sup> |
| 0.080 . . . . .                                                           | 1740                                                        | 2105              | 2750           | 3339              | 3965              |
| 0.100 . . . . .                                                           | 1794                                                        | 2310              | 3063           | 3777              | 4415              |
| 0.125 . . . . .                                                           | 1915                                                        | 2455              | 3875           | 4770              | 5666              |
| 0.160 . . . . .                                                           | 2098                                                        | 2660              | 4219           | 6181              | 7339              |
| 0.190 . . . . .                                                           | 2252                                                        | 2840              | 4450           | 6483              | 8788              |
| 0.250 . . . . .                                                           | 2281                                                        | 3062              | 4925           | 7067              | 9589              |
| 0.312 . . . . .                                                           | ...                                                         | ...               | 5300           | 7670              | 10362             |
| 0.375 . . . . .                                                           | ...                                                         | ...               | ...            | 8280              | 11079             |
| 0.500 . . . . .                                                           | ...                                                         | ...               | ...            | ...               | 11930             |
| Fastener shear strength <sup>c</sup> . . . . .                            | 2281                                                        | 3062              | 5300           | 8280              | 11930             |
| Sheet or plate thickness, in.:                                            | Yield Strength <sup>d</sup> , lbs                           |                   |                |                   |                   |
|                                                                           | 734                                                         | ...               | ...            | ...               | ...               |
| 0.040 . . . . .                                                           | 882                                                         | 1044              | 1394           | ...               | ...               |
| 0.050 . . . . .                                                           | 1076                                                        | 1300              | 1750           | 2190              | ...               |
| 0.063 . . . . .                                                           | 1184                                                        | 1406              | 1938           | 2472              | 2995              |
| 0.071 . . . . .                                                           | 1320                                                        | 1540              | 2188           | 2774              | 3332              |
| 0.080 . . . . .                                                           | 1392                                                        | 1680              | 2375           | 3066              | 3768              |
| 0.090 . . . . .                                                           | 1480                                                        | 1810              | 2569           | 3358              | 4120              |
| 0.125 . . . . .                                                           | 1700                                                        | 2085              | 3031           | 4010              | 5019              |
| 0.160 . . . . .                                                           | 1870                                                        | 2380              | 3563           | 4818              | 6074              |
| 0.190 . . . . .                                                           | 1978                                                        | 2530              | 3937           | 5354              | 6749              |
| 0.250 . . . . .                                                           | 2178                                                        | 2740              | 4375           | 6269              | 8183              |
| 0.312 . . . . .                                                           | ...                                                         | ...               | 4687           | 6883              | 9209              |
| 0.375 . . . . .                                                           | ...                                                         | ...               | ...            | 7418              | 9870              |
| 0.500 . . . . .                                                           | ...                                                         | ...               | ...            | ...               | 11039             |
| Head height (nom.), in. . . . .                                           | 0.040                                                       | 0.046             | 0.060          | 0.067             | 0.077             |

a Data supplied by Hi-Shear Corporation.

b Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.

c Fastener shear strength based on areas computed from indicated nominal shank diameter and  $F_{su} = 108$  ksi.

d Permanent set at yield load: the greater of 0.012 inch or 4% of nominal diameter.

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**Table 8.1.5.2(k). Static Joint Strength of 100° Flush Head Ti-6Al-6V-2Sn or Alloy Steel, Shear Type Fasteners in Machine-Countersunk Aluminum Alloy Sheet**

|                                                                                                                                                                                            |                                                                                    |                 |                 |                   |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-----------------|-----------------|-------------------|
| Fastener Type .....                                                                                                                                                                        | NAS 4452S and KS 100-FV Pins <sup>a</sup> ( $F_{su} = 108$ ksi),<br>NAS 4445DD Nut |                 |                 |                   |
| Sheet Material .....                                                                                                                                                                       | 7075-T6                                                                            |                 |                 |                   |
| Fastener Diameter, in. ....<br>(Nominal Shank Diameter, in.) .....                                                                                                                         | 1/8<br>(0.138)                                                                     | 5/32<br>(0.164) | 3/16<br>(0.190) | 1/4<br>(0.250)    |
| Sheet thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 ..... | Ultimate Strength, lbs                                                             |                 |                 |                   |
|                                                                                                                                                                                            | 644                                                                                | ...             | ...             | ...               |
|                                                                                                                                                                                            | 857                                                                                | 976             | 1065            | ...               |
|                                                                                                                                                                                            | 1131                                                                               | 1305            | 1458            | 1750              |
|                                                                                                                                                                                            | 1268                                                                               | 1512            | 1697            | 2062 <sup>b</sup> |
|                                                                                                                                                                                            | 1428                                                                               | 1703            | 1964            | 2406              |
|                                                                                                                                                                                            | 1499                                                                               | 1910            | 2227            | 2794              |
|                                                                                                                                                                                            | 1539                                                                               | 2084            | 2458            | 3181              |
|                                                                                                                                                                                            | 1615                                                                               | 2200            | 2848            | 4063              |
|                                                                                                                                                                                            | ...                                                                                | 2281            | 3036            | 4900              |
|                                                                                                                                                                                            | ...                                                                                | ...             | 3062            | 5113              |
|                                                                                                                                                                                            | ...                                                                                | ...             | ...             | 5300              |
|                                                                                                                                                                                            | 1615                                                                               | 2281            | 3062            | 5300              |
| Fastener shear strength <sup>c</sup> .....                                                                                                                                                 |                                                                                    |                 |                 |                   |
| Sheet thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 ..... | Yield Strength <sup>d</sup> , lbs                                                  |                 |                 |                   |
|                                                                                                                                                                                            | 609                                                                                | ...             | ...             | ...               |
|                                                                                                                                                                                            | 766                                                                                | 906             | 1029            | ...               |
|                                                                                                                                                                                            | 946                                                                                | 1157            | 1325            | 1706              |
|                                                                                                                                                                                            | 1044                                                                               | 1278            | 1505            | 1956              |
|                                                                                                                                                                                            | 1152                                                                               | 1412            | 1668            | 2219              |
|                                                                                                                                                                                            | 1261                                                                               | 1555            | 1848            | 2500              |
|                                                                                                                                                                                            | 1320                                                                               | 1694            | 2014            | 2762              |
|                                                                                                                                                                                            | 1444                                                                               | 1904            | 2397            | 3350              |
|                                                                                                                                                                                            | ...                                                                                | 2106            | 2661            | 4100              |
|                                                                                                                                                                                            | ...                                                                                | ...             | 2845            | 4419              |
|                                                                                                                                                                                            | ...                                                                                | ...             | ...             | 4925              |
|                                                                                                                                                                                            |                                                                                    |                 |                 |                   |
| Head height (max.), in. ....                                                                                                                                                               | 0.037                                                                              | 0.040           | 0.049           | 0.063             |

a Data supplied by Huck Manufacturing Company.  
b Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.  
c Fastener shear strength is documented in NAS 4444.  
d Permanent set at yield load: the greater of 0.012 inch or 4% of nominal diameter.

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**Table 8.1.5.2(I). Static Joint Strength of 70° Flush Head Straight Shank Ti-6Al-4V Fasteners in Non-Matching Machine-Countersunk Aluminum Alloy Sheet and Plate**

|                                                  |                                         |         |          |         |
|--------------------------------------------------|-----------------------------------------|---------|----------|---------|
| Fastener Type .....                              | HPT-V <sup>a</sup> ( $F_{su}$ = 95 ksi) |         |          |         |
| Sheet and Plate Material .....                   | Clad 7075-T6 and T651                   |         |          |         |
| Fastener Diameter .....                          | 3/16                                    | 1/4     | 5/16     | 3/8     |
| (Nominal Shank Diameter, in.) <sup>b</sup> ..... | (0.193)                                 | (0.255) | (0.3175) | (0.380) |
| Sheet Countersink Angle .....                    | 82°                                     | 82°     | 82°      | 75°     |
| Ultimate Strength, lbs                           |                                         |         |          |         |
| Sheet or plate thickness, in.:                   |                                         |         |          |         |
| 0.063 .....                                      | 1348                                    | ...     | ...      | ...     |
| 0.071 .....                                      | 1546                                    | 1970    | ...      | ...     |
| 0.080 .....                                      | 1704                                    | 2275    | ...      | ...     |
| 0.090 .....                                      | 1814                                    | 2580    | 3125     | ...     |
| 0.100 .....                                      | 1948                                    | 2873    | 3528     | 4100    |
| 0.125 .....                                      | 2265                                    | 3282    | 4465     | 5270    |
| 0.160 .....                                      | 2700                                    | 3868    | 5171     | 6642    |
| 0.190 .....                                      | 2779                                    | 4361    | 5826     | 7393    |
| 0.250 .....                                      | ...                                     | 4851    | 7056     | 8880    |
| 0.312 .....                                      | ...                                     | ...     | 7521     | 10396   |
| 0.375 .....                                      | ...                                     | ...     | ...      | 10774   |
| Fastener shear strength <sup>c</sup> .....       | 2779                                    | 4851    | 7521     | 10774   |
| Yield Strength <sup>d</sup> , lbs                |                                         |         |          |         |
| Sheet or plate thickness, in.:                   |                                         |         |          |         |
| 0.063 .....                                      | 1180                                    | ...     | ...      | ...     |
| 0.071 .....                                      | 1378                                    | 1651    | ...      | ...     |
| 0.080 .....                                      | 1590                                    | 1944    | ...      | ...     |
| 0.090 .....                                      | 1702                                    | 2321    | 2631     | ...     |
| 0.100 .....                                      | 1818                                    | 2620    | 3024     | 3350    |
| 0.125 .....                                      | 2112                                    | 3055    | 4133     | 4664    |
| 0.160 .....                                      | 2496                                    | 3601    | 4848     | 6209    |
| 0.190 .....                                      | 2734                                    | 4062    | 5413     | 6902    |
| 0.250 .....                                      | ...                                     | 4745    | 6552     | 8288    |
| 0.312 .....                                      | ...                                     | ...     | 7378     | 9631    |
| 0.375 .....                                      | ...                                     | ...     | ...      | 10584   |
| Head height (max.), in. ....                     | 0.060                                   | 0.070   | 0.080    | 0.090   |

a Data supplied by PB Fasteners.  
b Fasteners installed in interference holes (0.0045-0.0055) (Ref. 8.1.5).  
c Fastener shear strength based on areas computed from the indicated nominal shank diameter and  $F_{su}$  = 95 ksi.  
d Permanent set at yield load: the greater of 0.012 inch or 4% of nominal diameter.



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**Table 8.1.5.2(m). Static Joint Strength of 100° Flush Shear Head STA Ti-6Al-4V Fasteners in Machine-Countersunk Aluminum Alloy Sheet**

|                                                                                                                                                                                                     |                                                                |                   |                |                  |                |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|-------------------|----------------|------------------|----------------|
| Fastener Type .....                                                                                                                                                                                 | NAS 4452V Pin ( $F_{su} = 95$ ksi), NAS 4445D Nut <sup>a</sup> |                   |                |                  |                |
| Sheet Material .....                                                                                                                                                                                | Clad 7075-T6                                                   |                   |                |                  |                |
| Fastener Diameter, in. ....<br>(Nominal Shank Diameter, in.) ...                                                                                                                                    | 5/32<br>(0.164)                                                | 3/16<br>(0.190)   | 1/4<br>(0.250) | 5/16<br>(0.312)  | 3/8<br>(0.375) |
| Sheet or plate thickness, in.:<br>0.040 .....<br>0.050 .....<br>0.063 .....<br>0.071 .....<br>0.080 .....<br>0.090 .....<br>0.100 .....<br>0.125 .....<br>0.160 .....<br>0.190 .....<br>0.250 ..... | Ultimate Strength, lbs                                         |                   |                |                  |                |
|                                                                                                                                                                                                     | 766                                                            | ...               | ...            | ...              | ...            |
|                                                                                                                                                                                                     | 1092                                                           | <sup>b</sup> 1173 | ...            | ...              | ...            |
|                                                                                                                                                                                                     | 1450                                                           | 1639              | 1886           | ...              | ...            |
|                                                                                                                                                                                                     | 1633                                                           | 1889              | 2290           | <sup>b</sup> ... | ...            |
|                                                                                                                                                                                                     | 1805                                                           | 2136              | 2710           | 3028             | ...            |
|                                                                                                                                                                                                     | 1955                                                           | 2368              | 3135           | 3651             | ...            |
|                                                                                                                                                                                                     | 2007                                                           | 2557              | 3515           | 4230             | 4669           |
|                                                                                                                                                                                                     | ...                                                            | 2694              | 4273           | 5485             | 6428           |
|                                                                                                                                                                                                     | ...                                                            | ...               | 4660           | 6776             | 8426           |
|                                                                                                                                                                                                     | ...                                                            | ...               | ...            | 7290             | 9708           |
|                                                                                                                                                                                                     | ...                                                            | ...               | ...            | ...              | 10490          |
|                                                                                                                                                                                                     | 2007                                                           | 2694              | 4660           | 7290             | 10490          |
|                                                                                                                                                                                                     | Yield Strength <sup>d</sup> , lbs                              |                   |                |                  |                |
|                                                                                                                                                                                                     | 712                                                            | ...               | ...            | ...              | ...            |
|                                                                                                                                                                                                     | 891                                                            | 1034              | ...            | ...              | ...            |
|                                                                                                                                                                                                     | 1103                                                           | 1295              | 1712           | ...              | ...            |
|                                                                                                                                                                                                     | 1223                                                           | 1445              | 1932           | ...              | ...            |
|                                                                                                                                                                                                     | 1349                                                           | 1604              | 2169           | 2715             | ...            |
|                                                                                                                                                                                                     | 1475                                                           | 1768              | 2420           | 3056             | ...            |
|                                                                                                                                                                                                     | 1489                                                           | 1920              | 2658           | 3383             | 4082           |
|                                                                                                                                                                                                     | ...                                                            | 2241              | 3196           | 4145             | 5072           |
|                                                                                                                                                                                                     | ...                                                            | ...               | 3812           | 5076             | 6321           |
|                                                                                                                                                                                                     | ...                                                            | ...               | ...            | 5746             | 7265           |
|                                                                                                                                                                                                     | ...                                                            | ...               | ...            | ...              | 8802           |
| Head height (max.), in. ....                                                                                                                                                                        | 0.040                                                          | 0.049             | 0.063          | 0.077            | 0.091          |

- a Data supplied by Huck Manufacturing Company.
- b Values above line are for knife-edge condition and the use of fasteners in this condition is undesirable. The use of knife-edge condition in design of military aircraft requires specific approval of the procuring agency.
- c Fastener shear strength is documented in NAS 4444.
- d Permanent set at yield load: the greater of 0.012 inch or 4% of nominal diameter.

**Table 8.1.5.2(n). Static Joint Strength of Protruding Shear Head Alloy Steel Hi-Lok Fasteners in Aluminum Alloy Sheet**

|                                                                                    |                                                           |                 |                |                 |
|------------------------------------------------------------------------------------|-----------------------------------------------------------|-----------------|----------------|-----------------|
| Fastener Type . . . . .                                                            | HL 18 Pin ( $F_{su} = 95$ ksi), HL 70 Collar <sup>a</sup> |                 |                |                 |
| Sheet Material . . . . .                                                           | Clad 7075-T6                                              |                 |                |                 |
| Fastener Diameter, in. . . . .<br>(Nominal Shank Diameter, in.) <sup>b</sup> . . . | 5/32<br>(0.164)                                           | 3/16<br>(0.190) | 1/4<br>(0.250) | 5/16<br>(0.312) |
| Sheet thickness, in.:                                                              | Ultimate Strength, lbs.                                   |                 |                |                 |
| 0.050 . . . . .                                                                    | 1078                                                      | ...             | ...            | ...             |
| 0.063 . . . . .                                                                    | 1353                                                      | 1559            | ...            | ...             |
| 0.071 . . . . .                                                                    | 1520                                                      | 1776            | ...            | ...             |
| 0.080 . . . . .                                                                    | 1718                                                      | 1957            | 2593           | ...             |
| 0.090 . . . . .                                                                    | 1890                                                      | 2224            | 2937           | ...             |
| 0.100 . . . . .                                                                    | 1930                                                      | 2473            | 3250           | 4050            |
| 0.125 . . . . .                                                                    | 2007                                                      | 2580            | 4063           | 5075            |
| 0.160 . . . . .                                                                    | ...                                                       | 2694            | 4450           | 6509            |
| 0.190 . . . . .                                                                    | ...                                                       | ...             | 4620           | 6880            |
| 0.250 . . . . .                                                                    | ...                                                       | ...             | 4660           | 7290            |
| Rivet shear strength <sup>c</sup> . . . . .                                        | 2007                                                      | 2694            | 4660           | 7290            |
| Sheet thickness, in.:                                                              | Yield Strength <sup>d</sup> , lbs.                        |                 |                |                 |
| 0.050 . . . . .                                                                    | 976                                                       | ...             | ...            | ...             |
| 0.063 . . . . .                                                                    | 1251                                                      | 1426            | ...            | ...             |
| 0.071 . . . . .                                                                    | 1430                                                      | 1624            | ...            | ...             |
| 0.080 . . . . .                                                                    | 1589                                                      | 1848            | 2344           | ...             |
| 0.090 . . . . .                                                                    | 1746                                                      | 2065            | 2687           | ...             |
| 0.100 . . . . .                                                                    | 1875                                                      | 2242            | 3031           | 3660            |
| 0.125 . . . . .                                                                    | ...                                                       | 2563            | 3750           | 4734            |
| 0.160 . . . . .                                                                    | ...                                                       | ...             | 4406           | 6051            |
| 0.190 . . . . .                                                                    | ...                                                       | ...             | ...            | 6686            |

a Data supplied by Hi-Shear Corporation.  
b Fasteners installed in clearance holes (0.0005-0.0025) (Ref. Section 8.1.5).  
c Fastener shear strength based on areas computed from indicated nominal shank diameter and  $F_{su} = 95$  ksi.  
d Permanent set at yield load: the greater of 0.012 inch or 4% of nominal diameter.

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**Table 8.1.5.2(o). Static Joint Strength of 100° Flush Shear Head Alloy Steel Hi-Lok Fasteners in Machine-Countersunk Aluminum Alloy Sheet**

| Fastener Type . . . . .                                                            | HL 19 Pin ( $F_{su} = 95$ ksi), HL 70 Collar <sup>a</sup> |                 |                |                 |
|------------------------------------------------------------------------------------|-----------------------------------------------------------|-----------------|----------------|-----------------|
| Sheet Material . . . . .                                                           | Clad 7075-T6                                              |                 |                |                 |
| Fastener Diameter, in. . . . .<br>(Nominal Shank Diameter, in.) <sup>b</sup> . . . | 5/32<br>(0.164)                                           | 3/16<br>(0.190) | 1/4<br>(0.250) | 5/16<br>(0.312) |
| Sheet thickness, in.:                                                              | Ultimate Strength, lbs.                                   |                 |                |                 |
| 0.050 . . . . .                                                                    | 968                                                       | ...             | ...            | ...             |
| 0.063 . . . . .                                                                    | 1251                                                      | 1408            | ...            | ...             |
| 0.071 . . . . .                                                                    | 1400                                                      | 1606            | ...            | ...             |
| 0.080 . . . . .                                                                    | 1595                                                      | 1823            | 2344           | ...             |
| 0.090 . . . . .                                                                    | 1815                                                      | 2050            | 2675           | ...             |
| 0.100 . . . . .                                                                    | 1903                                                      | 2300            | 3000           | 3660            |
| 0.125 . . . . .                                                                    | 2005                                                      | 2570            | 3781           | 4685            |
| 0.160 . . . . .                                                                    | ...                                                       | 2694            | 4420           | 6051            |
| 0.190 . . . . .                                                                    | ...                                                       | ...             | 4625           | 6832            |
| 0.250 . . . . .                                                                    | ...                                                       | ...             | 4660           | 7290            |
| Rivet shear strength <sup>c</sup> . . . . .                                        | 2007                                                      | 2694            | 4660           | 7290            |
| Sheet thickness, in.:                                                              | Yield Strength <sup>d</sup> , lbs.                        |                 |                |                 |
| 0.050 . . . . .                                                                    | 839                                                       | ...             | ...            | ...             |
| 0.063 . . . . .                                                                    | 1031                                                      | 1191            | ...            | ...             |
| 0.071 . . . . .                                                                    | 1141                                                      | 1336            | ...            | ...             |
| 0.080 . . . . .                                                                    | 1279                                                      | 1480            | 2013           | ...             |
| 0.090 . . . . .                                                                    | 1416                                                      | 1632            | 2219           | ...             |
| 0.100 . . . . .                                                                    | 1540                                                      | 1805            | 2420           | 3143            |
| 0.125 . . . . .                                                                    | 1807                                                      | 2173            | 3000           | 3777            |
| 0.160 . . . . .                                                                    | ...                                                       | 2545            | 3670           | 4800            |
| 0.190 . . . . .                                                                    | ...                                                       | ...             | 4144           | 5514            |
| 0.250 . . . . .                                                                    | ...                                                       | ...             | ...            | 6686            |
| Head height (nom.), in. . . . .                                                    | 0.040                                                     | 0.046           | 0.060          | 0.067           |

- a Data supplied by Hi-Shear Corporation.  
b Fasteners installed in clearance holes (0.0005-0.0025) (Ref. Section 8.1.5).  
c Fastener shear strength based on areas computed from indicated nominal shank diameter and  $F_{su} = 95$  ksi.  
d Permanent set at yield load: the greater of 0.012 inch or 4% of nominal diameter.

**8.1.6 SPECIAL FASTENERS** — Due to the special nature of this classification of fastener, care must be exercised in their application. Consideration should be given to the proposed fastener application and its compatibility with data presented in this section. In particular, test and analysis methods used for fasteners in this section may necessarily be different than those used in preceding sections.

**8.1.6.1 Fastener Sleeves** — Fastener sleeves are precision-formed, tubular elements designed to replace oversize fasteners used in the repair of damaged or enlarged holes.

**8.1.6.1.1 A-286 ACRES Sleeves in 7075-T6 Aluminum Alloy Sheet and Plate** — Analysis of static lap joint data indicates that a single 100° low profile head, A-286 [ACRES Sleeve (part number JK5512C)] installed with titanium or steel Hi-Loks and alloy steel lockbolts (up to 108 ksi  $F_{su}$ ) provided static joint allowable shear loads equivalent to those developed by the above-noted fasteners when tested without sleeves. Fasteners and sleeves were installed to the same comparable hole tolerance and fit condition as fasteners when tested alone. The analysis was restricted to static lap joint data (in accordance with MIL-STD-1312 Test 4) and equivalency to fastener systems other than those listed above is not implied. Other properties such as tensile strength, preload, fatigue strength, and corrosion characteristics should be verified by test data. When using sleeves, knife-edge conditions should be avoided.

**8.1.6.2 Sleeve Bolts** — Tables 8.1.6.2(a) and (b) contain joint allowables for various sleeve bolt/sheet material combinations. Sleeve bolts are made of precision-formed aluminum alloy sleeve elements assembled on standard taper shank bolts. When the assembly is placed in a cylindrical hole and the bolt is drawn into the sleeve, the sleeve expands, thus filling the hole and causing an interference-fit condition.

The allowable loads were established from test data using the following criteria:

*Ultimate Load* — Average ultimate test load divided by a factor of 1.15, as defined in Section 9.4. This factor is not applicable to shear strength cutoff values which are defined by the procurement specification.

*Yield Load* — Average yield test load as defined in Section 9.4.1.3.3 and the load which results in a joint permanent set equal to 0.04D, where D is the hole size.

The allowable loads shown for flush-head fasteners are applicable to joints having  $e/D$  equal to or greater than 2.0.

For machine countersunk joints, the sheet gage specified in the tables herein is that of the countersunk sheet. When the noncountersunk sheet is thinner than the countersunk sheet, the bearing allowable for the noncountersunk sheet-fastener combination should be computed, compared to the table value, and the lower of the two values selected.

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**Table 8.1.6.2(a). Static Joint Strength of 100° Reduced Flush Head, Alloy Steel Pin, Aluminum Alloy Sleeve, Fastener in Machine-Countersunk Aluminum Alloy Sheet and Plate**

|                                                                               |                                                 |                 |                  |                 |                  |                 |
|-------------------------------------------------------------------------------|-------------------------------------------------|-----------------|------------------|-----------------|------------------|-----------------|
| Fastener Type . . . . .                                                       | MIL-B-8831/4 <sup>a</sup> ( $F_{su} = 108$ ksi) |                 |                  |                 |                  |                 |
| Sheet Material . . . . .                                                      | Clad 7075-T6                                    |                 |                  |                 |                  |                 |
| Fastener Diameter, in. . . . .<br>(Nominal Hole Diameter, in.) <sup>b,c</sup> | 3/16<br>(0.2390)                                | 1/4<br>(0.3032) | 5/16<br>(0.3695) | 3/8<br>(0.4350) | 7/16<br>(0.5022) | 1/2<br>(0.5735) |
| Sheet thickness, in.:                                                         | Ultimate Strength, lbs.                         |                 |                  |                 |                  |                 |
| 0.100 . . . . .                                                               | 2585                                            | ...             | ...              | ...             | ...              | ...             |
| 0.125 . . . . .                                                               | 3205                                            | 4100            | 5035             | ...             | ...              | ...             |
| 0.160 . . . . .                                                               | 3290                                            | 5205            | 6385             | 7560            | 8790             | ...             |
| 0.190 . . . . .                                                               | ...                                             | 5670            | 7535             | 8925            | 10360            | 11900           |
| 0.250 . . . . .                                                               | ...                                             | ...             | 8760             | 11640           | 13495            | 15480           |
| 0.312 . . . . .                                                               | ...                                             | ...             | ...              | 12395           | 16195            | 19180           |
| 0.375 . . . . .                                                               | ...                                             | ...             | ...              | 12640           | 16625            | 21265           |
| 0.500 . . . . .                                                               | ...                                             | ...             | ...              | ...             | 17100            | 22250           |
| Rivet shear strength <sup>d</sup> . . . . .                                   | 3290                                            | 5670            | 8760             | 12640           | 17100            | 22250           |
| Sheet thickness, in.:                                                         | Yield Strength <sup>e</sup> , lbs.              |                 |                  |                 |                  |                 |
| 0.100 . . . . .                                                               | 2080                                            | ...             | ...              | ...             | ...              | ...             |
| 0.125 . . . . .                                                               | 2570                                            | 3300            | 4075             | ...             | ...              | ...             |
| 0.160 . . . . .                                                               | 3255                                            | 4170            | 5135             | 6105            | 7125             | ...             |
| 0.190 . . . . .                                                               | ...                                             | 4915            | 6040             | 7175            | 8360             | 9635            |
| 0.250 . . . . .                                                               | ...                                             | ...             | 7855             | 9310            | 10825            | 12450           |
| 0.312 . . . . .                                                               | ...                                             | ...             | ...              | 11520           | 13375            | 15360           |
| 0.375 . . . . .                                                               | ...                                             | ...             | ...              | 12355           | 15620            | 18320           |
| 0.500 . . . . .                                                               | ...                                             | ...             | ...              | ...             | ...              | 21570           |
| Sleeve head height (ref.), in. . .                                            | 0.062                                           | 0.075           | 0.082            | 0.093           | 0.115            | 0.120           |

- a Data supplied by P.B. Fasteners.
- b Nominal hole diameter based on  $\left( \frac{\text{max. expanded sleeve} - \text{min. hole}}{2} \right) + \text{min. hole}$  using larger expanded diameter from MIL-B-8831/4 dated 23 August 1982.
- c Fasteners installed to interference levels of 0.0025-0.008 in.
- d Fastener shear strength is documented in NAS 1724 as 108 ksi.
- e Permanent set at yield load: 4% of nominal hole diameter (Ref. 9.4.1.3.3).

**Table 8.1.6.2(b). Static Joint Strength of 100° Reduced Flush Head, Alloy Steel Pin, Aluminum Alloy Sleeve, Fastener in Machine-Countersunk Aluminum Alloy Sheet and Plate**

|                                                                                 |                                                 |                 |                  |                 |                  |                 |
|---------------------------------------------------------------------------------|-------------------------------------------------|-----------------|------------------|-----------------|------------------|-----------------|
| Fastener Type . . . . .                                                         | MIL-B-8831/4 <sup>a</sup> ( $F_{su}$ = 108 ksi) |                 |                  |                 |                  |                 |
| Sheet Material . . . . .                                                        | Clad 2024-T3                                    |                 |                  |                 |                  |                 |
| Fastener Diameter, in. . . . .<br>(Nominal Hole Diameter, in.) <sup>b,c</sup> . | 3/16<br>(0.2390)                                | 1/4<br>(0.3032) | 5/16<br>(0.3695) | 3/8<br>(0.4350) | 7/16<br>(0.5022) | 1/2<br>(0.5735) |
| Sheet thickness, in.:                                                           | Ultimate Strength, lbs.                         |                 |                  |                 |                  |                 |
| 0.100 . . . . .                                                                 | 2175                                            | ...             | ...              | ...             | ...              | ...             |
| 0.125 . . . . .                                                                 | 2720                                            | 3450            | 4205             | ...             | ...              | ...             |
| 0.160 . . . . .                                                                 | 3290                                            | 4415            | 5380             | 6335            | 7315             | ...             |
| 0.190 . . . . .                                                                 | ...                                             | 5240            | 6390             | 7525            | 8685             | 9920            |
| 0.250 . . . . .                                                                 | ...                                             | 5480            | 7945             | 9895            | 11425            | 13050           |
| 0.312 . . . . .                                                                 | ...                                             | 5655            | 8165             | 11085           | 14260            | 16285           |
| 0.375 . . . . .                                                                 | ...                                             | 5670            | 8385             | 11345           | 14845            | 19070           |
| 0.500 . . . . .                                                                 | ...                                             | ...             | 8760             | 11865           | 15445            | 19755           |
| 0.625 . . . . .                                                                 | ...                                             | ...             | ...              | 12385           | 16045            | 20440           |
| 0.750 . . . . .                                                                 | ...                                             | ...             | ...              | 12640           | 16645            | 21225           |
| 0.875 . . . . .                                                                 | ...                                             | ...             | ...              | ...             | 17100            | 21805           |
| 1.000 . . . . .                                                                 | ...                                             | ...             | ...              | ...             | ...              | 22250           |
| Rivet shear strength <sup>d</sup> . . . . .                                     | 3290                                            | 5670            | 8760             | 12640           | 17100            | 22250           |
| Sheet thickness, in.:                                                           | Yield Strength <sup>e</sup> , lbs.              |                 |                  |                 |                  |                 |
| 0.100 . . . . .                                                                 | 1575                                            | ...             | ...              | ...             | ...              | ...             |
| 0.125 . . . . .                                                                 | 1880                                            | 2505            | 3200             | ...             | ...              | ...             |
| 0.160 . . . . .                                                                 | 2310                                            | 3050            | 3865             | 4720            | 5655             | ...             |
| 0.190 . . . . .                                                                 | ...                                             | 3515            | 4435             | 5395            | 6430             | 7595            |
| 0.250 . . . . .                                                                 | ...                                             | 4450            | 5570             | 6735            | 7980             | 9360            |
| 0.312 . . . . .                                                                 | ...                                             | 5055            | 6745             | 8115            | 9580             | 11185           |
| 0.375 . . . . .                                                                 | ...                                             | 5560            | 7460             | 9525            | 11205            | 13040           |
| 0.500 . . . . .                                                                 | ...                                             | ...             | 8680             | 11010           | 13655            | 16720           |
| 0.625 . . . . .                                                                 | ...                                             | ...             | ...              | 12385           | 15315            | 18625           |
| 0.750 . . . . .                                                                 | ...                                             | ...             | ...              | 12640           | 16645            | 20520           |
| 0.875 . . . . .                                                                 | ...                                             | ...             | ...              | ...             | 17100            | 21805           |
| 1.000 . . . . .                                                                 | ...                                             | ...             | ...              | ...             | ...              | 22250           |
| Sleeve head height (ref.), in. . . .                                            | 0.062                                           | 0.075           | 0.082            | 0.093           | 0.115            | 0.120           |

a Data supplied by P.B. Fasteners.

b Nominal hole diameter based on  $\left(\frac{\text{max. expanded sleeve} - \text{min. hole}}{2}\right) + \text{min. hole}$  using larger expanded diameter from MIL-B-8831/4 dated 23 August 1982.

c Fasteners installed to interference levels of 0.002-0.008 in.

d Fastener shear strength is documented in NAS 1724 as 108 ksi.

e Permanent set at yield load: 4% of nominal hole diameter (Ref. 9.4.1.3.3).

## 8.2 METALLURGICAL JOINTS

In the design of metallurgical joints, the strength of the joining material (for example, weld metal) and the adjacent parent material must be considered. The joint should be analyzed on the basis of its loading, the specified allowable strengths, dimensions and geometry.

**8.2.1 INTRODUCTION AND DEFINITIONS**— The allowable strength for both the adjacent parent metal and the weld metal is given below in the particular section dealing with the method of forming used, and the material being joined. The following subparagraphs define certain joining processes.

*Welding* — Welding consists of joining two or more pieces of metal by applying heat, pressure or both, with or without filler material, to produce a localized union through fusion or recrystallization across the joint interface. Examples of common welding processes include: fusion [inert-gas, shielded-arc welding with tungsten electrode (TIG) and inert-gas shielded metal-arc welding using covered electrodes (MIG)], resistance (spot and seam), and flash. Several terms used in describing various sections of a welded joint are illustrated in Figure 8.2.1.

*Brazing* — Brazing consists of joining metals by the application of heat causing the flow of a thin layer, capillary thickness, of nonferrous filler metal into the space between the pieces. Bonding results from the intimate contact produced by the dissolution of a small amount of base metal in the molten filler metal, without fusion of the base metal.

**8.2.2 WELDED JOINTS** — The weld metal section of a joint should be analyzed on the basis of its loading, specified allowable strength, dimensions and geometry. The effects of the parent metal are to be accounted for as specified herein.

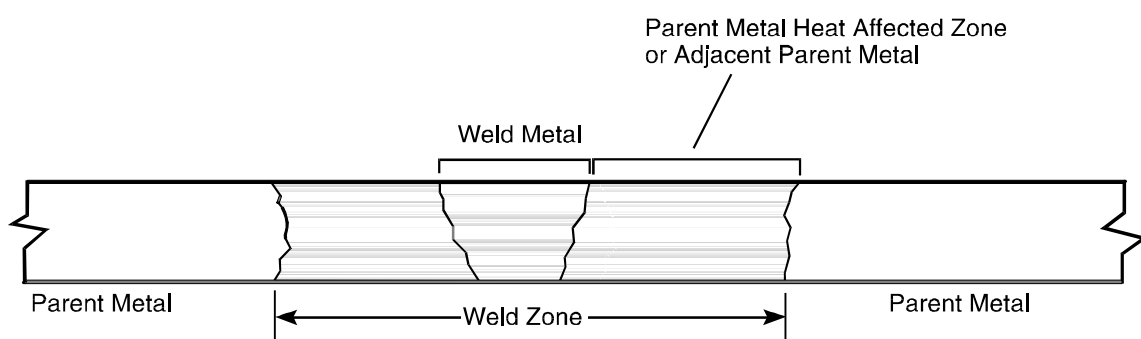


**Figure 8.2.1. Schematic diagram of weld and parent metal.**

**8.2.2.1 Fusion Welding--Arc and Gas** — Section 9.4.2 contains a detailed discussion of one acceptable method of establishing fusion welding allowables. As stated in that section, other methods can be employed as approved by certifying agencies. The following subsections contain specific information for a number of materials.

**8.2.2.1.1 Strength of Fusion Welded Joints of Steel Alloys** — Allowable fusion weld-metal strengths of steel alloys are shown in Table 8.2.2.1.1(a). Design allowable stresses for the weld metal are based on 85 percent of the respective minimum tensile ultimate test values.

For steel joints welded after heat treatment, the allowable strengths near the weld are given in Tables 8.2.2.1.1(b) and (c).

**8.2.2.1.1(a). Strength of Fusion Welded Joints of Steel Alloys**

| Material                    | Heat Treatment<br>Subsequent to Welding | Welding Rod<br>or Electrode                                                | $F_{su}$ , ksi | $F_w$ ,<br>ksi |
|-----------------------------|-----------------------------------------|----------------------------------------------------------------------------|----------------|----------------|
| Carbon and alloy steels . . | None . . . . .                          | AMS 6457 . . . . .                                                         | 32             | 51             |
|                             |                                         | AWSA5.1 classes E6010<br>and E6013 . . . . .                               | 32             | 51             |
| Alloy steels . . . . .      | None . . . . .                          | AMS 6452 . . . . .                                                         | 43             | 72             |
| Alloy steels . . . . .      | Stress relieved . . . . .               | AWSA5.5 class E10013 . . . . .<br>MIL-E-22200/10, classes MIL-<br>10018-M1 | 50             | 85             |

**Table 8.2.2.1.1(b). Allowable Ultimate Tensile Stresses Near Fusion Welds in 4130, 4140, or 8630 Steels<sup>a</sup>**

| Section Thickness ¼ inch or less                     |                              |
|------------------------------------------------------|------------------------------|
| Type of Joint                                        | Ultimate Tensile Stress, ksi |
| Tapered joints of 30° or less <sup>b</sup> . . . . . | 90                           |
| All others . . . . .                                 | 80                           |

a Welded after heat treatment or normalized after weld.  
b Gussets or plate inserts considered 0° taper with centerline.

**Table 8.2.2.1.1(c). Allowable Bending Modulus of Rupture Near Fusion Welds in 4130, 4140, 4340, or 8630 Steels<sup>a</sup>**

| Type of Joint                                        | Bending Modulus of Rupture, ksi                                      |
|------------------------------------------------------|----------------------------------------------------------------------|
| Tapered joints of 30° or less <sup>b</sup> . . . . . | $F_b$ from Figure 2.8.1.1 for $F_w = 90$ ksi                         |
| All others . . . . .                                 | 0.9 of the values of $F_b$ from Figure<br>2.8.1.1 for $F_w = 90$ ksi |

a Welded after heat treatment or normalized after weld.  
b Gussets or plate inserts considered 0° taper with centerline.



For materials heat treated after welding, the allowable strength in the parent metal near a welded joint may equal the allowable strength for the material in the heat treated condition as given in the tables of design mechanical properties of the specific alloys; however, it should be noted that the weld metal allowables are based on 85 percent of these values.

**8.2.2.2 Flash and Pressure Welding** — The ultimate tensile allowable strength and bending allowable modulus of rupture for flash and pressure welds are given in Tables 8.2.2.2(a) and (b). A higher efficiency may be permitted in special cases by the applicable procuring or certifying agency upon approval of the manufacturer's process specification.

**8.2.2.3 Spot and Seam Welding** — Permission to use spot and seam welding on structural parts is governed by the requirements of the procuring or certifying agency. Table 8.2.2.3 gives the recommended allowable edge distance for spot and seam welds.

**8.2.2.3.1 Design Shear Strengths for Spot and Seam Welds in Uncoated Steels and Nickel and Cobalt Alloys** — The design shear strength for spot welds for these materials are given in Tables 8.2.2.3.1(a) and (b). The thickness ratio of the thickest sheet to the thinnest outer sheet in the combination should not exceed 4:1.

**8.2.2.3.1.1 Effects of Spot-Welds on the Parent Metal Strength of 300 Series Stainless Steel** — In applications of spot welding where ribs, intercostals, or doublers are attached to sheet, either at splices or at other joints on the sheet panels, the allowable ultimate strength of the spot-welded stainless steel sheet shall be determined by multiplying the ultimate tensile strength of the sheet (A or S-value) by the appropriate efficiency factors shown in Figures 8.2.2.3.1.1(a) through (c). Efficiencies for gages under 0.012 shall be determined by test.

**8.2.2.3.2 Design Shear Strengths for Spot and Seam Weldings in Aluminum Alloys** — The acceptable aluminum and aluminum alloy combinations for spot and seam welding are given in Table 8.2.2.3.2(a).

Design shear-strength for spot welds in aluminum alloys are given in Tables 8.2.2.3.2(b) and (c). The thickness ratio of the thickest to the thinnest outer sheet in the combination should not exceed 4:1.

Design shear-strength for spot-welded joints, based on tearing of the sheet, is given in Table 8.2.2.3.2(d) for some aluminum alloys, together with the "maximum" pitches that permit attainment of these strengths. Joints having larger pitches fail in the spot welds rather than by tearing of the sheet, and are governed by Tables 8.2.2.3.2(b) and (c). The design shear strengths listed are also applicable to seam welds.

**8.2.2.3.2.1 Effects of Spot Welds on Parent Metal Strength of Aluminum Alloys** — In applications of spot welding other than splices, where ribs, intercostals, or doublers are attached to sheet, the allowable ultimate strength of the spot-welded sheet may be determined by multiplying the ultimate tensile strength of the sheet (A or S-values) by the appropriate efficiency factor shown on Figure 8.2.2.3.2.1. Efficiencies for gages under 0.020 shall be determined by test.

**8.2.2.3.2.2 Fatigue Strength of Spot-Welded Joints in Aluminum Alloys** — The fatigue strength of spot-welded joints in aluminum alloy are given in Figures 8.2.2.3.2.2(a) through 8.2.2.3.2.2(e).

**8.2.2.3.3 Design Shear Strengths for Spot and Seam Welds in Magnesium Alloys** — Design shear-strength for spot welds in magnesium alloys are given in Table 8.2.2.3.3. The thickness ratio of the thickest sheet to the thinnest outer sheet in the combination should not exceed 4:1.

**8.2.2.3.4 Design Shear Strengths for Spot and Seam Welds in Titanium and Titanium Alloys** — Design shear strength for spot welds in titanium and titanium alloys are given in Tables 8.2.2.3.4(a) and (b). The thickness ratio of the thickest sheet to the thinnest outer sheet in the combination should not exceed 4:1.

**Table 8.2.2.2(a). Allowable Ultimate Tensile Stress for Flash Welds in Steel Tubing**

| Tubing                                                                                                              | Allowable Ultimate Tensile Stress of Welds            |
|---------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|
| Normalized tubing — not heat treated (including normalizing) after welding                                          | 1.0 $F_{tu}$ (based on $F_{tu}$ of normalized tubing) |
| Heat-treated tubing welded after heat treatment . . . . .                                                           | 1.0 $F_{tu}$ (based on $F_{tu}$ of normalized tubing) |
| Tubing heat treated (including normalizing) after welding. $F_{tu}$ of unwelded material in heat-treated condition: |                                                       |
| < 100 ksi . . . . .                                                                                                 | 0.9 $F_{tu}$                                          |
| 100 to 150 ksi . . . . .                                                                                            | 0.6 $F_{tu}$ + 30                                     |
| > 150 ksi . . . . .                                                                                                 | 0.8 $F_{tu}$                                          |

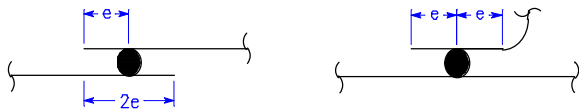
**Table 8.2.2.2(b). Allowable Bending Modulus of Rupture for Flash Welds in Steel Tubing**

| Tubing                                                                                                              | Allowable Bending Modulus of Rupture of Welds ( $F_b$ from Figure 2.8.1.1 using values of $F_{tu}$ listed) |
|---------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|
| Normalized tubing — not heat treated (including normalizing after welding                                           | 1.0 $F_{tu}$ (based on $F_{tu}$ of normalized tubing)                                                      |
| Heat-treated tubing welded after heat treatment . . . . .                                                           | 1.0 $F_{tu}$ (based on $F_{tu}$ of normalized tubing)                                                      |
| Tubing heat treated (including normalizing) after welding. $F_{tu}$ of unwelded material in heat-treated condition: |                                                                                                            |
| < 100 ksi . . . . .                                                                                                 | 0.9 $F_{tu}$                                                                                               |
| 100 to 150 ksi . . . . .                                                                                            | 0.6 $F_{tu}$ + 30                                                                                          |
| > 150 ksi . . . . .                                                                                                 | 0.8 $F_{tu}$                                                                                               |

**Table 8.2.2.3. Recommended Minimum Edge Distance and Spacing for Spot-Welded Joints<sup>a</sup>**

| Nominal Thickness <sup>b</sup><br>of Thinner Sheet, inch | Minimum Lap Joint <sup>c,d</sup><br>Edge Distance, inch | Minimum Spacing <sup>e</sup> , inch |
|----------------------------------------------------------|---------------------------------------------------------|-------------------------------------|
| 0.016                                                    | 0.19                                                    | 0.19                                |
| 0.020                                                    | 0.20                                                    | 0.30                                |
| 0.025                                                    | 0.22                                                    | 0.38                                |
| 0.032                                                    | 0.25                                                    | 0.46                                |
| 0.040                                                    | 0.28                                                    | 0.52                                |
| 0.050                                                    | 0.31                                                    | 0.58                                |
| 0.063                                                    | 0.38                                                    | 0.67                                |
| 0.071                                                    | 0.41                                                    | 0.73                                |
| 0.080                                                    | 0.44                                                    | 0.79                                |
| 0.090                                                    | 0.47                                                    | 0.89                                |
| 0.100                                                    | 0.50                                                    | 1.00                                |
| 0.125                                                    | 0.56                                                    | 1.25                                |
| 0.160                                                    | 0.69                                                    | 1.60                                |

- a Reference Aluminum Association and American Welding Society Handbook.
- b Intermediate gages will require interpolation between adjacent gages.
- c Edge distances are measured materials in contact; this can be to a free edge or to a sheet metal radius where one material bends away from another. Edge distances less than those specified above may be used provided there is no expulsion of weld material or bulging of the edge of the sheet; however, these joints may have less static strength and shorter fatigue life.



- d Minimum contacting overlap is twice the minimum edge distance.
- e Less than minimum recommended spacing may cause shunting that leads to deterioration of weld strengths and joint life.

**Table 8.2.2.3.1(a). Spot-Weld Design Shear Strength<sup>a,b</sup> in Thin Sheet and Foil for Uncoated Steels<sup>c</sup> and Nickel and Cobalt Alloys (Welding Specification MIL-W-6858)**

| Thickness of<br>Thinnest Outer<br>Sheet, in. | Spots/inch                    |                      | Material Ultimate Tensile Strength, ksi            |            |           |          |
|----------------------------------------------|-------------------------------|----------------------|----------------------------------------------------|------------|-----------|----------|
|                                              | Standard<br>(Ns) <sup>d</sup> | Range <sup>e,f</sup> | Above 185                                          | 150 to 185 | 90 to 149 | Below 90 |
|                                              |                               |                      | Design Shear Strength, pounds per linear inch (Xm) |            |           |          |
| 0.001                                        | 40                            | 1-50                 | 72                                                 | 64         | 52        | 36       |
| 0.002                                        | 20                            | 1-30                 | 144                                                | 128        | 104       | 72       |
| 0.003                                        | 12                            | 1-17                 | 240                                                | 208        | 164       | 120      |
| 0.004                                        | 10                            | 1-14                 | 324                                                | 280        | 228       | 152      |
| 0.005                                        | 9                             | 1-13                 | 392                                                | 340        | 272       | 188      |
| 0.006                                        | 7                             | 1-10                 | 432                                                | 380        | 304       | 220      |
| 0.007                                        | 6                             | 1-8                  | 504                                                | 440        | 352       | 256      |
| 0.008                                        | 5                             | 1-7                  | 552                                                | 488        | 392       | 284      |

- a Strength based on 80 percent of minimum values specified in Specification MIL-W-6858.
- b The allowable tensile strength of spot-welds is 25 percent of the design shear strength. Higher values may be used, however, if these are substantiated by tests acceptable to the procuring or certifying agency.
- c Refers to plain carbon steels containing not more than 0.15 percent carbon, austenitic, heat and corrosion resistant, and precipitation hardening steels. The reduction in strength of spot-welds due to the cumulative effects of time-temperature-stress factors is not greater than the reduction in strength of the parent metal.
- d When the number of spots per inch is within 15 percent of the standard spot per inch requirement, the design shear strengths tabulated above shall apply.
- e When the number of spots differs from the standard spots per inch by 15 percent or greater, but does not exceed the noted range of spots per inch, applicable design strength shall be determined as noted below:

$$\frac{Xm}{Ns} (K) Nr = Xr$$

- where
- Xm = design shear strength in accordance with the above table
- Ns = standard spots per inch in accordance with the above table
- Nr = required spots per inch (production part)
- Xr = actual design shear strength requirement
- K = 1.15 when number of spots per inch is reduced more than 15 percent of the standard spacing of the above table
- K = 0.90 when number of spots is increased more than 15 percent of the standard spacing but within range of the tabular spacing.
- f When the number of spots per inch is above the range indicated in the table, the design shear strength shall remain constant at the value obtained at the top of the range.

**Table 8.2.2.3.1(b). Spot-Weld Design Shear Strength<sup>a,b</sup> in Panels for Uncoated Steels<sup>c</sup> and Nickel and Cobalt Alloys (Welding Specification MIL-W-6858)**

| Material Ultimate<br>Tensile Strength, ksi  | Design Shear Strength, pounds per spot |               |              |             |
|---------------------------------------------|----------------------------------------|---------------|--------------|-------------|
|                                             | Above<br>185                           | 150 to<br>185 | 90 to<br>149 | Below<br>90 |
| Nominal thickness of<br>thinner sheet, in.: |                                        |               |              |             |
| 0.009.....                                  | 160                                    | 140           | 104          | 80          |
| 0.010.....                                  | 196                                    | 164           | 128          | 92          |
| 0.012.....                                  | 280                                    | 220           | 160          | 120         |
| 0.016.....                                  | 384                                    | 320           | 236          | 172         |
| 0.018.....                                  | 472                                    | 392           | 272          | 200         |
| 0.020.....                                  | 508                                    | 424           | 312          | 224         |
| 0.022.....                                  | 584                                    | 488           | 360          | 264         |
| 0.025.....                                  | 696                                    | 580           | 424          | 320         |
| 0.028.....                                  | 820                                    | 684           | 508          | 372         |
| 0.032.....                                  | 1000                                   | 836           | 620          | 452         |
| 0.036.....                                  | 1200                                   | 1004          | 736          | 552         |
| 0.040.....                                  | 1400                                   | 1168          | 852          | 652         |
| 0.045.....                                  | 1680                                   | 1436          | 1028         | 804         |
| 0.050.....                                  | 1960                                   | 1700          | 1204         | 956         |
| 0.056.....                                  | 2304                                   | 2040          | 1416         | 1168        |
| 0.063.....                                  | 2840                                   | 2472          | 1688         | 1408        |
| 0.071.....                                  | 3360                                   | 2984          | 2028         | 1664        |
| 0.080.....                                  | 3880                                   | 3528          | 2404         | 1964        |
| 0.090.....                                  | 4480                                   | 4072          | 2812         | 2308        |
| 0.100.....                                  | 5040                                   | 4576          | 3200         | 2640        |
| 0.112.....                                  | 5600                                   | 5092          | 3636         | 3036        |
| 0.125.....                                  | 6228                                   | 5664          | 4052         | 3440        |

a Strength based on 80 percent of minimum values specified in Specification MIL-W-6858.

b The allowable tensile strength of spot-welds is 25 percent of the design shear strength. Higher values may be used, however, if these are substantiated by tests acceptable to the procuring or certifying agency.

c Refers to plain carbon steels containing not more than 0.15 percent carbon and to austenitic heat and corrosion resistant, precipitation hardening steels. The reduction in strength of spot-welds due to the cumulative effects of time-temperature-stress factors is not greater than the reduction in strength of the parent metal.

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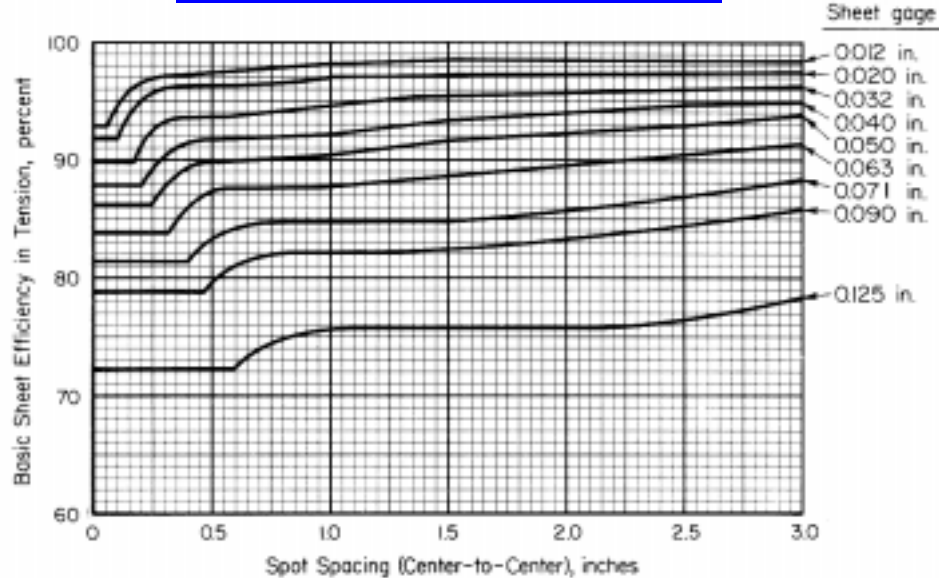


Figure 8.2.2.3.1.1(a). Efficiency of the parent metal in tension for spot-welded AISI 301-A, and AISI 347-A, and AISI 301-1/4 stainless steel.

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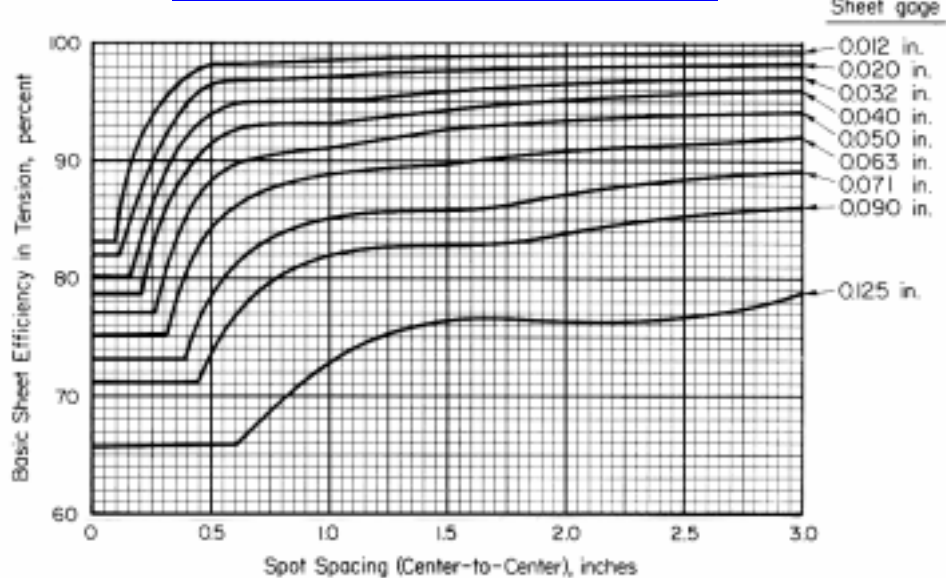


Figure 8.2.2.3.1.1(b). Efficiency of the parent metal in tension for spot-welding AISI 301-1/2H stainless steel

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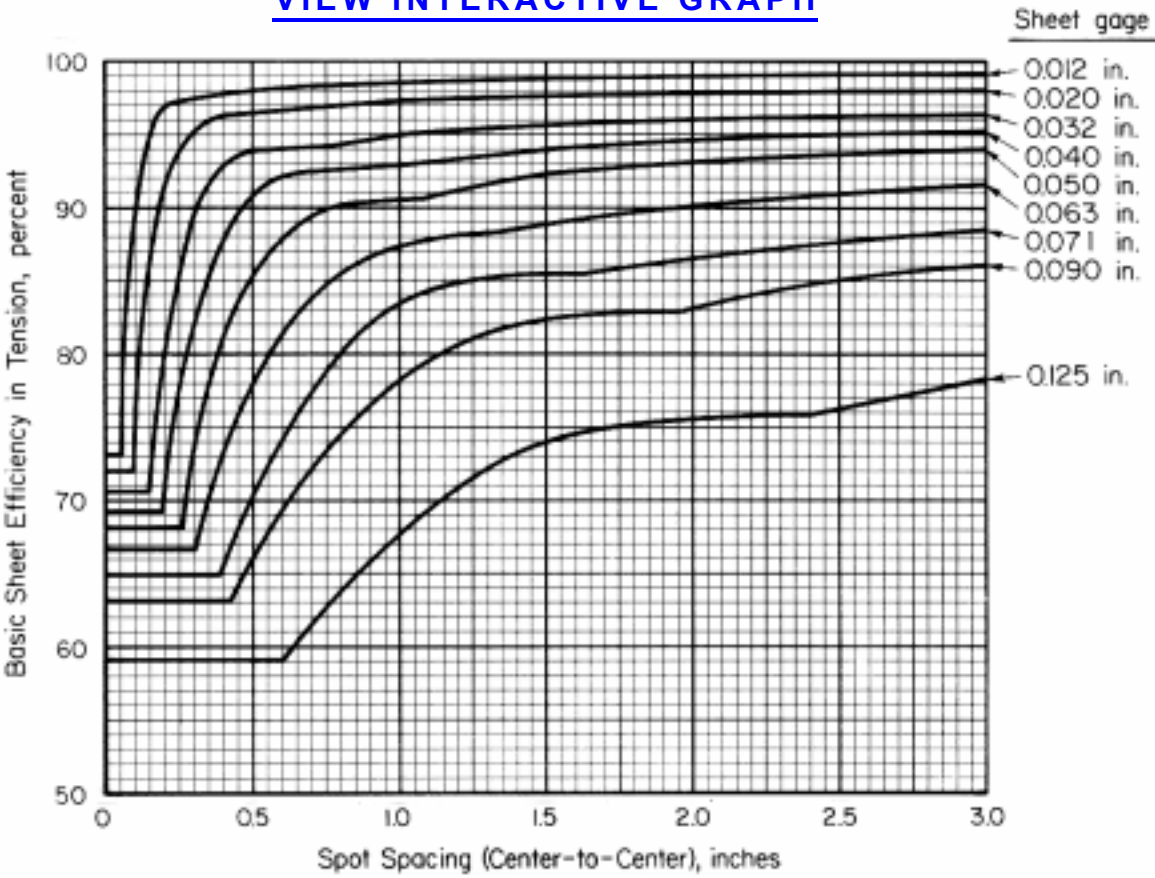


Figure 8.2.2.3.1.1(c). Efficiency of the parent metal in tension for spot-welded AISI 301-H stainless steel.

**Table 8.2.2.3.2(a). Acceptable Aluminum and Aluminum Alloy Combination<sup>a</sup> for Spot and Seam Welding**

| Specification . . . . . | AMS-QQ-A-250/1         | AMS-4029 <sup>b</sup> | AMS-QQ-A-250/3 | AMS-QQ-A-250/4 <sup>b</sup> | AMS-QQ-A-250/5 | AMS-QQ-A-250/2 | AMS-QQ-A-250/8 | AMS-QQ-A-250/11 | AMS-QQ-A-250/12 <sup>b</sup> | AMS-QQ-A-250/13 <sup>c</sup> |
|-------------------------|------------------------|-----------------------|----------------|-----------------------------|----------------|----------------|----------------|-----------------|------------------------------|------------------------------|
| Material . . . . .      | 1100                   | Bare 2014             | Clad 2014      | Bare 2024                   | Clad 2024      | 3003           | 5052           | 6061            | Bare 7075                    | Clad 7075                    |
| Specification           | Material               | ...                   | ...            | ...                         | ...            | ...            | ...            | ...             | ...                          | ...                          |
| AMS-QQ-A-250/1          | 1100                   | ...                   | ...            | ...                         | ...            | ...            | ...            | ...             | ...                          | ...                          |
| AMS-4029                | Bare 2014 <sup>b</sup> | ...                   | *              | *                           | ...            | ...            | ...            | ...             | *                            | ...                          |
| AMS-QQ-A-250/3          | Clad 2014              | ...                   | *              | ...                         | *              | ...            | ...            | ...             | *                            | ...                          |
| AMS-QQ-A-250/4          | Bare 2024 <sup>b</sup> | ...                   | *              | *                           | *              | ...            | ...            | ...             | *                            | ...                          |
| AMS-QQ-A-250/5          | Clad 2024              | ...                   | ...            | ...                         | ...            | ...            | ...            | ...             | ...                          | ...                          |
| AMS-QQ-A-250/2          | 3003                   | ...                   | ...            | ...                         | ...            | ...            | ...            | ...             | ...                          | ...                          |
| AMS-QQ-A-250/8          | 5052                   | ...                   | ...            | ...                         | ...            | ...            | ...            | ...             | ...                          | ...                          |
| AMS-QQ-A-6061           | 6061                   | ...                   | ...            | ...                         | ...            | ...            | ...            | ...             | ...                          | ...                          |
| AMS-QQ-A-250/11         | Bare 7075 <sup>b</sup> | ...                   | *              | *                           | *              | ...            | ...            | ...             | *                            | ...                          |
| AMS-QQ-A-250/12         | Clad 7075 <sup>b</sup> | ...                   | ...            | ...                         | ...            | ...            | ...            | ...             | ...                          | ...                          |
| AMS-QQ-A-250/13         |                        |                       |                |                             |                |                |                |                 |                              |                              |

a The various aluminum and aluminum-alloy materials referred to in this table may be spot-welded in any combinations except the combinations indicated by the asterisk(\*) in the table. The combinations indicated by the asterisk (\*) may be spot-welded only with the specific approval of the procuring or certifying agency.

b This table applies to construction of land- and carrier-based aircraft only. The welding of bare, high-strength alloys in construction of seaplanes and amphibians is prohibited unless specifically authorized by the procuring or certifying agency.

c Clad heat-treated and aged 7075 material in thicknesses less than 0.020 inch shall not be welded without specific approval of the procuring or certifying agency.



**Table 8.2.2.3.2(b). Spot-Weld Design Shear Strength in Thin Sheet and Foil for Bare and Clad Aluminum Alloys<sup>a,b,c</sup> (Welding Specification MIL-W-6858)**

| Thickness of<br>Thinnest Outer<br>Sheet, in. | Spots/inch                    |                      | Material Ultimate Tensile Strength, ksi               |          |
|----------------------------------------------|-------------------------------|----------------------|-------------------------------------------------------|----------|
|                                              | Standard<br>(Ns) <sup>d</sup> | Range <sup>e,f</sup> | 56 and Above                                          | Below 56 |
|                                              |                               |                      | Design Shear Strength, pounds per<br>linear inch (Xm) |          |
| 0.001.....                                   | 40                            | 1-50                 | 24                                                    | 16       |
| 0.002.....                                   | 20                            | 1-30                 | 48                                                    | 32       |
| 0.003.....                                   | 12                            | 1-17                 | 80                                                    | 52       |
| 0.004.....                                   | 10                            | 1-14                 | 108                                                   | 72       |
| 0.005.....                                   | 9                             | 1-13                 | 132                                                   | 92       |
| 0.006.....                                   | 7                             | 1-10                 | 148                                                   | 100      |
| 0.007.....                                   | 6                             | 1-8                  | 168                                                   | 112      |
| 0.008.....                                   | 5                             | 1-7                  | 188                                                   | 128      |

- a The reduction in strength of spot-welds due to the cumulative effects of time-temperature-stress factors is not greater than the reduction in strength of the parent metal.
- b Strength based on 80 percent of minimum values specified in Specification MIL-W-6858.
- c The allowable tensile strength of spot-welds is 25 percent of the design shear strength. Higher values may be used, however, if these are substantiated by tests acceptable to the procuring or certifying agency.
- d When the number of spots per inch is within 15 percent of the standard spot per inch requirement, the design shear strengths tabulated above shall apply.
- e When the number of spots differs from the standard spots per inch by 15 percent or greater, but does not exceed the noted range of spots per inch, applicable design strength shall be determined as noted below:

$$\frac{Xm}{Ns} (K) Nr = Xr$$

where

- Xm = design shear strength in accordance with the above table
- Ns = standard spots per inch in accordance with the above table
- Nr = required spots per inch (production part)
- Xr = actual design shear strength requirement
- K = 1.15 when number of spots per inch is reduced more than 15 percent of the standard spacing of the above table
- K = 0.90 when number of spots is increased more than 15 percent of the standard spacing but within range of the tabular spacing.
- f When the number of spots per inch is above the range indicated in the table, the design shear strength shall remain constant at the value obtained at the top of the range.

**Table 8.2.2.3.2(c). Spot-Weld Design Shear Strength in Panels for Bare and and Clad Aluminum Alloys<sup>a,b,c</sup> (Welding Specification MIL-W-6858)**

| Material Ultimate Tensile Strength, ksi... | Design Shear Strength, pounds per spot |          |              |            |
|--------------------------------------------|----------------------------------------|----------|--------------|------------|
|                                            | 56 and Above                           | 35 to 56 | 19.5 to 34.9 | Below 19.5 |
| Nominal thickness of thinner sheet, in.:   |                                        |          |              |            |
| 0.010 .....                                | 48                                     | 40       | ...          | ...        |
| 0.012 .....                                | 60                                     | 52       | 24           | 16         |
| 0.016 .....                                | 88                                     | 80       | 56           | 40         |
| 0.018 .....                                | 100                                    | 92       | 68           | 52         |
| 0.020 .....                                | 112                                    | 108      | 80           | 64         |
| 0.022 .....                                | 128                                    | 124      | 96           | 76         |
| 0.025 .....                                | 148                                    | 140      | 116          | 88         |
| 0.028 .....                                | 172                                    | 164      | 140          | 108        |
| 0.032 .....                                | 208                                    | 188      | 168          | 132        |
| 0.036 .....                                | 244                                    | 220      | 204          | 156        |
| 0.040 .....                                | 276                                    | 248      | 240          | 180        |
| 0.045 .....                                | 324                                    | 296      | 280          | 208        |
| 0.050 .....                                | 372                                    | 344      | 320          | 236        |
| 0.056 .....                                | 444                                    | 412      | 380          | 272        |
| 0.063 .....                                | 536                                    | 488      | 456          | 316        |
| 0.071 .....                                | 660                                    | 576      | 516          | 360        |
| 0.080 .....                                | 820                                    | 684      | 612          | 420        |
| 0.090 .....                                | 1004                                   | 800      | 696          | 476        |
| 0.100 .....                                | 1192                                   | 936      | 752          | 540        |
| 0.112 .....                                | 1424                                   | 1072     | 800          | 588        |
| 0.125 .....                                | 1696                                   | 1300     | 840          | 628        |
| 0.140 .....                                | 2020                                   | 1538     | ...          | ...        |
| 0.160 .....                                | 2496                                   | 1952     | ...          | ...        |
| 0.180 .....                                | 2980                                   | 2400     | ...          | ...        |
| 0.190 .....                                | 3228                                   | 2592     | ...          | ...        |
| 0.250 .....                                | 5880                                   | 5120     | ...          | ...        |

- a The reduction in strength of spot-welds due to the cumulative effects of time-temperature-stress factors is not greater than the reduction in strength of the parent metal.
- b Strength based on 80 percent of minimum values specified in Specification MIL-W-6858.
- c The allowable tensile strength of spot-welds is 25 percent of the design shear strength. Higher values may be used, however, if these are substantiated by tests acceptable to the procuring or certifying agency.

**Table 8.2.2.3.2(d). Maximum Static Strength of Spot-Welded Joints in Aluminum Alloys and Corresponding Maximum Design Spot-Weld Pitch<sup>a,b</sup>**

| Material.....                    | Single Row Joints |            |                   |            |                   |            | Multiple Row Joints |                        |                   |                        |                   |                        |
|----------------------------------|-------------------|------------|-------------------|------------|-------------------|------------|---------------------|------------------------|-------------------|------------------------|-------------------|------------------------|
|                                  | 7075-T6 clad      |            | 2024-T3 clad      |            | 6061-T6           |            | 7075-T6 clad        |                        | 2024-T3 clad      |                        | 6061-T6           |                        |
| Thickness of Thinnest Sheet, in. | Strength, lbs/in. | Pitch, in. | Strength, lbs/in. | Pitch, in. | Strength, lbs/in. | Pitch, in. | Strength, lbs/in.   | Pitch÷No. of Rows, in. | Strength, lbs/in. | Pitch÷No. of Rows, in. | Strength, lbs/in. | Pitch÷No. of Rows, in. |
| 0.010.....                       | 288               | 0.167      | 250               | 0.192      | 210               | 0.190      | 438                 | 0.110                  | 384               | 0.125                  | 329               | 0.122                  |
| 0.012.....                       | 346               | 0.173      | 300               | 0.200      | 252               | 0.206      | 526                 | 0.114                  | 461               | 0.130                  | 395               | 0.132                  |
| 0.016.....                       | 461               | 0.191      | 400               | 0.220      | 336               | 0.238      | 701                 | 0.126                  | 614               | 0.143                  | 526               | 0.152                  |
| 0.020.....                       | 577               | 0.194      | 500               | 0.224      | 420               | 0.257      | 876                 | 0.128                  | 768               | 0.146                  | 658               | 0.164                  |
| 0.025.....                       | 721               | 0.205      | 625               | 0.237      | 525               | 0.267      | 1095                | 0.135                  | 960               | 0.154                  | 822               | 0.170                  |
| 0.032.....                       | 923               | 0.225      | 800               | 0.260      | 672               | 0.280      | 1402                | 0.148                  | 1229              | 0.169                  | 1053              | 0.179                  |
| 0.040.....                       | 1059              | 0.261      | 918               | 0.301      | 778               | 0.319      | 1752                | 0.158                  | 1536              | 0.180                  | 1316              | 0.188                  |
| 0.050.....                       | 1230              | 0.302      | 1067              | 0.349      | 910               | 0.378      | 2190                | 0.170                  | 1920              | 0.194                  | 1645              | 0.209                  |
| 0.063.....                       | 1452              | 0.369      | 1259              | 0.426      | 1082              | 0.451      | 2759                | 0.194                  | 2419              | 0.222                  | 2073              | 0.235                  |
| 0.071.....                       | 1589              | 0.415      | 1378              | 0.479      | 1187              | 0.485      | 3110                | 0.212                  | 2726              | 0.242                  | 2336              | 0.247                  |
| 0.080.....                       | 1742              | 0.471      | 1511              | 0.543      | 1306              | 0.524      | 3504                | 0.234                  | 3072              | 0.267                  | 2632              | 0.260                  |
| 0.090.....                       | 1913              | 0.525      | 1660              | 0.605      | 1438              | 0.556      | 3942                | 0.255                  | 3456              | 0.290                  | 2961              | 0.270                  |
| 0.100.....                       | 2084              | 0.572      | 1808              | 0.659      | 1580              | 0.596      | 4380                | 0.272                  | 3840              | 0.310                  | 3290              | 0.284                  |
| 0.112.....                       | 2289              | 0.622      | 1986              | 0.717      | 1728              | 0.620      | 4906                | 0.290                  | 4301              | 0.331                  | 3685              | 0.291                  |
| 0.125.....                       | 2511              | 0.675      | 2179              | 0.788      | 1900              | 0.684      | 5475                | 0.310                  | 4800              | 0.353                  | 4112              | 0.316                  |

a For multiple row joints row spacing is at minimum and same pitch in all rows.  
b For pitches greater than those shown, strength is governed by Tables 8.2.2.3.2(b) and (c).

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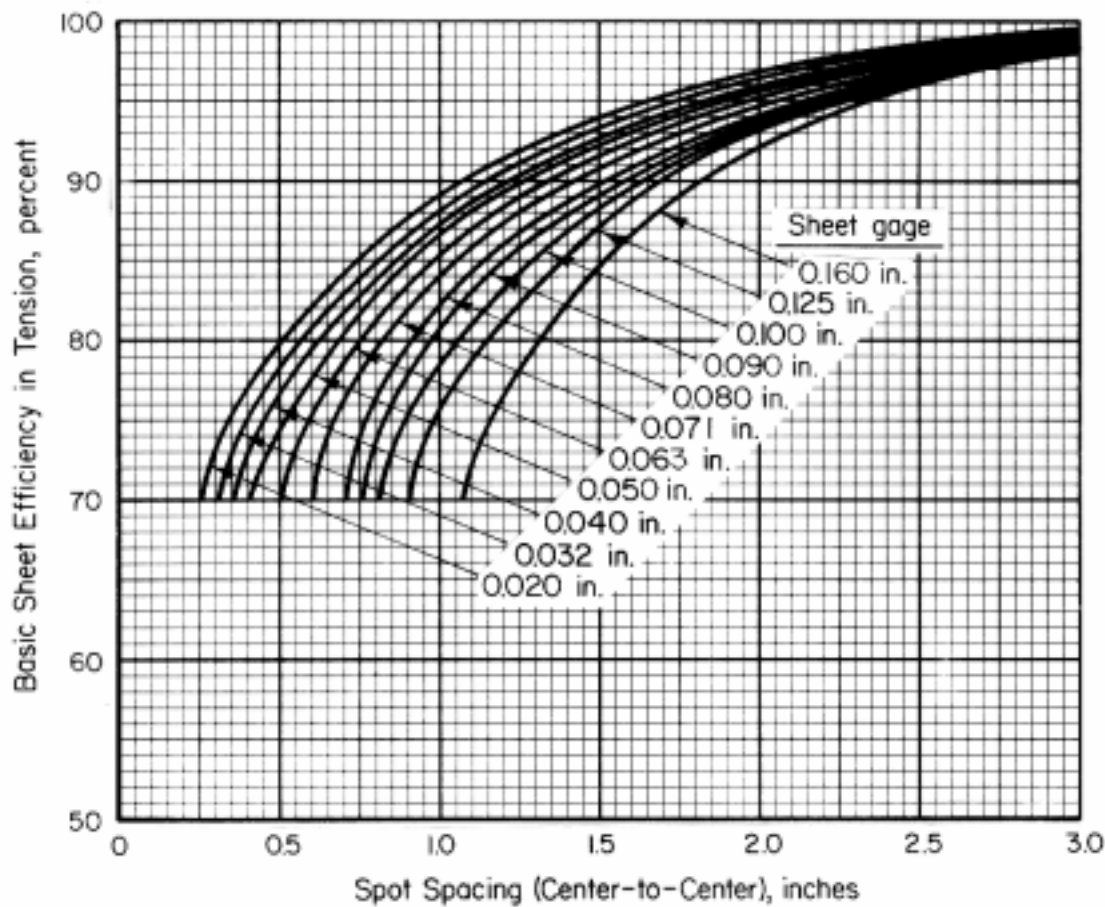


Figure 8.2.2.3.2.1. Efficiency of the parent metal in tension for spot-welded aluminum alloys.

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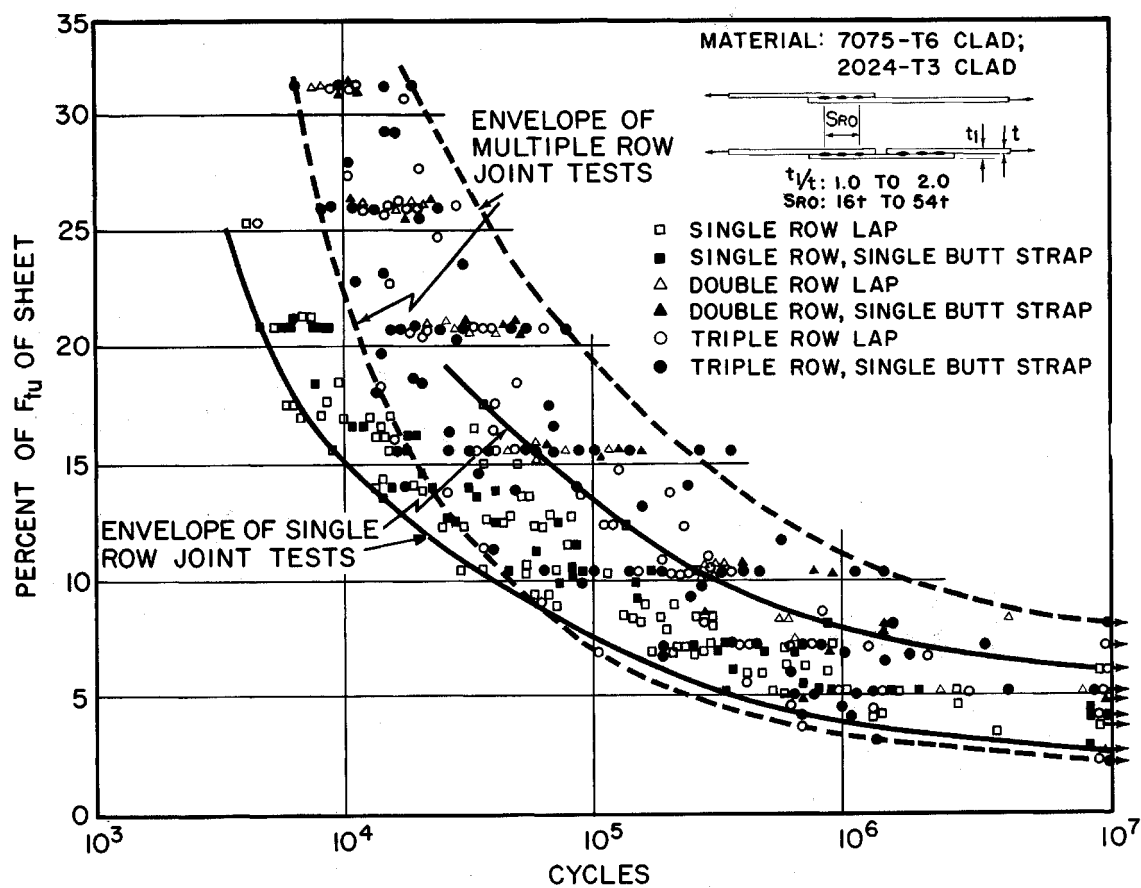


Figure 8.2.2.3.2.2(a). Fatigue strength of spot-welded joints in aluminum alloy sheet. Load Ratio = 0.05 (static failure by tearing sheet).

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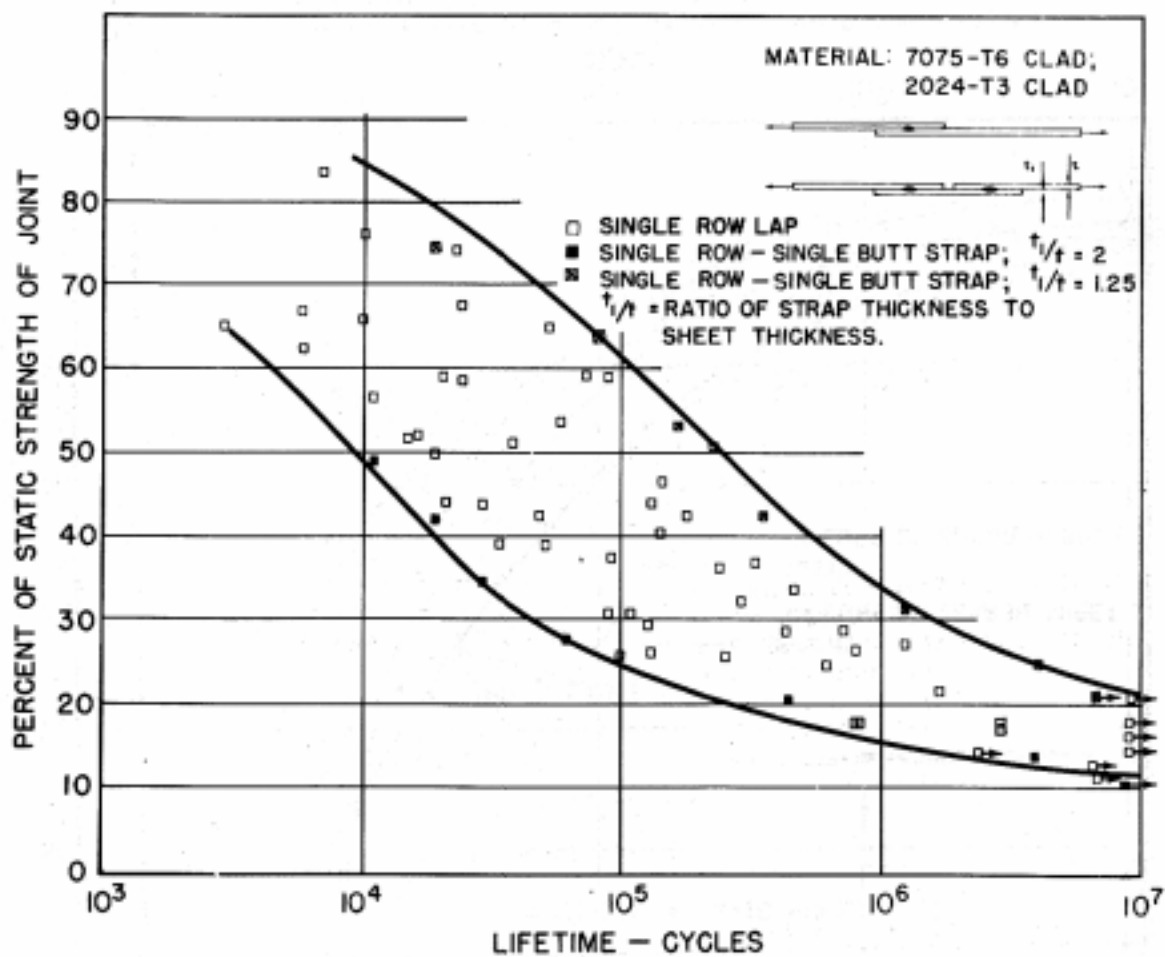


Figure 8.2.2.3.2.2(b). Fatigue strength of spot-welded joints in aluminum alloy sheet. Load Ratio = 0.05 (static failure by shear in the spot welds).

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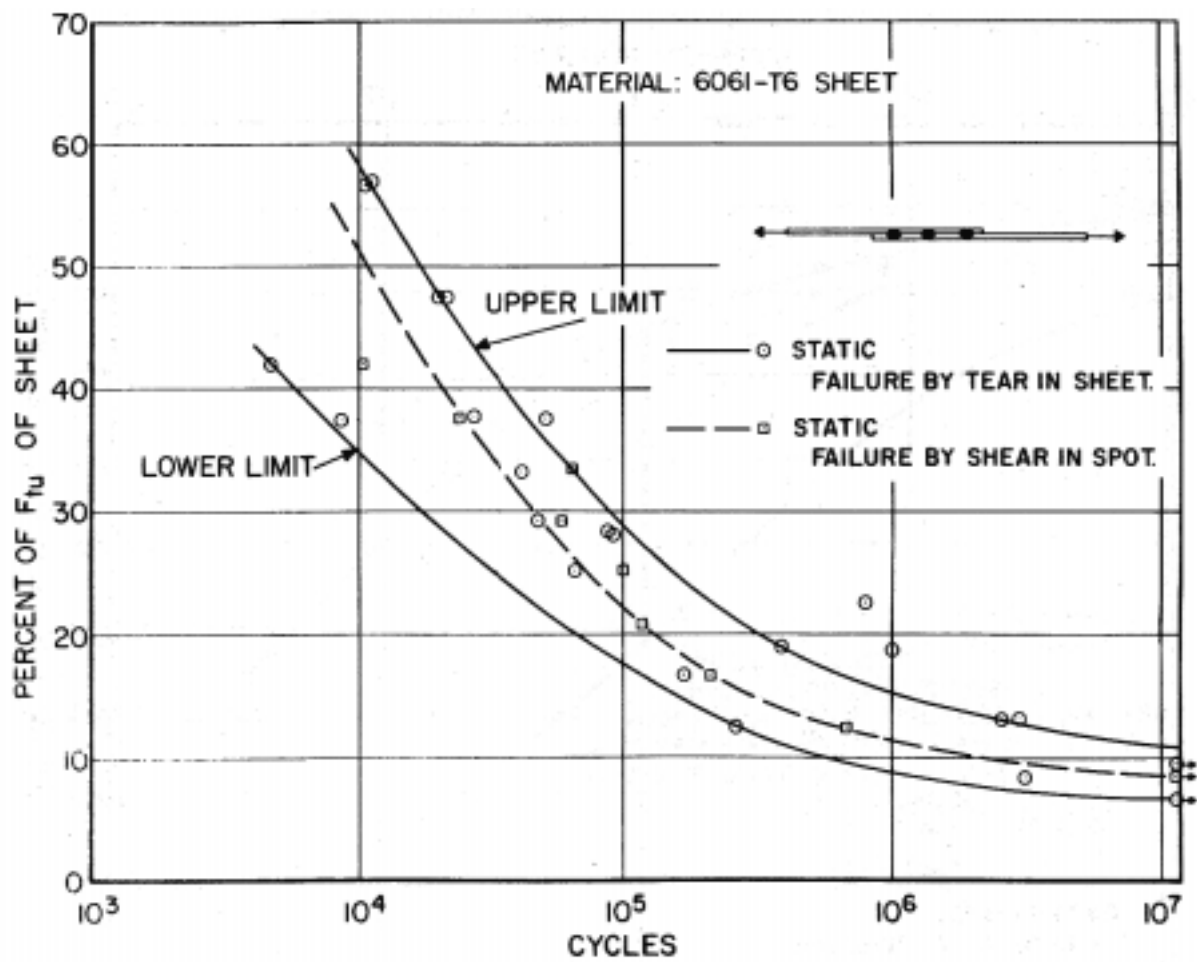


Figure 8.2.2.3.2.2(c). Fatigue strength of triple row spot-welded lap joints in 6061-T6 aluminum alloy sheet. Load Ratio = 0.05.

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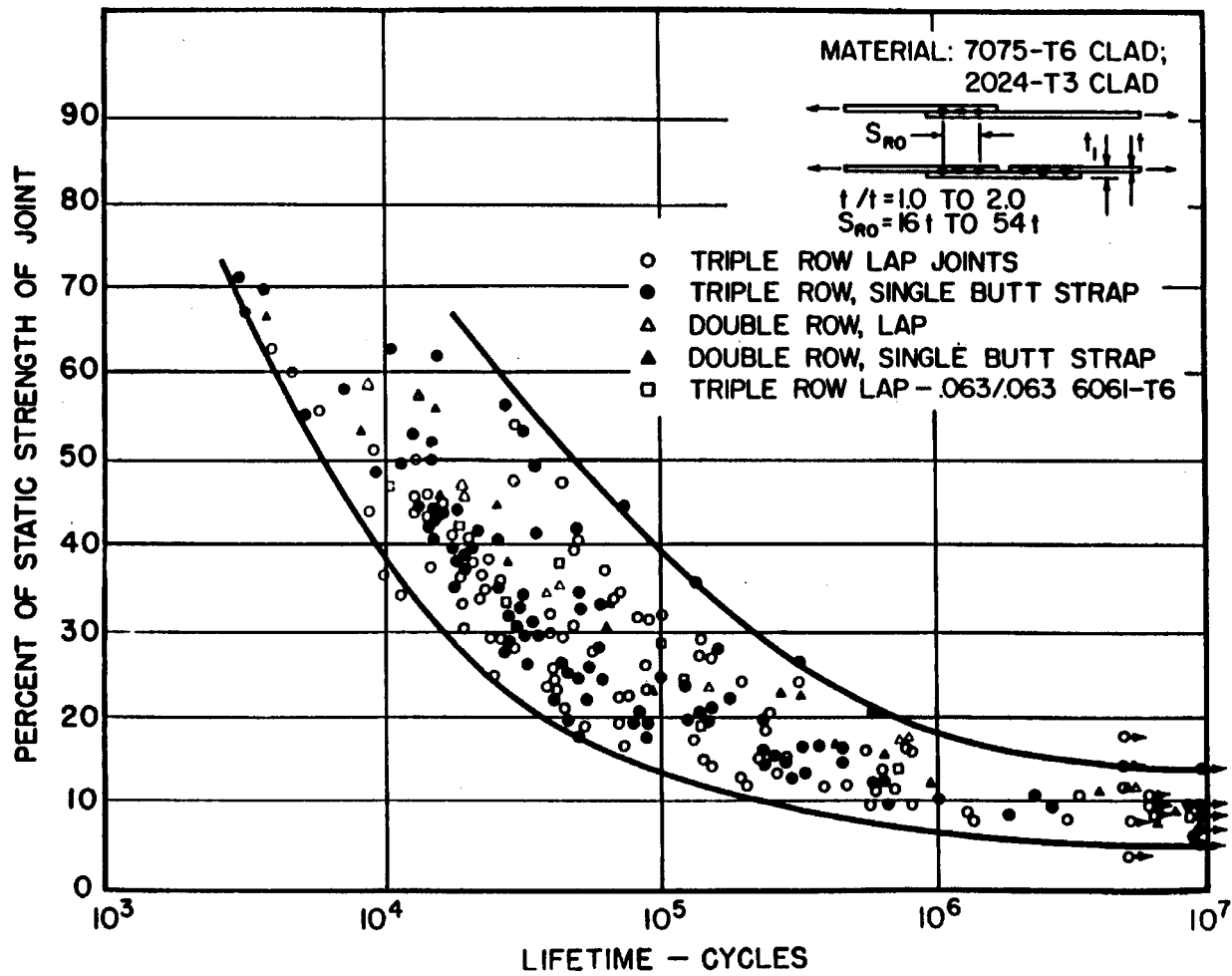


Figure 8.2.2.3.2.2(d). Fatigue strength of spot-welded multiple row joints in aluminum alloy sheet. Load Ratio = 0.05 (static failure by shear in the spot welds).



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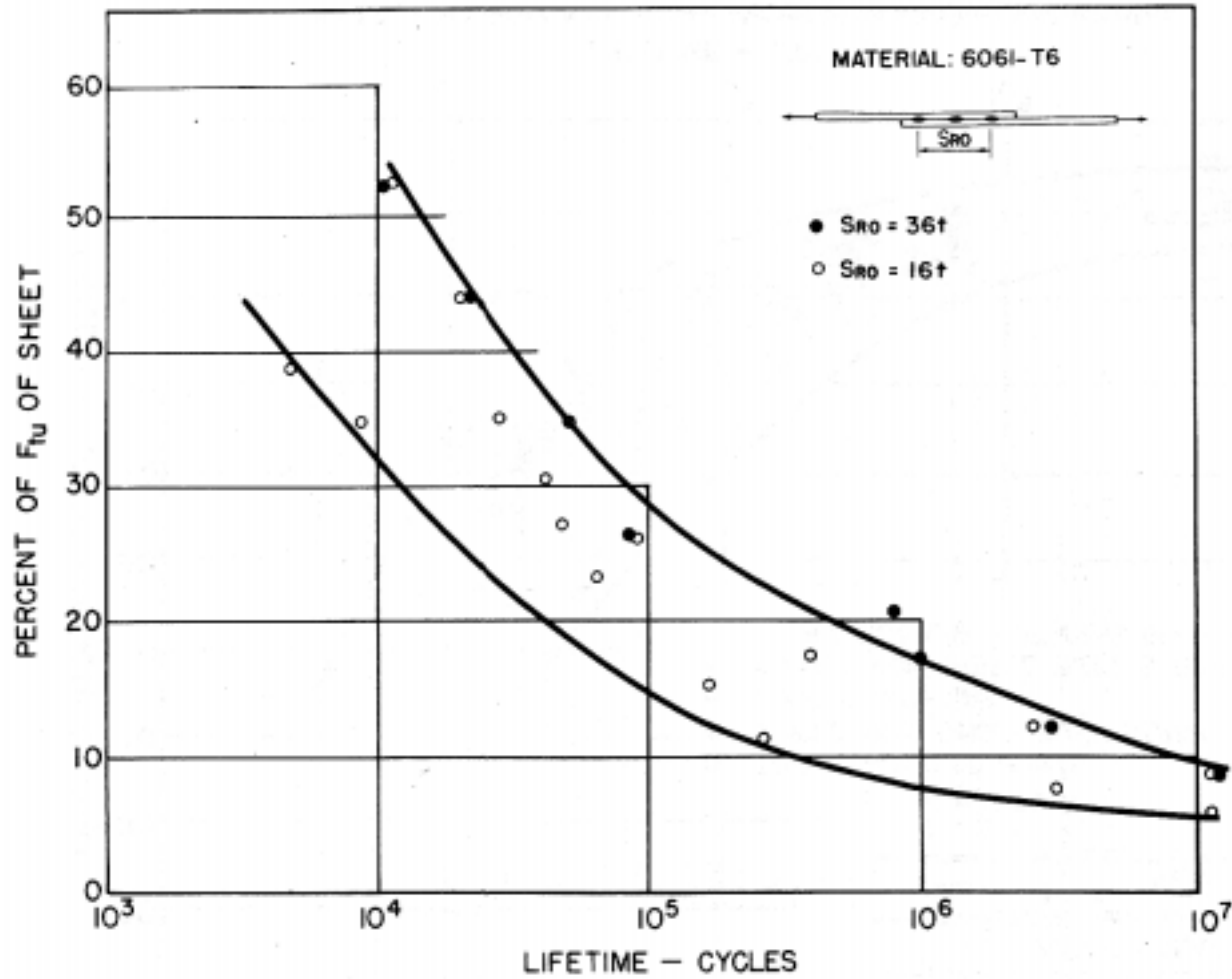


Figure 8.2.2.3.2.2(e). Fatigue strength of triple row spot-welded lap joints in 6061-T6 aluminum alloy sheet. Load Ratio = 0.05 (static failure by tear in sheets).

**Table 8.2.2.3.3. Spot-Weld Design Shear Strength in Panels for Magnesium Alloys<sup>a,b,c</sup> (Welding Specification MIL-W-6858)**

| Material Ultimate Tensile Strength, ksi... | Design Shear Strength, pounds per spot |                |
|--------------------------------------------|----------------------------------------|----------------|
|                                            | Greater than 19.5                      | Less than 19.5 |
| Nominal thickness of thinner sheet, in.:   |                                        |                |
| 0.012 .....                                | 24                                     | 16             |
| 0.016 .....                                | 56                                     | 40             |
| 0.018 .....                                | 68                                     | 52             |
| 0.020 .....                                | 80                                     | 64             |
| 0.022 .....                                | 96                                     | 76             |
| 0.025 .....                                | 116                                    | 88             |
| 0.028 .....                                | 140                                    | 108            |
| 0.032 .....                                | 168                                    | 132            |
| 0.036 .....                                | 204                                    | 156            |
| 0.040 .....                                | 240                                    | 180            |
| 0.045 .....                                | 280                                    | 208            |
| 0.050 .....                                | 320                                    | 236            |
| 0.056 .....                                | 380                                    | 272            |
| 0.063 .....                                | 456                                    | 316            |
| 0.071 .....                                | 516                                    | 360            |
| 0.080 .....                                | 612                                    | 420            |
| 0.090 .....                                | 696                                    | 476            |
| 0.100 .....                                | 752                                    | 540            |
| 0.112 .....                                | 800                                    | 588            |
| 0.125 .....                                | 840                                    | 628            |

a Strength based on 80 percent of minimum values specified in Specification MIL-W-6858.  
b The allowable tensile strength of spot-welds is 25 percent of the design shear strength. Higher values may be used, however, if these are substantiated by tests acceptable to the procuring or certifying agency.  
c Magnesium alloys AZ31B and HK31A may be spot-welded in any combination.

**Table 8.2.2.3.4(a). Spot-Weld Design Shear Strength in Thin Sheet and Foils for Titanium and Titanium Alloys<sup>a,b,c</sup> (Welding Specification MIL-W-6858)**

| Thickness of<br>Thinnest Outer<br>Sheet, in. | Spots/inch                    |                      | Materials Ultimate Tensile Strength, ksi           |            |           |          |
|----------------------------------------------|-------------------------------|----------------------|----------------------------------------------------|------------|-----------|----------|
|                                              | Standard<br>(Ns) <sup>d</sup> | Range <sup>e,f</sup> | Above 185                                          | 150 to 185 | 90 to 149 | Below 90 |
|                                              |                               |                      | Design Shear Strength, pounds per linear inch (Xm) |            |           |          |
| 0.001 . . . . .                              | 40                            | 1-50                 | 72                                                 | 64         | 52        | 36       |
| 0.002 . . . . .                              | 20                            | 1-30                 | 144                                                | 128        | 104       | 72       |
| 0.003 . . . . .                              | 12                            | 1-17                 | 240                                                | 208        | 164       | 120      |
| 0.004 . . . . .                              | 10                            | 1-14                 | 324                                                | 280        | 228       | 152      |
| 0.005 . . . . .                              | 9                             | 1-13                 | 392                                                | 340        | 272       | 188      |
| 0.006 . . . . .                              | 7                             | 1-10                 | 432                                                | 380        | 304       | 220      |
| 0.007 . . . . .                              | 6                             | 1-8                  | 504                                                | 440        | 352       | 256      |
| 0.008 . . . . .                              | 5                             | 1-7                  | 552                                                | 488        | 392       | 284      |

- a The reduction in strength of spot-welds due to the cumulative effects of time-temperature-stress factors is not greater than the reduction in strength of the parent metal.
- b Strength based on 80 percent of minimum values specified in Specification MIL-W-6858.
- c The allowable tensile strength of spot-welds is 25 percent of the design shear strength. Higher values may be used, however, if these are substantiated by tests acceptable to the procuring or certifying agency.
- d When the number of spots per inch is within 15 percent of the standard spot per inch requirement, the design shear strengths tabulated above shall apply.
- e When the number of spots differs from the standard spots per inch by 15 percent or greater, but does not exceed the noted range of spots per inch, applicable design strength shall be determined as noted below:

$$XM/Ns(K)Nr = Xr$$

where

- Xm = design shear strength in accordance with the above table
- Ns = standard spots per inch in accordance with the above table
- Nr = required spots per inch (production part)
- Xr = actual design shear strength requirement
- K = 1.15 when number of spots per inch is reduced more than 15 percent of the standard spacing of the above table
- K = 0.90 when number of spots is increased more than 15 percent of the standard spacing but within range of the tabular spacing.
- f When the number of spots per inch is above the range indicated in the table, the design shear strength shall remain constant at the value obtained at the top of the range.

**Table 8.2.2.3.4(b). Spot-Weld Design Shear Strength in Panels for Titanium and Titanium Alloy<sup>a,b,c</sup> (Welding Specification MIL-W-6858)**

| Material Ultimate Tensile Strength, ksi . . . . . | Design Shear Strength, pounds per spot |               |
|---------------------------------------------------|----------------------------------------|---------------|
|                                                   | Above 100                              | 100 and Below |
| Nominal thickness of thinner sheet, in.:          |                                        |               |
| 0.010 . . . . .                                   | 164                                    | 128           |
| 0.012 . . . . .                                   | 220                                    | 160           |
| 0.016 . . . . .                                   | 320                                    | 236           |
| 0.018 . . . . .                                   | 392                                    | 272           |
| 0.020 . . . . .                                   | 424                                    | 312           |
| 0.022 . . . . .                                   | 488                                    | 360           |
| 0.025 . . . . .                                   | 580                                    | 424           |
| 0.028 . . . . .                                   | 684                                    | 508           |
| 0.032 . . . . .                                   | 836                                    | 620           |
| 0.036 . . . . .                                   | 1004                                   | 736           |
| 0.040 . . . . .                                   | 1168                                   | 852           |
| 0.045 . . . . .                                   | 1438                                   | 1028          |
| 0.050 . . . . .                                   | 1702                                   | 1204          |
| 0.056 . . . . .                                   | 2040                                   | 1416          |
| 0.063 . . . . .                                   | 2400                                   | 1688          |
| 0.071 . . . . .                                   | 2702                                   | 1914          |
| 0.080 . . . . .                                   | 3048                                   | 2160          |
| 0.090 . . . . .                                   | 3430                                   | 2435          |
| 0.100 . . . . .                                   | 3810                                   | 2702          |
| 0.112 . . . . .                                   | 4260                                   | 3030          |
| 0.125 . . . . .                                   | 4760                                   | 3380          |

a The reduction in strength of spot-welds due to the cumulative effects of time-temperature-stress factors is not greater than the reduction in strength of the parent metal.

b Strength based on 80 percent of minimum value specified in Specification MIL-W-6858.

c The allowable tensile strength of spot-wells is 25 percent of the design shear strength. Higher values may be used, however, if these are substantiated by tests acceptable to the procuring or certifying agency.

8.2.3 BRAZING

**8.2.3.1 Copper Brazing** — The allowable shear strength for copper brazing of steel alloys shall be 15 ksi, for all conditions of heat treatment. Higher values may be allowed upon approval of the procuring or certifying agency.

The effect of the brazing process on the strength of the parent or base metal of steel alloys shall be considered in the structural design. Where copper furnace brazing is employed, the calculated allowable strength of the base metal which is subjected to the temperatures of the brazing process shall be in accordance with the following:

| Material                                                                      | Allowable Strength                                              |
|-------------------------------------------------------------------------------|-----------------------------------------------------------------|
| Heat-treated material (including normalized) used in “as-brazed” condition    | Mechanical properties of normalized material                    |
| Heat-treated material (including normalized) reheated during or after brazing | Mechanical properties corresponding to heat treatment performed |

**8.2.3.2 Silver Brazing** — Silver-brazed areas should not be subjected to temperatures exceeding 900°F. Silver brazing alloys are listed in specification QQ-B-654. Deviation from this specification may be allowed upon approval of the procuring or certifying agency.

The allowable shear strength for silver brazing of steel alloys shall be 15 ksi, provided that clearances or gaps between parts to be brazed do not exceed 0.010 in. Deviation from this specified allowable value may be allowed upon approval of the procuring or certifying agency.

The effect of silver brazing on the strength of the parent or base metal is the same as shown for copper brazing in Section 8.2.3.1.

8.3 BEARINGS, PULLEYS, AND WIRE ROPE

*Bearings* — Design, strengths, selection criteria, and other data for plain and antifriction bearings are found in AFSC Design Handbook AFSC DH-2-1, Chapters 3 and 6.

*Pulleys* — Pulley strengths and design data are to be utilized in accordance with Specification MIL-P-7034.

*Wire Rope* — Strengths and design data for wire rope are to be selected from the following specifications, whichever is appropriate: MIL-W-83420 or MIL-W-87161.

**REFERENCES**

- 8.1(a) Hartman, E. C. and Westcoat, C., "The Shear Strength of Aluminum Alloy Driven Rivets as Affected by Increasing D/t Ratios," U.S. National Advisory Committee for Aeronautics, Technical Note No. 942, 23 pp (July 1944).
- 8.1.2.1 Fugazzi, G. R., "Results of Test Evaluation Program to Develop Design Joint Strength Load Allowable Values for A-286 Solid Rivets Under Room and Elevated Temperature Conditions," Almay Research and Testing Corporation Report No. G8058, 63 pp (November 1964).
- 8.1.2.2 "Report on Flush Riveted Joint Strength," Airworthiness Requirements Committee, A/C Industries Association of America, Inc., Airworthiness Project 12 (Revised May 25, 1948).
- 8.1.5.2 "Report on Flush Screw Joint Strength," Airworthiness Requirements Committee, A/C Industries Association of American, Inc., Airworthiness Project 20 (Revised April 6, 1953).

## CHAPTER 9

### GUIDELINES FOR THE PRESENTATION OF DATA

This chapter contains Guidelines for judging adequacy of data, procedures for analyzing data in determining property values for inclusion in previous chapters, and formats for submitting results of analyses to the MIL-HDBK-5 Coordination Group for approval.

The following index can be used to locate sections of the Guidelines applicable to various properties:

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## 9.0 SUMMARY

The objective of this summary is to provide a global overview of Chapter 9 without defining specific statistical details. This overview will be most helpful to those unfamiliar with the statistical procedures used in MIL-HDBK-5 and to those who would like to learn more about the philosophy behind the MIL-HDBK-5 guidelines.

Chapter 9 is the “rule book” for MIL-HDBK-5. Since 1966, these guidelines have described statistical procedures used to calculate mechanical properties for alloys included in the Handbook. Recommended changes in the guidelines are reviewed first by the Guidelines and Emerging Materials Task Group (GEMTG) and later approved by the entire coordination committee. Recommended changes in statistical procedures within the guidelines are evaluated first by the Statistics Working Group (SWG), which supports the GEMTG. Similarly, recommended changes in fastener analysis procedures are examined by the Fastener Task Group (FTG) before approval by the coordination committee.

Chapter 9 is divided into 6 subchapters which cover the analysis methods used to define room and elevated temperature properties. The room temperature mechanical properties are tensile, compression, bearing, shear, fatigue, fracture toughness, elongation and elastic modulus. The elevated temperature properties are the same, except that creep and stress rupture properties are added to the list. Analysis procedures for fatigue, fatigue crack growth and mechanically fastened joints are also covered since these data are commonly used in aircraft design. The presentation of these data varies depending upon the data type. For instance, the room temperature mechanical properties (tensile, compression, bearing, shear, elongation and elastic modulus) are provided in a tabular format, while the fatigue, elevated temperature properties, and typical stress-strain curves are presented in graphical format.

Before an alloy can be considered for inclusion in MIL-HDBK-5, it must be covered by a commercial or government specification. There are two main reasons for this: (1) the alloy, and its method of manufacture, must be “reduced to standard practice” to increase confidence that the material, if obtained from different suppliers, will still demonstrate similar mechanical properties, and (2) specification minimum properties are included in MIL-HDBK-5 tables as design properties in situations where there are insufficient data to determine statistically based material design values.

The majority, by far, of the data in MIL-HDBK-5 are room temperature design properties: including tensile ( $F_{tu}$ ,  $F_{ty}$ ), shear ( $F_{su}$ ), compression ( $F_{cy}$ ), bearing strengths ( $F_{bru}$  and  $F_{bry}$ ), elongation and elastic modulus. Room temperature design properties are the primary focus in the Handbook because most aircraft, commercial and military, typically operate at near-ambient temperatures and because most material specifications include only room temperature property requirements.

Design minimum mechanical properties tabulated in MIL-HDBK-5 are calculated either by “direct” or “indirect” statistical procedures. The minimum sample size required for the direct computation of  $T_{99}$  and  $T_{90}$  values (from which A and B-basis design properties are established) is 100. These 100 observations must include data from at least 10 heats and lots (as defined in the next paragraph). A  $T_{99}$  value is a statistically computed, one-sided lower tolerance limit, representing a 95 percent confidence lower limit on the first percentile of the distribution. Similarly, a  $T_{90}$  value is a statistically computed, one-sided lower tolerance limit, representing a 95 percent lower confidence limit on the tenth percentile of the distribution. If the sample cannot be described by a Pearson<sup>1</sup> or Weibull distribution, the  $T_{99}$  and  $T_{90}$  values must be computed by nonparametric (distribution free) means, which can only be done if there are at least 299 observations.

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<sup>1</sup>A Pearson distribution analysis with zero skewness is comparable to the normal analysis method used in earlier versions of MIL-HDBK-5.



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In most cases, only minimum tensile ultimate and yield strength values are determined by the direct method.  $T_{90}$  values are not computed if there are insufficient data to compute  $T_{99}$  values, even though a much smaller sample size is required to compute nonparametric  $T_{90}$  values. This is because the general consensus within the MIL-HDBK-5 committee has been that a large number of observations (in the realm of 100) are needed from a large number of heats and lots (e.g. 10) for a particular material to properly characterize the variability in strength of that product.

A lot represents all of the material of a specific chemical composition, heat treat condition or temper, and product form that has passed through all processing operations at the same time. Multiple lots can be obtained from a single heat. A heat of material, in the case of batch melting, is all of the material that is cast at the same time from the same furnace and is identified with the same heat number. In the case of continuous melting, a single heat of material is generally poured without interruption. The exception is for ingot metallurgy wrought aluminum products, where a single heat is commonly cast in sequential aluminum ingots, which are melted from a single furnace charge and poured in one or more drops without changes in the processing parameters (see Table 9.1.6.2).

Minimum compression, bearing, and shear strengths are typically determined through the indirect method. This is done to reduce cost, because as few as 10 data points (from 3 heats and 10 lots) can be used, in combination with “paired” direct properties to compute a design minimum value. In this indirect method, the compression, bearing, and shear strengths are paired with tensile values determined in the same region of the product to produce a ratio. Statistical analyses of these ratios are conducted to obtain lower bound estimates of the relationship between the primary property and the ratioed property. These ratios are then multiplied with the appropriate  $F_{tu}$  or  $F_{ty}$  in the Handbook to obtain the  $F_{su}$ ,  $F_{cy}$ ,  $F_{bru}$ ,  $F_{bry}$  values for shear, compression, and bearing (ultimate and yield), respectively.

Many mechanical property tables in the Handbook include data for specific grain directions and thickness ranges. This is done to better represent anisotropic materials, such as wrought products, that often display variations in mechanical properties as a function of grain direction and/or product thickness. Therefore, it is common practice to test for variability in mechanical properties as a function of product thickness. This is done through the use of regression analysis for both direct and indirect properties. If a regression is found to be significant, properties may be computed separately (without regression) for reduced thickness ranges.

To compliment the mechanical property tables, the Handbook also contains typical stress-strain curves. These curves are included to illustrate each material’s yield behavior and to graphically display differences in yield behavior for different grain directions, tempers, etc. These curves are identified as typical because they are based upon only a few test points. Typical curves are shown for both tension and compression and are extended to just beyond the 0.2 percent yield stress. Each typical curve also contains a shape factor called the Ramberg-Osgood number ( $n$ ). These numbers can be used in conjunction with a material’s elastic modulus to empirically develop a stress-strain curve. Typical tensile full-range stress-strain curves are also provided that illustrate deformation behavior from the proportional limit to fracture. In addition, compression tangent-modulus curves are provided to describe compression instability.

Effect of temperature and thermal exposure curves are included throughout the Handbook. For tensile properties, the curves are presented as a percentage of the room temperature design value. For these curves, there is a minimum data requirement and statistical procedures have been established to construct the curves. The creep rupture plots are shown as typical isothermal curves of stress versus time. The physical properties are shown as a function of temperature for each property, i.e., specific heat, thermal conductivity, etc. Physical properties are reported as average actual values, not a percentage of a room temperature value.

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In addition to the mechanical properties, statistically based S/N fatigue curves are provided in the Handbook, since many airframe structures experience dynamic loading conditions. The statistical procedures are fairly rigorous. For example, the procedure describes how to treat outliers and run-outs (discontinued tests), and which models to use to best-fit a specific set of data. Each fatigue figure includes relevant information such as  $K_t$ , R value, material properties, sample size and equivalent stress equation. Each figure should be closely examined by the user to properly identify the fatigue curves required for a particular design.

Design properties for mechanical fasteners and mechanically fastened elements are also included in MIL-HDBK-5. A unique analysis procedure has been developed for mechanical fasteners because fasteners generally do not develop the full bearing strength of materials in which they are installed. Realistic joint allowables are determined from test data using the statistical analysis procedures described in Chapter 9. There are four different types of fasteners for which design allowables must be determined, as described in Section 4.

The last section in the Handbook (Section 6) provides a detailed description of statistical procedures used in Chapter 9 for the analysis of data. Most of these procedures are backed up with examples and appropriate statistical tables.

**9.0.1 TESTING STANDARDS** — Testing standards used in MIL-HDBK-5 are summarized in Table 9.0.1. In most cases, testing standards maintained by the American Society for Testing and Materials, ASTM, are referenced. The primary exception is fastener testing, where NASM-1312 is used as the reference standard. The mostly recently approved version of each standard is used as the baseline for all test data reviewed for inclusion in MIL-HDBK-5.

**9.0.2 DATA REQUIREMENTS** — Data requirements for determination of mechanical and physical properties within MIL-HDBK-5 are summarized in Table 9.0.2. The customary statistical basis of each material property is listed, along with the relative importance of each data type within the Handbook. Potential extenuating circumstances, such as special material usage requirements, are also considered. Where applicable for each data type, the minimum sample size and the minimum number of heats and lots are identified. Applicable MIL-HDBK-5 introductory or guideline sections are also referenced.

**Table 9.0.1. Summary of Recommended Testing Standards within MIL-HDBK-5**

| <b>Property to be Determined or Procedure to be Followed</b> | <b>Designation</b> | <b>Title of Testing Standard</b>                                                                         | <b>Relevant Section(s) within Guidelines</b> |
|--------------------------------------------------------------|--------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------|
| Bearing                                                      | ASTM E 238         | Method for Pin-Type Bearing Test of Metallic Materials                                                   | 9.1.6.4, 1.4.7.1, 3.1.2                      |
| Classification of Extensometers                              | ASTM E 83          | Method of Verification and Classification of Extensometers                                               | 9.1.6.6, 9.3.2.2                             |
| Coefficient of Thermal Expansion                             | ASTM E 228         | Test Method for Linear Thermal Expansion of Solid Materials with a Vitreous Silica Dilatometer           | 9.2.14                                       |
| Compression                                                  | ASTM E 9           | Compression Testing of Metallic Materials                                                                | 1.7.1                                        |
| Creep and Rupture                                            | ASTM E 139         | Rec. Practice for Conducting Creep, Creep-Rupture, & Stress-Rupture Tests of Metallic Materials          | 9.3.6.3                                      |
| Density                                                      | ASTM C 693         | Test Method for Density of Glass by Buoyancy                                                             | 9.2.14                                       |
| Elastic Modulus – Compression                                | ASTM E 111         | Test Method for Young's Modulus, Tangent Modulus, and Chord Modulus                                      | 9.1.6.6, 9.2.13                              |
| Elastic Modulus – Shear                                      | ASTM E 143         | Test Method for Shear Modulus at Room Temperature                                                        | 9.2.13                                       |
| Elastic Modulus – Tension                                    | ASTM E 111         | Test Method for Young's Modulus, Tangent Modulus, and Chord Modulus                                      | 9.1.6.6, 9.2.13                              |
| Elongation                                                   | ASTM E 8           | Test Method for Tension Testing of Metallic Materials                                                    | 1.4.3.5                                      |
| Exfoliation Corrosion                                        | ASTM G 34          | Test Method for Exfoliation Corrosion Susceptibility in 2XXX and 7XXX Series Aluminum Alloys (EXCO Test) | 3.1.2.3.1                                    |
| Fastener Mechanical Properties                               | NASM-1312          | Fastener Test Methods                                                                                    | 9.4.1.3.1                                    |
| Fatigue - Load Control                                       | ASTM E 466         | Recommended Practice for Constant Amplitude Axial Fatigue Tests of Metallic Materials                    | 9.3.4.1                                      |
| Fatigue - Strain Control                                     | ASTM E 606         | Recommended Practice for Constant Amplitude Low Cycle Fatigue Testing                                    | 9.3.4.1                                      |
| Fatigue Crack Growth                                         | ASTM E 647         | Test Method for Measurements of Fatigue Crack Growth Rates                                               | 9.3.5.2                                      |

**Table 9.0.1. Summary of Recommended Testing Standards within MIL-HDBK-5, Continued**

| <b>Property to be Determined<br/>or Procedure to be<br/>Followed</b> | <b>Designation</b> | <b>Title of Testing Standard</b>                                                                                 | <b>Relevant<br/>Section(s) within<br/>Guidelines</b> |
|----------------------------------------------------------------------|--------------------|------------------------------------------------------------------------------------------------------------------|------------------------------------------------------|
| Fracture Toughness - Plane Strain                                    | ASTM E 399         | Test Method for Plane-Strain Fracture Toughness of Metallic Materials                                            | 9.5.1                                                |
| Fracture Toughness - Plane Stress                                    | ASTM E 561         | Recommended Practice for R Curve Determination                                                                   | 9.5.1                                                |
| Poisson's Ratio                                                      | ASTM E 132         | Test Method for Poisson's Ratio at Room Temperature                                                              | 9.2.13                                               |
| Reduction in Area                                                    | ASTM E 8           | Test Method for Tension Testing of Metallic Materials                                                            | 1.4.3.5                                              |
| Shear – Pin                                                          | ASTM B 769         | Test Method for Shear Testing of Aluminum Alloys                                                                 | 9.1.6.4, 3.1.2                                       |
| Shear – Slotted                                                      | ASTM B 831         | Standard Test Method for Shear Testing of Thin Aluminum Alloy Products                                           | 9.1.6                                                |
| Specific Heat                                                        | ASTM D 2766        | Test Method for Specific Heat of Liquids and Solids                                                              | 9.2.14                                               |
| Stress Corrosion Cracking                                            | ASTM G 47          | Test Method for Determining Susceptibility to Stress-Corrosion Cracking of High Strength Aluminum Alloy Products | 3.1.2.3.1                                            |
| Tension                                                              | ASTM E 8           | Test Method for Tension Testing of Metallic Materials                                                            | 1.4.4.1                                              |
|                                                                      | ASTM B 557         | Test Methods of Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products                          | 1.4.4.1                                              |
| Tension - Elevated Temperatures                                      | ASTM E 21          | Recommended Practice for Elevated Temperature Tension Tests of Metallic Materials                                | 1.4.4.1                                              |
| Thermal Conductivity                                                 | ASTM C 714         | Test Method for Thermal Diffusivity of Carbon and Graphite by a Thermal Pulse Method                             | 9.2.14                                               |

Table 9.0.2. Summary of Data Requirements within MIL-HDBK-5

| Mechanical or Physical Property                   | Customary Statistical Basis       | Relative Importance in MIL-HDBK-5 | Extenuating Circumstances for Special Material Usage Requirements         | Minimum Data Requirements                                                  |              |             | Applicable Handbook Sections |
|---------------------------------------------------|-----------------------------------|-----------------------------------|---------------------------------------------------------------------------|----------------------------------------------------------------------------|--------------|-------------|------------------------------|
|                                                   |                                   |                                   |                                                                           | Sample Size                                                                | No. of Heats | No. of Lots |                              |
| Bearing Yield and Ultimate Strength               | Derived form Paired Tensile Tests | Mandatory                         | Except for elevated temperature applications                              | 20                                                                         | 3            | 10          | 9.1.6.4, 1.4.7.1, 3.1.2      |
| Coefficient of Thermal Expansion                  | Typical                           | Strongly recommended              | Especially for anticipated range of usage                                 | Triplicate measurements                                                    |              |             | 9.2.14                       |
| Compression Yield Strength                        | Derived from Paired Tensile Tests | Mandatory                         |                                                                           | 20                                                                         | 3            | 10          | 1.7.1                        |
| Creep and Rupture                                 | Raw Data w/ Best-Fit Curves       | Recommended                       | Especially for elevated temperature applications                          | 6 tests per creep strain level and temp, at least 4 temps over usage range |              |             | 9.3.6.3                      |
| Density                                           | Typical                           | Mandatory                         |                                                                           | Duplicate measurements                                                     |              |             | 9.2.14                       |
| Elastic Modulus (Tension and Compression)         | Typical                           | Mandatory                         | Clad materials must have primary and secondary modulus properties defined | 9                                                                          | 3            | Multiple    | 9.1.6.6, 9.2.13              |
| Elastic Modulus (T and C) - Elevated Temperatures | Typical                           | Mandatory                         | For anticipated usage range                                               | 9                                                                          | 3            | Multiple    | 9.2.13                       |
| Elongation                                        | S-basis                           | Mandatory                         | Two-inch gage length preferred                                            | 30                                                                         | 3            | 10          | 1.4.3.5                      |
| Fastener Yield and Ultimate Load                  | B-basis                           | Mandatory                         |                                                                           | 100                                                                        | 3            | 10          | 9.4.1.3.1                    |
| Fastener Shear Strength                           | B-basis                           | Mandatory                         | At least 15 tests per fastener diameter                                   | 100                                                                        | 3            | 10          | 9.4                          |
| Fatigue-Load Control                              | Raw Data w/ Best-Fit Curves       | Recommended                       | Especially for high-cycle fatigue critical applications                   | 6 tests per R ratio, 3 R ratios, no minimum heat or lot requirements       |              |             | 9.3.4.5                      |
| Fatigue-Strain Control                            | Raw Data w/ Best-Fit Curves       | Recommended                       | Especially for low-cycle fatigue critical applications                    | 10 tests for R <sub>e</sub> = -1.0, 6 tests other strain ratios            |              |             | 9.3.4.5                      |

**Table 9.0.2. Summary of Data Requirements within MIL-HDBK-5, Continued**

| Mechanical or Physical Property   | Customary Statistical Basis       | Relative Importance in MIL-HDBK-5 | Extenuating Circumstances for Special Material Usage Requirements                          | Minimum Data Requirements                                                     |              |             | Applicable Handbook Sections |
|-----------------------------------|-----------------------------------|-----------------------------------|--------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|--------------|-------------|------------------------------|
|                                   |                                   |                                   |                                                                                            | Sample Size                                                                   | No. of Heats | No. of Lots |                              |
| Fatigue Crack Growth              | Raw Data w/ Best-Fit Curves       | Recommended                       | Especially for damage tolerance critical applications                                      | Duplicate da/dN results for relevant stress ratios and stress intensity range |              |             | 9.3.5.3                      |
| Fracture Toughness - Plane Strain | Basic Statistical Information     | Recommended                       | Mandatory for materials with spec. min. requirements for plane strain fracture toughness   | 30                                                                            | 3            | 10          | 9.5.1                        |
| Fracture Toughness - Plane Stress | Raw Data w/ Best-Fit Curves       | Recommended                       | Mandatory for materials with spec minimum requirements for plane stress fracture toughness | a                                                                             | 2            | 5           | 9.5.1                        |
| Poisson's Ratio                   | Typical                           | Strongly recommended              |                                                                                            | Duplicate measurements                                                        |              |             | 9.2.13                       |
| Reduction In Area                 | Typical                           | Recommended                       |                                                                                            | When tested, use same criteria as for elongation                              |              |             | 9.2.15                       |
| Shear Ultimate Strength           | Derived from Paired Tensile Tests | Mandatory                         | Except for elevated temperature applications                                               | 20                                                                            | 3            | 10          | 1.4.6.4, 9.1.6.4             |
| Specific Heat                     | Typical                           | Strongly recommended              | Important to document over anticipated usage range                                         | Duplicate measurements                                                        |              |             | 9.2.14                       |
| Stress Corrosion Cracking         | Letter Rating                     | Recommended                       | Especially for susceptible aluminum alloys                                                 | Conform to replication requirements in G47                                    |              |             | 3.1.2.3                      |
| Stress/Strain Curves (To Yield)   | Typical                           | Mandatory                         | Desirable to have accurate plastic strain offsets from $10^{-6}$ to $3 \times 10^{-2}$     | 6                                                                             | 3            | 6           | 9.3.2                        |
| Stress/Strain Curves (Full Range) | Typical                           | Mandatory                         |                                                                                            | 6                                                                             | 3            | 6           | 9.3.2                        |

Table 9.0.2. Summary of Data Requirements within MIL-HDBK-5, Continued

| Mechanical or Physical Property                      | Customary Statistical Basis | Relative Importance in MIL-HDBK-5 | Extenuating Circumstances for Special Material Usage Requirements                                  | Minimum Data Requirements |              |             | Applicable Handbook Sections |
|------------------------------------------------------|-----------------------------|-----------------------------------|----------------------------------------------------------------------------------------------------|---------------------------|--------------|-------------|------------------------------|
|                                                      |                             |                                   |                                                                                                    | Sample Size               | No. of Heats | No. of Lots |                              |
| Tension Yield and Ultimate Strength                  | S-basis                     | Mandatory                         |                                                                                                    | 30                        | 3            | Multi-ple   | 1.4.4.1                      |
| Tension Yield and Ultimate Strength                  | A- and B-basis              | Strongly recommended              | Especially for strength critical applications; a parametric representation of data is possible     | 100                       | 10           | 10          | 1.4.4.1                      |
| Tension Yield and Ultimate Strength                  | A- and B-basis              | Strongly recommended              | Especially for strength critical applications; a parametric representation of data is not possible | 300                       | 10           | 10          | 1.4.4.1                      |
| Tension Yield and Ultimate Strength - Elevated Temps | Typical                     | Recommended                       | Mandatory for elevated temperature applications                                                    | b                         | 2            | 5           | 1.4.4.1                      |
| Thermal Conductivity                                 | Typical                     | Strongly recommended              | Important to document over anticipated usage range                                                 | Duplicate measurements    |              |             | 9.2.14                       |

a Minimum sample size not specified, testing should be conducted at 6 or more panel widths to confidently represent trends over the panel widths of interest. Refer to ASTM E561 for testing details.

b Minimum sample size not specified, testing should be conducted at 6 or more temperatures to confidently represent trends over the temperature range of interest. Testing in regions where properties are expected to change rapidly with changes in temperature must be done at temperature intervals sufficiently small to clearly identify mean trends.

## 9.1 GENERAL

This section of the Guidelines covers general information. Information specific to individual properties can be found in pertinent sections.

**9.1.1 INTRODUCTION** — Design properties in MIL-HDBK-5 are used in the design of aerospace structures and elements. Thus, it is exceedingly important that the values presented in MIL-HDBK-5 reflect as accurately as possible the actual properties of the products covered.

Throughout the Guidelines, many types of statistical computations are referenced. Since these may not be familiar to all who may be analyzing data in the preparation of MIL-HDBK-5 proposals, a detailed description of each operation is required. To present the detailed description in the individual sections, however, would unnecessarily complicate the orderly presentation of the overall computational procedures. Therefore, the detailed description of the statistical techniques have been covered in Section 9.6.

**9.1.2 APPLICABILITY** — Minimum data requirements and analytical procedures defined in these Guidelines for establishment of MIL-HDBK-5 design properties and elevated temperature curves for these properties should be used to obtain approval of such values or curves when proposed to the MIL-HDBK-5 Coordination Group or a certifying agency. However, the minimum data requirements and analytical procedures are not mandatory; to the extent of precluding use of other analytical procedures which can be substantiated. Any exceptions or deviations must be reported when requesting approval of these values or curves by the Coordination Group or certifying agency.

**9.1.3 APPROVAL PROCEDURES** — The MIL-HDBK-5 Coordination Group (a voluntary, joint Government-Industry activity) meets twice yearly. At each meeting, this group acts upon proposed changes or additions to the document submitted in writing in advance of the meeting. The agenda is normally mailed to attendees four weeks prior to the meeting date, and the minutes four weeks following the meeting. Attachments for either the agenda or the minutes should be delivered to the Secretariat well in advance of the mailing date.

Attachments containing proposed changes or additions to the document shall include specific notations of changes or additions to be made; adequate documentation of supporting data; analytical procedures used (see Section 9.1.4); discussion of analysis of data; and a listing of exceptions or deviations from the requirements of these Guidelines.

Approval procedures for establishment of MIL-HDBK-5 equivalent design values are defined by the individual certifying agency.

**9.1.4 DOCUMENTATION REQUIREMENTS** — The purpose of adequate documentation of proposals submitted to the MIL-HDBK-5 Coordination Group is to permit an independent evaluation of proposals by each interested attendee and to provide a historical record of actions of the Coordination Group. For this reason, both supporting data and a description of analytical procedures employed must be made available to attendees, either as an integral portion of an attachment to the agenda or minutes, or by reference to other documents that may reasonably be expected to be in the possession of MIL-HDBK-5 Meeting attendees. A specific example of the latter would be certain reports of Government-sponsored research or material evaluations for which distribution included the MIL-HDBK-5 attendance list. In some cases involving large quantities of supporting data, it may suffice (at the discretion of the Coordination Group) to furnish a single copy of these data to the Secretariat, from whom they would be available to interested attendees.



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All relevant reference documents (specifications, testing standards, data submissions, etc.) for proposals must be provided in English, to facilitate interpretation and evaluation by the MIL-HDBK-5 Coordination Group. If metric units are used as the primary system of units in these documents, a soft conversion to English units must also be provided. The following English units are standard within MIL-HDBK-5:

- Coefficient of thermal expansion,  $10^{-6}$  in./in./F
- Density, lb./in<sup>3</sup>
- Fracture toughness, ksi-in<sup>1/2</sup>
- Frequency, Hz (cycles per second), or cpm (cycles per minute)
- Load, lbs., or kips ( $10^3$  lbs.)
- Modulus of elasticity (Tension and Compression),  $10^3$  ksi
- Shear Modulus,  $10^3$  ksi
- Specific heat, Btu/(lb.)(F)
- Strain, in./in.
- Stress or strength, ksi
- Temperature, F
- Thermal conductivity, Btu/[(hr)(ft<sup>2</sup>)(F)/ft]
- Thickness, in.
- Time, hrs.

Refer to Section 9.2.2.2 for the terminology used within MIL-HDBK-5 for mechanical properties.

**9.1.5 SYMBOLS AND DEFINITIONS** (also see Sections 9.2.2, 9.3.4.2, 9.3.6.2, 9.4.1.2, 9.5.1.2, and 9.6) —

|                  |   |                                                                                                                                                                                                                                                                                                                 |
|------------------|---|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\alpha$         | — | Significance level; probability (risk) of erroneously rejecting the null hypothesis (see Section 9.6.2).                                                                                                                                                                                                        |
| $\alpha_{99,90}$ | — | Shape parameter estimates for a $T_{99}$ or $T_{90}$ tolerance bound based on an assumed three-parameter Weibull distribution.                                                                                                                                                                                  |
| $\alpha_{50}$    | — | Shape parameter estimate for the Anderson-Darling goodness-of-fit test based on an assumed three-parameter Weibull distribution.                                                                                                                                                                                |
| A                | — | A-basis for mechanical property (see Section 9.2.2.1).                                                                                                                                                                                                                                                          |
| AD               | — | Anderson-Darling test statistic, computed in goodness-of-fit tests for normality or Weibullness.                                                                                                                                                                                                                |
| $\beta_{99,90}$  | — | Scale parameter estimate for a $T_{99}$ or $T_{90}$ tolerance bound based on an assumed three-parameter Weibull distribution.                                                                                                                                                                                   |
| $\beta_{50}$     | — | Scale parameter estimate for the Anderson-Darling goodness-of-fit test based on an assumed three-parameter Weibull distribution.                                                                                                                                                                                |
| B                | — | B-basis for mechanical property (see Section 9.2.2.1).                                                                                                                                                                                                                                                          |
| df               | — | Degrees of freedom.                                                                                                                                                                                                                                                                                             |
| F                | — | The ratio of two sample variances.                                                                                                                                                                                                                                                                              |
| heat             | — | All material identifiable to a single molten metal source. (All material from a heat is considered to have the same composition. A heat may yield one or more ingots. A heat may be divided into several lots by subsequent processing.)                                                                        |
| $k_{99,90}$      | — | The $T_{99}$ or $T_{90}$ tolerance limit factor for the normal distribution, based on 95 percent confidence and a sample of size n.                                                                                                                                                                             |
| log              | — | Base 10 logarithm.                                                                                                                                                                                                                                                                                              |
| lot              | — | All material from a heat or single molten metal source of the same product type having the same thickness or configuration, and fabricated as a unit under the same conditions. If the material is heat treated, a lot is the above material processed through the required heat-treating operations as a unit. |
| ln               | — | Natural (base e) logarithm.                                                                                                                                                                                                                                                                                     |
| n                | — | Number of individual measurements or pairs of measurements; Ramberg-Osgood parameter.                                                                                                                                                                                                                           |
| r                | — | Ratio of two paired measurements; rank of test point within a sample.                                                                                                                                                                                                                                           |
| $\bar{r}$        | — | Average ratio of paired measurements.                                                                                                                                                                                                                                                                           |
| S                | — | S-basis for mechanical property values (see Section 9.2.2.1).                                                                                                                                                                                                                                                   |
| s                | — | Estimated population standard deviation.                                                                                                                                                                                                                                                                        |
| $\tau_{99,90}$   | — | Threshold estimates for a $T_{99}$ or $T_{90}$ tolerance bound based on an assumed three-parameter Weibull distribution.                                                                                                                                                                                        |
| $\tau_{50}$      | — | Threshold estimate for the Anderson-Darling goodness-of-fit test based on an assumed three-parameter Weibull distribution.                                                                                                                                                                                      |
| t                | — | Tolerance factor for the “t” distribution with the specified “confidence” and appropriate degrees of freedom.                                                                                                                                                                                                   |
| $T_{90}$         | — | Statistically based lower tolerance bound for a mechanical property such that at least 90 percent of the population is expected to exceed $T_{90}$ with 95 percent confidence.                                                                                                                                  |
| $T_{99}$         | — | Statistically based lower tolerance bound for a mechanical property such that at least 99 percent of the population is expected to exceed $T_{99}$ with 95 percent confidence.                                                                                                                                  |
| $V_{99,90}$      | — | The $T_{99}$ or $T_{90}$ tolerance limit factor for the three-parameter Weibull distribution, based on 95 percent confidence, a sample of size n, and a specified degree of upper tail censoring.                                                                                                               |
| $X_i$            | — | Value of an individual measurement.                                                                                                                                                                                                                                                                             |
| $\bar{X}$        | — | Average value of individual measurements.                                                                                                                                                                                                                                                                       |
| $\Sigma$         | — | The sum of.                                                                                                                                                                                                                                                                                                     |
| '                | — | Value determined by regression analysis.                                                                                                                                                                                                                                                                        |

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**9.1.6 DATA REQUIREMENTS FOR INCORPORATION OF A NEW PRODUCT INTO MIL-HDBK-5**—This section specifies requirements for the incorporation of a new product into MIL-HDBK-5 on an S-basis (see Section 9.2.2.1 for definition). These requirements are applicable to each alloy, product form, and heat treat condition or temper. Sections 9.1.6.2 through 9.1.6.7 delineate requirements for a test program for the determination of mechanical property data suitable for computation of derived properties (see Section 9.2.10). A test matrix, based on these requirements, is shown in Table 9.1.6.

**9.1.6.1 Material Specification** — To be considered for inclusion in MIL-HDBK-5, a product must be covered by an industry specification (AMS specification issued by SAE Aerospace Materials Division or an ASTM standard published by the American Society for Testing and Materials), or a government specification (Military or Federal). If a public specification for the product is not available, action should be initiated to prepare a draft specification. Standard manufacturing procedures shall have been established for the fabrication and processing of production material before a draft specification is prepared. The draft specification shall describe a product which is commercially available on a production basis. An AMS draft specification should be submitted to the SAE Aerospace Materials Division and an ASTM standard should be transmitted to the American Society for Testing and Materials for publication. See Section 9.1.6.8 for requirements to substantiate the S-basis properties.

Foreign-produced materials not covered by a U.S. industry specification, but covered by an internationally recognized material specification may be considered for publication first in the Preliminary Material Properties (PMP) Handbook, which is a periodically updated MIL-HDBK-5 supplemental data source. This approach allows for the rapid initial review and publication of preliminary design properties on these materials, while the required U.S. industry specifications and standards are being developed and approved. Once the specifications are in place and other data requirements for introduction of these materials into MIL-HDBK-5 are satisfied, a proposal can be made to have the applicable data tables and curves transferred to MIL-HDBK-5.

**9.1.6.2 Material** — The product used for the determination of mechanical properties suitable for use in the determination of minimum design (derived) values for incorporation into MIL-HDBK-5 shall be production material. The material shall have been produced using production facilities and standard fabrication and processing procedures. If a test program to determine requisite mechanical properties is initiated before a public specification describing this product is available, precautionary measures shall be taken to ensure that the product supplied for the test program conforms to the specification, when published, and represents production material.

Ten lots of material from at least three production heats, casts or melts for each product form and heat treat condition shall be tested to determine required mechanical properties. See Table 9.1.6.2 for definitions of heat, cast, and melt. A lot is defined as all material of a specific chemical composition, heat treat condition or temper, and product form which has been processed at the same time through all processing operations. Different sizes and configurations from a heat cast or melt shall be considered different lots. For a single lot of material, only one heat treat lot may be used to meet the ten-lot requirement. Thicknesses of the 10 lots to be tested shall span the thickness range of the product form covered by the material specification (or for the thickness range for which design values are to be established).

Dimensionally discrepant castings or special test configurations may be used for the development of derived properties with prior approval by the MIL-HDBK-5 Coordination Group, providing these castings meet the requirements of the applicable material specification. Design values for separately cast test specimens shall not be presented in MIL-HDBK-5.

**9.1.6.3 Test Specimens** — Mechanical property ratios are utilized in the analysis of data to determine minimum design values. Tensile yield in other than primary test direction, compressive yield, and

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bearing yield strengths are paired with the tensile yield strength in the primary test direction for each lot. Tensile ultimate in other than the primary test direction, shear ultimate, and bearing ultimate strengths are paired with the tensile ultimate strength in the primary test direction. See Table 9.2.10 for the primary testing direction for various products. Therefore, it is imperative that these test specimens be taken from the same sheet, plate, bar, extrusion, forging, or casting. Test specimens shall be located in close proximity. If coupons or specimens are machined prior to heat treatment, all specimens representing a lot shall be heat treated simultaneously in the same heat treat load through all heat treating operations. This procedure is necessary to provide precise mechanical property relationships (ratios).

Test specimens shall be located within the cross section of the product in accordance with the applicable material specification, or applicable sampling specification, such as AMS 2355, AMS 2370, and AMS 2371. Subsize tensile and compressive test specimens may be used when appropriate. Specimen drawings should be provided along with each data proposal, with English units included. The applicable testing standard should be identified along with the specimen drawings. If the standard is not routinely available in English, an English translation of the standard should be provided.

**Table 9.1.6. Test Matrix to Provide Required Mechanical Property Data for Determination of Design Values for Derived Properties (on S-Basis)**

| Lot<br>Letter <sup>a,b,c</sup> | Test Specimen Requirements   |    |                 |                      |    |                 |                  |    |                 |                                       |                 |                                       |                 |
|--------------------------------|------------------------------|----|-----------------|----------------------|----|-----------------|------------------|----|-----------------|---------------------------------------|-----------------|---------------------------------------|-----------------|
|                                | TUS & TYS <sup>d,e,f,g</sup> |    |                 | CYS <sup>d,e,g</sup> |    |                 | SUS <sup>h</sup> |    |                 | BUS & BYS <sup>i</sup> ,<br>e/D = 1.5 |                 | BUS & BYS <sup>i</sup> ,<br>e/D = 2.0 |                 |
|                                | L                            | LT | ST <sup>j</sup> | L                    | LT | ST <sup>j</sup> | L                | LT | ST <sup>j</sup> | L                                     | LT <sup>j</sup> | L                                     | LT <sup>j</sup> |
| A                              | 2 <sup>k</sup>               | 2  | 2               | 2                    | 2  | 2               | 2                | 2  | 2               | 2                                     | 2               | 2                                     | 2               |
| B                              | 2                            | 2  | 2               | 2                    | 2  | 2               | 2                | 2  | 2               | 2                                     | 2               | 2                                     | 2               |
| C                              | 2                            | 2  | 2               | 2                    | 2  | 2               | 2                | 2  | 2               | 2                                     | 2               | 2                                     | 2               |
| D                              | 2                            | 2  | 2               | 2                    | 2  | 2               | 2                | 2  | 2               | 2                                     | 2               | 2                                     | 2               |
| E                              | 2                            | 2  | 2               | 2                    | 2  | 2               | 2                | 2  | 2               | 2                                     | 2               | 2                                     | 2               |
| F                              | 2                            | 2  | 2               | 2                    | 2  | 2               | 2                | 2  | 2               | 2                                     | 2               | 2                                     | 2               |
| G                              | 2                            | 2  | 2               | 2                    | 2  | 2               | 2                | 2  | 2               | 2                                     | 2               | 2                                     | 2               |
| H                              | 2                            | 2  | 2               | 2                    | 2  | 2               | 2                | 2  | 2               | 2                                     | 2               | 2                                     | 2               |
| I                              | 2                            | 2  | 2               | 2                    | 2  | 2               | 2                | 2  | 2               | 2                                     | 2               | 2                                     | 2               |
| J                              | 2                            | 2  | 2               | 2                    | 2  | 2               | 2                | 2  | 2               | 2                                     | 2               | 2                                     | 2               |

a Ten lots, representing at least three production heats, or casts or melts, are required.

b Thicknesses of ten lots shall span thickness range of product form covered by material specification.

c For a single lot, multiple heat treat lots shall not be used to meet 10-lot requirement.

d If precision modulus values for  $E$  and  $E_c$  are not available, precision modulus tests should be conducted on three lots.

e Stress-strain data from at least three lots shall be submitted.

f Full-range tensile stress-strain data from at least one lot shall be submitted, but data from three or more lots are preferred.

g Products should also be tested in the 45° grain direction that are anticipated to have significantly different properties in this direction than the standard grain directions; these include materials such as aluminum-lithium alloys and Aramid fiber reinforced sheet laminate.

h It is recommended that sheet and strip  $\geq 0.050$  inch in thickness be selected for shear tests conducted according to ASTM B 831. Shear testing of sheet  $< 0.050$  inch in thickness may result in invalid results due to buckling around the pin hole areas during testing.

i It is recommended that minimum sheet and strip selected for bearing tests comply with the t/D ratio (0.25-0.50) specified in ASTM E 238. For failure modes, see Figure 9.4.1.7.2.

j As applicable, depending on product form and size.

k At least two specimens are recommended; however, a single test is acceptable if retesting can be accomplished to replace invalid tests.

Table 9.1.6.2 Definitions of Heat, Melt, and Cast

| Material                                                             | Heat, Melt, or Cast                                                                                                                                                                                                                                                                              |
|----------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Ingot Metallurgy Wrought Products Excluding Aluminum Alloys          | A heat is material which, in the case of batch melting, is cast at the same time from the same furnace and is identified with the same heat number; or, in the case of continuous melting, is poured without interruption.                                                                       |
| Ingot Metallurgy Wrought Aluminum Alloy Products                     | A cast consists of the sequential aluminum ingots which are melted from a single furnace charge and poured in one or more drops without changes in the processing parameters. (The cast number is for internal identification and is not reported.)                                              |
| Powder Metallurgy Wrought Products Including Metal-Matrix Composites | A heat is a consolidated (vacuum hot pressed) billet having a distinct chemical composition.                                                                                                                                                                                                     |
| Cast Alloy Products Including Metal-Matrix Composites                | A melt is a single homogeneous batch of molten metal for which all processing has been completed and the temperature has been adjusted and made ready to pour castings. (For metal-matrix composites, the molten metal includes unmelted reinforcements such as particles, fibers, or whiskers.) |

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Test specimens shall be excised in longitudinal, long transverse, and short transverse (when applicable) grain directions. Mechanical properties shall also be obtained in the 45° grain direction for materials that are anticipated to have significantly different properties in this direction than the standard grain directions. For some product configurations, it may be impractical to obtain transverse bearing specimens. For aluminum die forgings, the longitudinal grain direction is defined as orientations parallel, within  $\pm 15^\circ$ , to the predominate grain flow. The long transverse grain direction is defined as perpendicular, within  $\pm 15^\circ$ , to the longitudinal (predominate) grain direction and parallel, within  $\pm 15^\circ$ , to the parting plane. (Both conditions must be met.) The short transverse grain direction is defined as perpendicular, within  $\pm 15^\circ$ , to the longitudinal (predominate) grain direction and perpendicular, within  $\pm 15^\circ$ , to the parting plane. (Both conditions must be met.) All three grain directions are applicable and tests shall be conducted.

Triplicate test specimens are preferred. Single test specimens may be acceptable for some products providing retesting can be performed when needed. Duplicate specimens are recommended as an economical compromise. Some variation in strength within a product is expected. The use of replicate specimens provides multiple mechanical property observations so that lot averages can be used to form paired mechanical property ratios. Mechanical property ratios formed from lot averages are more reliable than those formed from individual observations.

**9.1.6.4 Test Procedures** — All tests shall be performed in accordance with applicable ASTM specifications, or their equivalent. The pin shear testing of aluminum alloys should be done in conformance to ASTM B 769, or an equivalent public specification. Grain orientations and loading directions for shear specimens must be defined in accordance with ASTM B 769, or an equivalent specification. Shear testing standards are not available in the U.S. for aluminum alloy sheet, strip, or thin extrusions or for products from other alloy systems. Bearing tests for products from all alloy systems shall be conducted in accordance with ASTM E 238, or an equivalent public specification, using “clean pin” test procedures. For aluminum alloy plate, bearing specimens are oriented flatwise and for aluminum alloy die and hand forgings, bearing specimens must be oriented edgewise, as described in Section 3.1.2.1.1.

**9.1.6.5 Mechanical Properties** — Tensile, compression, shear, and bearing tests shall be conducted at room temperature to determine tensile yield and ultimate strengths, compressive yield strength, shear ultimate strength, and bearing yield and ultimate strengths for  $e/D = 1.5$  and  $e/D = 2.0$  for each grain direction and each lot of material. All data shall be identified by lot, or heat, or melt. For materials used exclusively in high temperature applications, such as gas turbine or rocket engines, the determination of design values for compression, shear, and bearing strengths may be waived by the MIL-HDBK-5 Coordination Group. In lieu of data for these properties, sufficient elevated temperature data for tensile yield and ultimate strengths, as well as modulus of elasticity, shall be submitted so that elevated temperature curves can be constructed. Data should be submitted for the useful temperature range of the product. See Section 9.3.1.1.1 for data requirements for elevated temperature curves.

**9.1.6.6 Modulus of Elasticity Data** — Tensile and compressive modulus of elasticity values shall be determined for at least three lots of material. Elastic modulus values are those obtained using a Class B-1 or better extensometer. The method of determining or verifying the classification of extensometers is identified in ASTM E 83. ASTM E 111 is the standard test method for the determination of Young's Modulus, tangent modulus, and chord modulus of structural materials. A modulus value shall also be obtained for the 45 degree grain orientation for materials that are anticipated to have significantly different properties in this direction than the standard grain directions.

**9.1.6.7 Other Data** — Room temperature, tensile, and compressive load-deformation curves or stress-strain data for each grain direction from at least three lots shall be provided. Room temperature, full-range, tensile load deformation curves or stress-strain data for each grain direction shall also be provided. Full-range stress-strain data shall be provided for at least one lot, but data for three lots are preferable. For heat resistant materials for which elevated temperature data for tensile yield and ultimate strengths are required, room and elevated temperature stress-strain data shall be provided. A precise density value in pounds per cubic inch shall be provided. Although not required, physical property data for coefficient of expansion, thermal conductivity, and specific heat should be submitted, when available. Also, information regarding manufacturing (fabrication and processing), environmental effects (corrosion resistance), heat treat condition and applicable specification shall be provided so that a comments and properties section can be prepared. Also, data for creep, stress rupture, fatigue crack propagation, fatigue and fracture toughness properties should be submitted whenever possible, especially when applicable specifications contain minimum property requirements, such as minimum fracture toughness values.

**9.1.6.8 Guideline Requirements for Specification Minimum Design Mechanical Properties (S-basis)** — A product must be covered by an industry specification prior to being considered for inclusion into MIL-HDBK-5 as indicated in 9.1.6.1. Within a specification, one of the basic requirements is to provide minimum properties (S-basis) which includes tension yield, tension ultimate, elongation and compression yield (when specified). As indicated in Section 9.2.2, the statistical significance to the S-basis properties is typically not known. However, it is known that minimum mechanical properties in the SAE/AMS specifications have been statistically justified in recent years (since ~ 1975) with a procedure contained in their documents. With that in mind, a procedure has been established to provide some level of statistical significance to these S-basis properties contained within the Handbook.

A material being submitted for inclusion into MIL-HDBK-5 shall include as part of the substantiation package the basis of the specification properties. This substantiation package should include the number of test samples, the number of lots, and the method of determining any property covered in the specification even if it is not to be reported in MIL-HDBK-5. This could include the development of minimum as well as maximum properties. Consideration must be made for the specified sizes, product forms, heat treatments and other variables affecting the physical and mechanical properties. It is also expected that the test material chemistry be in the nominal specification range and not tailored to the chemistry extremes.

It is recommended that the substantiation be based on a procedure similar to SAE/AMS in which the analysis of data or other appropriate documentation supports a statistical S-basis value where at least 99 percent of the population of values is expected to equal or exceed the minimum value with a confidence of 95 percent. Since only limited quantities of data are generally available for the basic mechanical properties (tension yield, tension ultimate, compression yield), it is recommended that at least 30 test samples from at least three heats or lots of material are provided for each thickness range or product form. The S-basis value may be computed by assuming the distribution of the sample population to be normal and using the following equation:

$$\text{Minimum } S = \bar{X} - s \cdot k_{99} \quad (9.1.6.8)$$

where

|           |   |                                                                                                                                                                                                  |
|-----------|---|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\bar{X}$ | = | sample mean                                                                                                                                                                                      |
| $s$       | = | standard deviation                                                                                                                                                                               |
| $k_{99}$  | = | one-sided tolerance-limit factor corresponding to a proportion at least 0.99 of a normal distribution and a confidence coefficient of 0.95 based on the number of specimens (See Table 9.6.4.1). |



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All data analyses must to be performed in English units. Strength data recorded in metric units should be converted to English units, to the nearest 0.01 ksi, before data analyses are undertaken. If desired by the data supplier, metric equivalent tables and figures can be included as part of the working data submitted with a data proposal, but the tables and/or figures proposed for inclusion in MIL-HDBK-5 will contain only English units.

When the tensile and compressive properties vary significantly with thickness, regression analysis should be used.

Although the establishment of an S-basis value should be based upon the statistically computed value, the S-basis value may be slightly lower, based on experience and judgement, to insure conservative values.

**9.1.7 PROCEDURE FOR THE SUBMISSION OF MECHANICAL PROPERTY DATA** — This section specifies the procedure for submission of mechanical property data for statistical analysis; specifically data supplied for the determination of  $T_{99}$  and  $T_{90}$  values for  $F_{tu}$  and  $F_{ty}$  and for data supplied to obtain derived property values for  $F_{cy}$ ,  $F_{su}$ ,  $F_{bru}$  and  $F_{bry}$ . The amount of data to be supplied for both of these are indicated in other sections of Chapter 9, such as Table 9.1.6 for derived property values. This section covers the format to submit the data in electronic form.

**9.1.7.1 Computer Software** — The data can be supplied on 3.5 inch disks for PC format or sent electronically. It is recommended that the software applications in Table 9.1.7.1 be used to construct the data files. Along with the floppy disk, provide a hard (paper) copy of the data contained on the disk and any other supporting documentation such as specimen dimensions, gage length etc. This information will be stored in the MIL-HDBK-5 archives for future reference.

**Table 9.1.7.1. Software Applications for Data Submission**

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ASCII text editor

- Current Spreadsheet or Database Applications
  - The Chairman or Secretary of MIL-HDBK-5 can be contacted concerning software compatibility questions.
- 

The data supplied on these disks are to be supplied in English units. For example, physical dimensions should be reported in units of inches to the nearest thousandth of an inch (X.XXX), stress should be reported in units of ksi to the nearest one hundredth of a ksi (X.XX), strain is to be reported in percent to the nearest tenth of a percent (X.X) and modulus is to be reported in units of  $10^3$  ksi to the nearest tenth of a msi (X.X). If necessary, refer to Table 1.2.2 to convert to English units of measure.

**9.1.7.2 General Data Format** — Tables 9.1.7.2(a) and (b), for wrought and cast products respectively, show the information that should be supplied in electronic form along with the mechanical test results. The columns (or data fields), in order, will contain alloy type, specification number, temper/heat treatment, lot and/or heat number, product form, product thickness, specimen location, grain direction, and specimen number. Columns will be added towards the right of the specimen number and will contain the individual test results as discussed in Sections 9.1.7.3 and 9.1.7.4.

When specifying grain direction for wrought product strengths, etc., use the conventions identified in Table 9.1.6: L for longitudinal, LT for long transverse, and ST for short transverse. Products that are anticipated to have significantly different properties in directions other than those stated above should be tested in the appropriate directions and the results reported.

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There are several types of product forms identified in the Handbook; therefore, the term product form should be properly defined and reported in this column. Examples for wrought products are sheet, plate, bar, and forging. Examples for cast products are sand casting, investment casting, and permanent mold casting. For cast products it is important to identify properties from designated or nondesignated areas.

**9.1.7.3 Data Format for the Determination of A and B-Basis Values of  $F_{tu}$  and  $F_{ty}$**  — The tensile test results that are to be reported for determination of A and B-basis properties are tensile ultimate strength (TUS), tensile yield strength (TYS), elongation (e), reduction of area (RA), and modulus. The results of these tests are to be reported as shown in Table 9.1.7.3 along with alloy designation, specification, lot and/or heat number, product thickness, grain direction, etc. as previously shown in Table 9.1.7.2. The number of tests required for determining A and B-basis properties are identified in Section 9.2.

**9.1.7.4 Data Format for Derived Property Values** — For the derived property values, several types of tests may be conducted such as tensile, compression, shear and bearing, as shown in Table 9.1.6. The results of these tests are to be reported as shown in Table 9.1.7.4 along with alloy designation, specification, lot and/or heat number, product thickness, grain direction, etc. as previously shown in Table 9.1.7.2. The ultimate strength properties are to be contained in one file as shown in Table 9.1.7.4(a) while the yield strength properties are to be contained in another file as shown in Table 9.1.7.4(b).

Generally, two tests are preferred (one required) for a given test type and product thickness. The results of these tests are to be reported in columns adjacent to each other. For example, TUS Test #1 and TUS Test #2 are on the same row for a given thickness and heat. An additional column should be created to report the specimen number for the second test. This column should be just to the left of the test result. The same procedure is to be used for the other properties. The abbreviations (see Section 1.2.2) for the other test types are CYS for compressive yield, SUS for shear ultimate, and BUS and BYS for bearing ultimate and bearing yield strengths, respectively. For the bearing properties, also identify the e/D ratio of either 1.5 or 2.0.

**9.1.7.5 Data Format for the Construction of Typical Stress-Strain Curves** — The tensile and compression stress-strain data should also be submitted in electronic form, if possible, so that typical tensile and compression stress-strain curves, compression tangent-modulus and typical tensile (full-range) curves can be constructed. In order to construct a typical stress-strain curve, the individual specimen curves must be documented up to slightly beyond the 0.2 percent offset yield strength. To construct a typical (full-range) stress-strain curve, the individual curves must be documented through to failure.

The data for the stress-strain curves must be supplied on a separate floppy disk from the mechanical property data. The data should be stored in a file which contains the load (or stress) in the first column and the displacement (or strain) in the second column. Each stress-strain pair should be identified with its corresponding specimen identification number.

For the load-displacement curves, the load should be reported in pounds (X.) and the displacement should be reported in units of thousandth of an inch (X.XXX). For stress-strain curves, the stress should be reported to the nearest hundredth of a ksi (X.XX) and strain should be reported to the nearest  $X.XX \times 10^{-6}$  units.

A hard copy of the load displacement curve should also be submitted for each stress-strain curve.

Table 9.1.7.2(a). General Data Format for Wrought Products

| Alloy<br>Trade<br>Name | Industry/<br>Government<br>Specification<br>No. | Temper/Heat<br>Treatment | Lot and/or<br>Heat No. | Product<br>Form | Product<br>Thickness<br>(in.), or<br>Area (in. <sup>2</sup> ) | Speci-<br>men<br>Location | Grain<br>Direc-<br>tion | Specimen<br>No. |
|------------------------|-------------------------------------------------|--------------------------|------------------------|-----------------|---------------------------------------------------------------|---------------------------|-------------------------|-----------------|
|                        |                                                 |                          |                        |                 |                                                               |                           |                         |                 |
|                        |                                                 |                          |                        |                 |                                                               |                           |                         |                 |
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|                        |                                                 |                          |                        |                 |                                                               |                           |                         |                 |

Table 9.1.7.2(b). General Data Format for Cast Products

| Alloy<br>Trade<br>Name | Industry/<br>Government<br>Specification<br>No. | Temper/Heat<br>Treatment | Lot<br>and/or<br>Heat No. | Product<br>Form | Product<br>Thickness | Specimen<br>Location<br>(Designated,<br>Nondesignated) | Specimen<br>No. |
|------------------------|-------------------------------------------------|--------------------------|---------------------------|-----------------|----------------------|--------------------------------------------------------|-----------------|
|                        |                                                 |                          |                           |                 |                      |                                                        |                 |
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**Table 9.1.7.3 Data Format for Determination of A and B-Basis Values of F<sub>tu</sub> and F<sub>ty</sub>**

| Alloy Trade Name | The information to be entered between these two columns        | Specimen No. | TUS<br>ksi | TYS<br>ksi | %<br>E | %<br>R | Elastic<br>Modulus, msi |
|------------------|----------------------------------------------------------------|--------------|------------|------------|--------|--------|-------------------------|
|                  |                                                                |              |            |            |        |        |                         |
|                  |                                                                |              |            |            |        |        |                         |
|                  |                                                                |              |            |            |        |        |                         |
|                  |                                                                |              |            |            |        |        |                         |
|                  | depends upon the product form,<br>see Table 9.1.7.2(a) or (b). |              |            |            |        |        |                         |
|                  |                                                                |              |            |            |        |        |                         |
|                  |                                                                |              |            |            |        |        |                         |
|                  |                                                                |              |            |            |        |        |                         |
|                  |                                                                |              |            |            |        |        |                         |

**Table 9.1.7.4(a). Derived Ultimate Properties**

| Alloy Trade Name |                                                                     | Specimen No. | TUS Test 1 | TUS Test 2* | SUS Test 1 | SUS Test 2* | BUS e/D=1.5 Test 1 | BUS e/D=1.5 Test 2* | BUS e/D=2.0 Test 1 | BUS e/D=2.0 Test 2* |
|------------------|---------------------------------------------------------------------|--------------|------------|-------------|------------|-------------|--------------------|---------------------|--------------------|---------------------|
|                  | The information to be entered between these two                     |              |            |             |            |             |                    |                     |                    |                     |
|                  |                                                                     |              |            |             |            |             |                    |                     |                    |                     |
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|                  |                                                                     |              |            |             |            |             |                    |                     |                    |                     |
|                  | columns depends upon the product form, see Table 9.1.7.2(a) or (b). |              |            |             |            |             |                    |                     |                    |                     |
|                  |                                                                     |              |            |             |            |             |                    |                     |                    |                     |
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|                  |                                                                     |              |            |             |            |             |                    |                     |                    |                     |

\* Two tests are preferred, only one is required.

Table 9.1.7.4(b). Derived Yield Properties

| Alloy Trade Name |                                                                     | Specimen No. | TYS Test 1 | TYS Test 2* | CYS Test 1 | CYS Test 2* | BYS e/D=1.5 Test 1 | BYS e/D=1.5 Test 2* | BYS e/D=2.0 Test 1 | BYS e/D=2.0 Test 2* |
|------------------|---------------------------------------------------------------------|--------------|------------|-------------|------------|-------------|--------------------|---------------------|--------------------|---------------------|
|                  | The information to be entered between these two                     |              |            |             |            |             |                    |                     |                    |                     |
|                  |                                                                     |              |            |             |            |             |                    |                     |                    |                     |
|                  |                                                                     |              |            |             |            |             |                    |                     |                    |                     |
|                  |                                                                     |              |            |             |            |             |                    |                     |                    |                     |
|                  |                                                                     |              |            |             |            |             |                    |                     |                    |                     |
|                  | columns depends upon the product form, see Table 9.1.7.2(a) or (b). |              |            |             |            |             |                    |                     |                    |                     |
|                  |                                                                     |              |            |             |            |             |                    |                     |                    |                     |
|                  |                                                                     |              |            |             |            |             |                    |                     |                    |                     |
|                  |                                                                     |              |            |             |            |             |                    |                     |                    |                     |
|                  |                                                                     |              |            |             |            |             |                    |                     |                    |                     |

\* Two tests are preferred, only one is required.

## 9.2 ROOM-TEMPERATURE DESIGN PROPERTIES

**9.2.1 INTRODUCTION** — This section contains detailed procedures for the determination of room-temperature design properties.

**9.2.2 DESIGNATIONS AND SYMBOLS** — Designations and Symbols presented in this section are applicable throughout the MIL-HDBK-5, but are particularly pertinent to computation and presentation of room-temperature mechanical properties.

**9.2.2.1 Data Basis** — There are four types of room-temperature mechanical properties included in MIL-HDBK-5. They are listed here, in order, from the least statistical confidence to the highest statistical confidence, as follows:

*Typical Basis* — A typical property value is an average value and has no statistical assurance associated with it.

*S-Basis* — This designation represents the specification minimum value specified by the governing industry specification (as issued by standardization groups such as SAE Aerospace Materials Division, ASTM, etc.) or federal or military standards for the material. (See MIL-STD-970 for order of preference of specifications.) For certain products heat treated by the user (for example, steels hardened and tempered to a designated  $F_u$ ), the S-basis value may reflect a specified quality-control requirement. Traditionally, the statistical assurance of S-basis values has not been known. However, the statistical assurance associated with S-basis values established since 1975 is known within the limitations of the qualification sample and the analysis method used to evaluate the data. Within those constraints S-basis values established since 1975 may be viewed as estimated A-basis values.

Wherever possible, the statistical validity of these estimated A-basis (S-basis) values should be verified as soon as sufficient heats and lots of material are available from the major producers to establish more rigorous A-basis properties by the methods described in MIL-HDBK-5. If the more rigorous A-basis property exceeds the S-basis value, the major suppliers and users of the material may benefit from updating or replacing the specification because then they will be able to take full advantage of the capabilities of the material within the design allowable tables in MIL-HDBK-5.

In the opposite (and fortunately infrequent) situation where the more rigorous A-basis property falls well below the S-basis value, the repercussions may be greater for both the user and producer. Actual design margins (as compared to originally perceived design margins) on primary structure may be reduced below desirable levels if the S-basis value must be downgraded to a lower A-basis value. The perceived adequacy of a material for a particular application may be reduced if the S-basis value is reduced to match a lower A-basis value. However, under most circumstances, the S-basis value should be reduced to match the A-basis value if process improvements cannot be instituted to raise the A-basis value to the level of the original S-basis value.

*B-Basis* — This designation indicates that at least 90 percent of the population of values is expected to equal or exceed the statistically calculated mechanical property value, with a confidence of 95 percent. This statistically calculated number is computed using the procedures specified in Section 9.2.

*A-Basis* — The lower value of either a statistically calculated number, or the specification minimum (S-basis). The statistically calculated number indicates that at least 99 percent of the population is expected to equal or exceed the statistically calculated mechanical property value with a confidence of 95 percent. This statistically calculated number is computed using the procedures specified in Section 9.2.

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Sections 9.2.5, 9.2.7.1, 9.2.8.1, and 9.2.9.1 contain discussions of data requirements for direct computation of design properties based on current process capability of the majority of suppliers of a given material and product form. To assure that the A- and B-basis values, defined above, represent true current process capability of a material, all available original test data for current material that is produced and supplied to the appropriate government, industry, or equivalent company specifications are included in calculating these values. (However, to be considered for inclusion in MIL-HDBK-5, a material must be covered by an industry, Federal, or Military specification per Section 9.1.6.) Only positive proof of improper processing or testing is cause for exclusion of original test data, except that the number of tests per lot shall not exceed the usual frequency of testing for the product. It is recognized, however, that extensive acceptance testing resulting in elimination of low-strength material from the population may justify establishment of higher mechanical-property values for the remaining material. Since this is a function of both the type of product and the nature and frequency of the acceptance tests practiced by each company, it is impractical to attempt to include these considerations in this document.

Usually, only tensile ultimate and yield strengths in a specified testing direction are determined in such a manner that they can be termed A- and B-basis values, in accordance with definitions given above. Only tensile ultimate strength, tensile yield strength, elongation, and reduction of area (for some alloys) are normally specified in the governing specifications and can be termed S-basis values. However, ratioing procedures (described in Section 9.2.10) have been established, by which other property values such as



compression, shear, and bearing are computed to have approximately the same assurance levels as A-, B-, or S-basis values for tensile ultimate and yield strength. Property values determined in this manner are presented as having the same data basis as tensile ultimate and yield strengths in the same column of the table.

Current practice regarding the use of the above data bases in the presentation of room-temperature design properties is as follows:

- (1) Room-temperature design properties for tensile ultimate and yield strengths are presented as A- and B- or S-basis values. A-basis values that are higher than corresponding S-basis values are presented as footnotes in MIL-HDBK-5 property tables, and these A-basis values are not qualified for general use in design unless the specification requirements are increased to equal the A-basis value. However, A-basis values that are equal to or lower than corresponding S-basis values replace S-basis values in the document.
- (2) The S-basis value is used for elongation and reduction of area.
- (3) If an A-basis value is presented for a strength property, the corresponding B-basis value is also presented.
- (4) A- and B-basis values, when available, replace S-basis values, based upon item (1) conditions.
- (5) A- and B-basis values, based upon data representing samples of material supplied in the annealed, solution treated, or as-fabricated conditions, which were heat treated to demonstrate response to heat treatment by suppliers, are incorporated into MIL-HDBK-5 with an explanatory footnote. It is recognized that structural fabrication and processing can alter mechanical properties. The use of A- and B-basis values for structural design requires consideration of such effects. These material property values are derived from the statistically computed  $T_{99}$  and  $T_{90}$  values defined earlier.
- (6) Strength at room temperature after thermal exposure is presented graphically as a percentage of the tabulated design property.
- (7) Design data for all other properties, such as elastic modulus, Poisson's ratio, creep, fatigue, and physical properties, are presented on a typical basis unless indicated otherwise.

**9.2.2.2 Mechanical-Property Terms** — Mechanical properties that are presented as room-temperature design properties are listed in Table 9.2.2.2. It is important that use of a subscripted, capital letter “*F*” should be limited to designation of minimum values. Its use to designate an individual test value can lead to confusion and should be avoided in MIL-HDBK-5 data proposals.

The absence of a directionality symbol implies that the property value is applicable to each of the grain directions when the product dimensions exceed approximately 2.5 inches.

**Table 9.2.2.2. Mechanical Property Terms**

| Property                   | Units   | Symbol                            |                                |
|----------------------------|---------|-----------------------------------|--------------------------------|
|                            |         | Room-Temperature<br>Minimum Value | Individual or<br>Typical Value |
| Tensile Ultimate Strength  | ksi     | $F_{tu}$                          | TUS                            |
| Tensile Yield Strength     | ksi     | $F_{ty}$                          | TYS                            |
| Compressive Yield Strength | ksi     | $F_{cy}$                          | CYS                            |
| Shear Ultimate Strength    | ksi     | $F_{su}$                          | SUS                            |
| Shear Yield Strength*      | ksi     | $F_{sy}$                          | SYS                            |
| Bearing Ultimate Strength  | ksi     | $F_{bru}$                         | BUS                            |
| Bearing Yield Strength     | ksi     | $F_{bry}$                         | BYS                            |
| Elongation                 | percent | $e$                               | elong.                         |
| Total Strain at Failure*   | percent | $e_t$                             | strain at failure              |
| Reduction of Area          | percent | RA                                | red. of area                   |

\* As applicable.

The listed mechanical property symbols should be followed by one of the following additional symbols for wrought alloys, not castings.

- L — Longitudinal direction; parallel to the principal direction of flow in a worked metal.
- T — Transverse direction; perpendicular to the principal direction of flow in a worked metal; may be further defined as LT or ST.
- LT — Long-transverse direction; the transverse direction having the largest dimension, often called the “width” direction.
- ST — Short-transverse direction; the transverse direction having the smallest dimension, often called the “thickness” direction.

Values of  $F_{bru}$  and  $F_{bry}$  should indicate the appropriate edge distance/hole diameter (e/D) ratio. Design properties are presented for two such ratios: e/D = 1.5 and e/D = 2.0.

Data for use in establishing these properties should be based on ASTM standard testing practices. The test practice and any deviations therefrom should be reported when submitting proposals to the MIL-HDBK-5 Coordination Group for consideration.

**9.2.2.3 Statistical Terms** — Proper use of the following statistical terms and equations will alleviate misunderstanding in the presentation of data analyses:

**Population** — All potential measurements having certain independent characteristics in common, i.e., “all possible TUS(L) measurements for 17-7PH stainless steel sheet in TH1050 condition.”

**Sample** — A finite number of observations drawn from the population.

**Sample Mean** — Average of all observed values in the sample. It is an estimate of the population mean. A mean is indicated by a bar over the symbol for the value observed. Thus, the mean of n observations of TUS would be expressed as:

$$\overline{TUS} = \frac{TUS_1 + TUS_2 + \dots + TUS_n}{n} = \frac{\sum_{i=1}^n (TUS_i)}{n}$$

Sample Variance — The sum of the squared deviations from the sample mean, divided by  $n - 1$ , and, based on  $n$  observations of TUS, expressed as

$$s_{TUS}^2 = \frac{\sum_{i=1}^n (TUS_i - \overline{TUS})^2}{n - 1} = \frac{n \sum_{i=1}^n (TUS_i)^2 - \left( \sum_{i=1}^n TUS_i \right)^2}{n(n - 1)}$$

Sample Standard Deviation — An estimate of the population standard deviation; the square root of the sample variance, or

$$s_{TUS} = \sqrt{s_{TUS}^2}$$

Degrees of Freedom — Number of degrees of freedom for  $n$  sample values is defined as that number minus the number of constraints. For example, the standard deviation calculation contains one fixed value (the mean); therefore, it has  $n - 1$  degrees of freedom.

$T_{99}$  — At least 99 percent of the population of values is expected to equal or exceed this tolerance bound with a confidence of 95 percent.

$T_{90}$  — At least 90 percent of the population of values is expected to equal or exceed this tolerance bound with a confidence of 95 percent.

Probability — Ratio of possible number of favorable events to total possible number of equally likely events. Probability, as related to design properties, means that chances of a material-property measurement equaling or exceeding a certain value (the one-sided lower tolerance limit) is 99 percent in the case of a  $T_{99}$  value and 90 percent in the case of a  $T_{90}$  value.

Confidence — A specified degree of certainty that at least a given proportion of all future measurements can be expected to equal or exceed the lower tolerance limit. Degree of certainty is referred to as the confidence coefficient. For MIL-HDBK-5, the confidence coefficient is 95 percent which, as related to tolerance bounds for design properties, means that, in the long run over many future samples, 95 percent of conclusions regarding exceedance of  $T_{99}$  and  $T_{90}$  values would be true.

**9.2.3 COMPUTATIONAL PROCEDURES, GENERAL** — Procedures used to determine tolerance bounds for mechanical properties vary somewhat from one sample to another. All involve a number of steps that are best illustrated by the flowchart in Figure 9.2.3. These steps are summarized as follows:

- (1) Specify the population to which the property applies
- (2) Decide on the procedure for computing the property
- (3) Compute the property.

These steps are described in greater detail in Sections 9.2.4 through 9.2.11, and a number of examples of the several procedures are presented in Section 9.2.12.

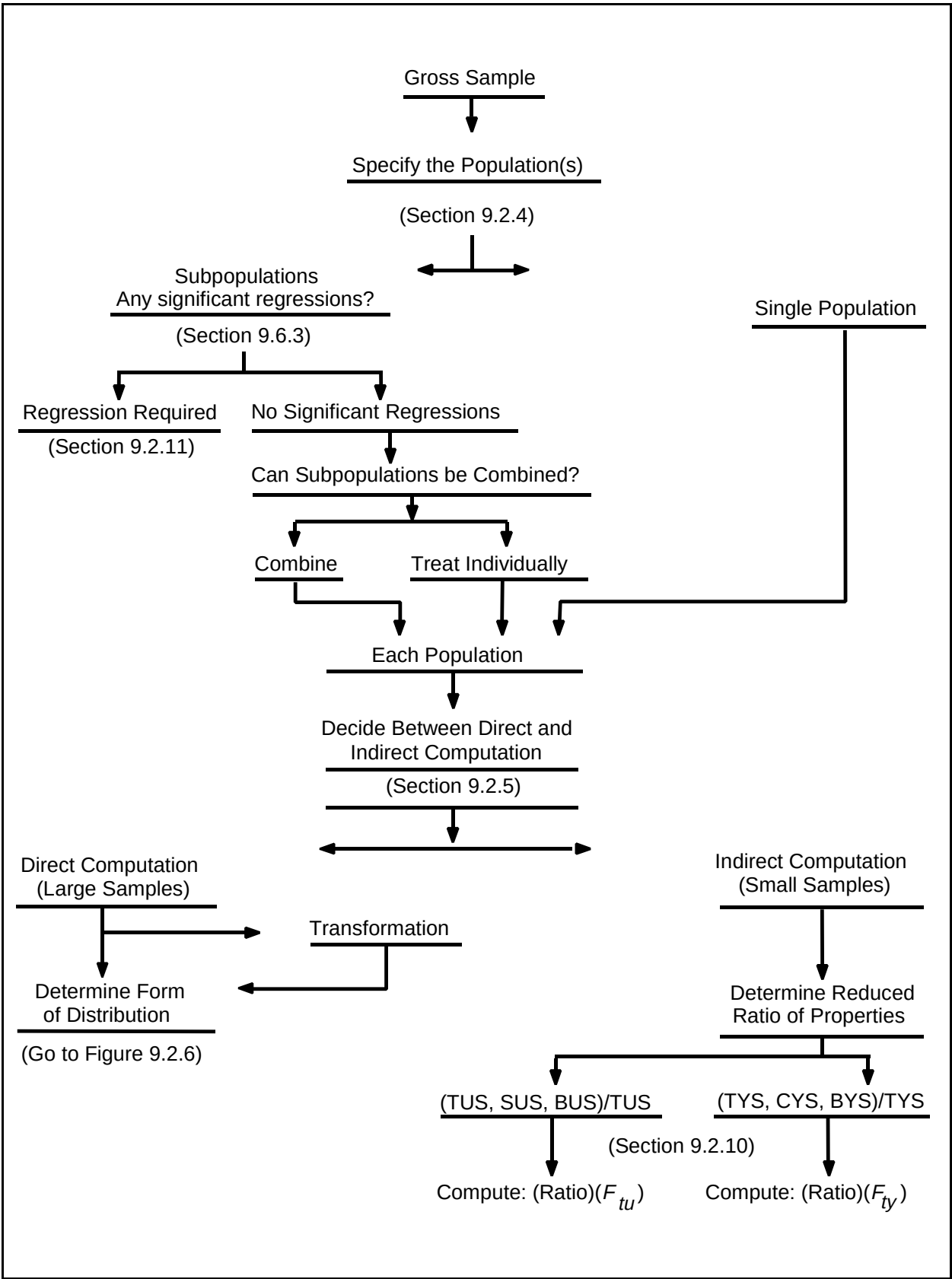


Figure 9.2.3. General procedures for determining design allowables.

**9.2.4 SPECIFYING THE POPULATION** — For computational purposes, definition of a population must be sufficiently restrictive to ensure that computed tolerance bounds for design properties are realistic and useful. This is done by establishing a range of products and test conditions for which a mechanical property can be characterized by a single statistical distribution. In most cases a homogeneous population of data for a measured test parameter should not include more than one alloy, heat-treated condition, or test temperature.

It is not necessarily obvious whether such a population may include more than one product form or size, grain direction or processing history. Strip, plate, bars, and forgings of one alloy may have essentially the same TYS, while for another material the TYS may differ greatly among those product forms. To resolve these questions, appropriate statistical tests of significance should be applied to the respective groups of data. These tests are described in detail in Section 9.6, and Section 9.2.12 presents examples of their use in MIL-HDBK-5 data analyses.

The step-by-step procedure for specifying the population is illustrated in Figure 9.2.4 and described in Section 9.2.4.1. This procedure is used to determine whether several available data sets may be combined for the purpose of computing design allowables. The procedure is applicable to data collections for which regression analysis is required as well as those for which regression is not required. In the latter case, an acceptability test is employed to eliminate unacceptable data sets. This procedure is described in Section 9.2.4.2. A corresponding acceptability test would be desirable for the regression setting; however, such a procedure has not yet been developed.

**9.2.4.1 Specification Procedure** — In most cases, these tests will provide a fairly clear-cut division between one population and another. For example, L and T properties either are or are not nearly identical. However, wrought product properties may sometimes vary continuously with some dimensional characteristic, such as thickness. It is necessary, therefore, to first test the data for the relationship between the property and the material dimension. Regression analysis procedures, which should be applied to each set of producer's data to determine if there is an effect due to a particular material dimension, are described in Section 9.6.3.

If any one of a group of data sets analyzed by regression shows a significant effect on properties due to the selected material dimension, all regressions should be tested for equality to determine whether the data sets may be combined and considered a homogeneous population. The procedure described in Section 9.6.3.3 should be used to perform this test.

If the regressions are accepted as equal, then  $T_{99}$  and  $T_{90}$  values can be calculated in one of two ways: (1) by regression; or (2) by dividing data into thickness ranges and calculating  $T_{99}$  and  $T_{90}$  values for each range. If the regressions are not equal,  $T_{99}$  and  $T_{90}$  values should be calculated separately for each data set and minimum  $T_{99}$  and  $T_{90}$  values determined for all data sets should be reported.

If none of the individual data sets (e.g. different producers) show significant regression due to the chosen material dimension, the different data sets should be tested for homogeneity using a k-sample Anderson-Darling test as described in Section 9.6.2.5. If data sets are found to be homogenous, data should be pooled and  $T_{99}$  and  $T_{90}$  values should be calculated using the single combined data set. If data from the various producers constitute more than one population, the following procedure should be used.

- (1) Data sets which do not comply to the minimum number of observations as stated in Sections 9.2.7.1, 9.2.8.1, and 9.2.9.1 data requirements should be excluded from any further evaluation until they meet the minimum requirements.

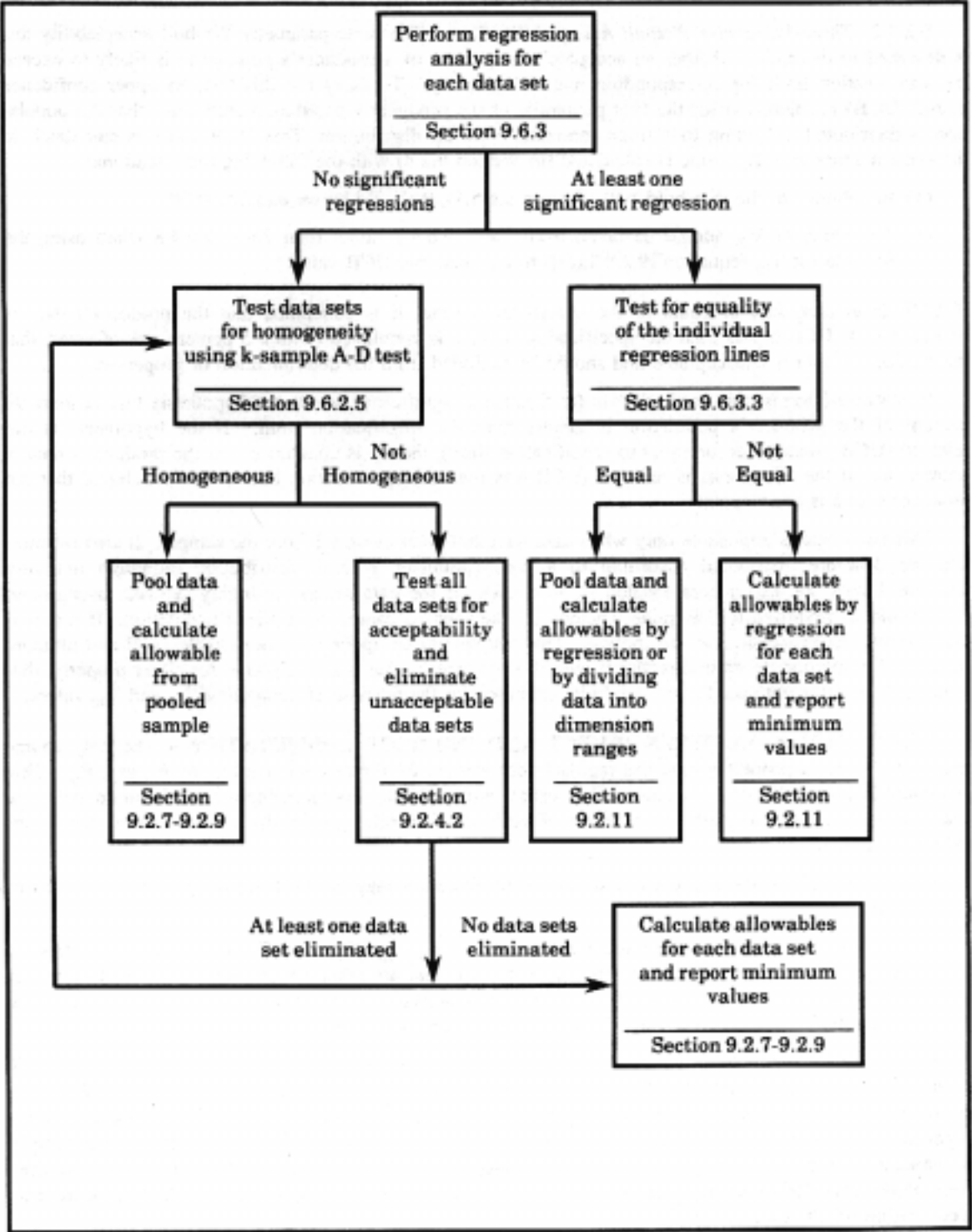


Figure 9.2.4. General procedures for specifying the population and calculating design allowables.

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- (2) Each remaining data set should be tested for acceptability using the three-parameter Weibull acceptability test described in Section 9.2.4.2. If there is statistical evidence that one or more statistically distinct data sets do not meet the specification minimum value, the results will be brought to the Material Data Review Working Group where a decision will be made on whether or not these data sets should be included in the computation of material property values.
- (3) All remaining data sets should be tested for homogeneity using the k-sample Anderson-Darling test. If the data sets are found to be homogeneous,  $T_{99}$  and  $T_{90}$  values can be calculated using a single combined data set. If the populations are not homogeneous, material property values must be determined by calculating  $T_{99}$  and  $T_{90}$  values for each data set.

**9.2.4.2 Three-Parameter Weibull Acceptability Test** — The three-parameter Weibull acceptability test is designed to determine whether an acceptable proportion of a producer's population is likely to exceed the specification limit for corresponding material property. To carry out this test, an upper confidence bound (UCB) is calculated for the first percentile of the producer's population assuming that the population is distributed according to a three-parameter Weibull distribution. This UCB value is calculated in the same manner as a  $T_{99}$  value is calculated (in Section 9.2.8) with the following modifications:

- (1) In solving for the threshold  $\tau(\theta)$  (Section 9.6.5.1),  $\theta$  should be set equal to 0.10.
- (2) The value of  $V_{99}$  should be taken from Table 9.6.4.7 rather than Table 9.6.4.8 when using the formula for  $T_{99}$  (Equation [9.2.8.2,(e)]) to calculate the UCB value.

If UCB is greater than or equal to the specification limit, it is concluded that the producer's data is acceptable. If UCB is less than the specification limit, it is concluded (with a 5 percent risk of error) that the producer's data do not meet the specification minimum value.

In statistical terms, this method tests (at 5 percent significance level) the hypothesis that at least 99 percent of the producer's population is greater than the specification limit. If the hypothesis is not rejected (UCB greater than or equal to specification limit), then it is concluded that the producer's data is acceptable. If the hypothesis is rejected (UCB less than the specification limit), it is concluded that the producer's data is unacceptable.

This technique is applicable only when data have not been censored from the sample. It also assumes that the data are distributed according to a three-parameter Weibull distribution (although normally distributed data are also accommodated by this test). If the data sample is highly skewed, background data should be reviewed to determine whether the skewness is caused by a mixed population. If it is not, the Weibull test procedure can be applied. This test should be applied to both tensile yield and ultimate strengths (in appropriate grain directions), and if a producer's data is unacceptable for either property, that producer's data for both properties should be excluded for the purpose of computing  $T_{99}$  and  $T_{90}$  values.

**9.2.5 DECIDING BETWEEN DIRECT AND INDIRECT COMPUTATION** — The only room-temperature design properties that are regularly determined by direct computation are  $F_u$  and  $F_{ty}$ . This procedure is usually limited to a specified or usual testing direction because there are seldom enough data available to determine properties in other test directions. Two rules govern the choice between direct and indirect computation:

- (1)  $F_u$  and  $F_{ty}$  in the specified or usual testing direction may be determined by direct computation only.

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- (2)  $F_{tu}$  and  $F_{ty}$  in other testing directions (as well as  $F_{cy}$ ,  $F_{su}$ ,  $F_{bru}$ , and  $F_{bry}$  in all directions) may be determined by direct computation only if (a) the data are adequate to determine the distribution form and reliable estimates of population parameters, or (b) the sample includes 300 or more individual, representative observations of the property to be determined.

For example, assume that available data for a relatively new alloy comprise 50 observations of TUS in the specified testing direction. This sample is not considered large enough to determine the distribution form and reliable estimates of population mean and standard deviation. Since only direct computation is permitted in this instance, determination of  $T_{99}$  and  $T_{90}$  values must be postponed until a larger sample is available. However, these properties may be considered for presentation on the S basis at the discretion of the MIL-HDBK-5 Coordination Group, contingent on availability of an acceptable procurement specification for the material.

If the number of observations increases to 100, this quantity may be adequate to allow determination of  $T_{99}$  and  $T_{90}$ -values, provided data can be described by a Pearson Type III (gamma) or Weibull distribution. If the distribution cannot be described parametrically, at least 299 observations are required so that computation can proceed without knowledge of the distributional form.

If the above example involved observations of SUS instead of TUS, the same criteria would apply for direct computation. However,  $F_{su}$  could be determined by indirect computation with as few as ten paired observations of SUS and TUS (representing at least ten lots and two heats), provided  $F_{tu}$  has been established.

## **9.2.6 DETERMINING THE APPROPRIATE COMPUTATION PROCEDURE**

**9.2.6.1 Background** — Prior to 1984, lower tolerance bound mechanical properties ( $T_{99}$ ,  $T_{90}$ ) were established by one of two methods. If the sample population was found to be normally distributed by a chi-square test, then standard normal distribution computation procedures were used. Otherwise, non-parametric procedures were used.

In 1984, use of the normal distribution was supplemented by use of the three-parameter Weibull distribution to accommodate skewness in material properties. In addition, the chi-square test was replaced by the more sensitive Anderson-Darling goodness-of-fit test. Because the Anderson-Darling test is especially sensitive to departures in the tails from the candidate distribution (the very high and very low observations) in many situations, the Weibull distribution is often rejected, even when the model fit (by a probability plot) appears adequate in the lower values.

To permit computation of lower tolerance bounds in more of these cases, the Weibull approach was expanded to incorporate two different levels of upper-tail censoring and a last-resort conservative “backoff” option. Also, a modified version of the A-D test was developed which places more emphasis on the lower tail than the upper tail.

During the development of the Weibull procedure (Section 9.2.8), it became evident how inadequate the traditional normal procedure is for computing tolerance bounds when the data come from a skewed distribution – even if a goodness-of-fit test is applied to screen out non-normal distributions. Table 9.2.6.1 illustrates the shortcomings of the normal procedure for computing  $T_{99}$  and  $T_{90}$  for distributions<sup>1</sup> ranging in skewness from minus 1 to plus 1. The second column provides estimates of the probability that a sample of size 100 will be “accepted” as normal. Notice that for very skewed Weibull distributions, the proportion

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<sup>1</sup> Table 9.2.6.1 is based on data generated from Weibull distributions with varying skewness. All distributions are standardized to a mean of 100 and standard deviation of 5.0.



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accepted by the normal Anderson-Darling test is small, but it increases for distributions with skewness near zero.

The third column of Table 9.2.6.1 estimates the coverage, which is the probability (or confidence) that the method will yield a  $T_{99}$  below the true first percentile. This should be 95 percent. If the distribution is negatively skewed then the coverage can be substantially lower than the claimed 95 percent. The fourth column estimates the systematic bias of the procedure. Bias for  $T_{99}$  represents the difference between the 95<sup>th</sup> percentile of the  $T_{99}$  values produced by the normal procedure minus the true first percentile. (Bias is presented in units of standard deviations. This can be converted to, say, ksi units, if the standard deviation is known.) It can be interpreted as the amount that would have to be subtracted from the  $T_{99}$  values produced by the procedure to get an appropriate answer. The problem is, in practice, one never knows true skewness. Notice that as bias goes up, coverage goes down. The last two columns provide coverage and bias estimates for  $T_{90}$ . Although still significant, the errors associated with  $T_{90}$  are much smaller than those for  $T_{99}$ . Figure 9.2.6.1 displays the bias of  $T_{90}$  and  $T_{99}$  for skewness between minus 1 and plus 1 (again, in units of standard deviations).

Normal-based methods can be very good for estimating the mean of a distribution - which is not very sensitive to skewness. However, in MIL-HDBK-5, much of the emphasis is on estimating the first and tenth percentiles - which are very sensitive to skewness. Table 9.2.6.1 and Figure 9.2.6.1 are provided to emphasize the notion that applying the normal method can result in very poor tolerance bound estimates due to undetected skewness. It is for this reason that the traditional normal method for computing tolerance bounds is not provided in the Handbook as a recommended procedure.

On the other hand, because methods based on the Weibull distribution are computationally intensive and have less intuitive appeal than methods based on the normal distribution, an alternative procedure was developed based on the Pearson Type III family of distributions. The Pearson family includes the normal distribution as a special case. The Pearson method was incorporated into the Guidelines in 1999.

The sequential Weibull procedure and the sequential Pearson procedure were developed based on distributions with skewness between minus 1 and 1. Therefore, the Weibull and Pearson procedures should not be applied if the sample skewness is outside this range. If no systematic effects (e.g., thickness) are identified as significant by regression, then only the nonparametric method (9.2.9) should be applied.

**9.2.6.2 Computation Procedures** — Current analysis procedures for computing lower tolerance bounds ( $T_{90}$ ,  $T_{99}$ ) are described in Figure 9.2.6(a). Three methods are permitted: the sequential Weibull procedure, the sequential Pearson procedure, and the nonparametric procedure. The remainder of this section provides an overview and a roadmap to these procedures. Figure 9.2.6(b) describes the procedure for translating  $T_{99}$  and  $T_{90}$  values to A and B values, and values for publication in the mechanical property tables in this Handbook.

Table 9.2.6.1. Performance of Normal Method for Calculating  $T_{90}$  and  $T_{99}$  on Samples of Varying Skewness

| Skewness | Percent Accepted | $T_{99}$         |                  | $T_{90}$         |                  |
|----------|------------------|------------------|------------------|------------------|------------------|
|          |                  | Percent Coverage | Bias (Std. Dev.) | Percent Coverage | Bias (Std. Dev.) |
| -1.00    | 16               | 3                | 1.0              | 66               | 0.22             |
| -0.75    | 40               | 11               | 0.7              | 78               | 0.16             |
| -0.50    | 68               | 43               | 0.4              | 83               | 0.12             |
| -0.25    | 91               | 82               | 0.2              | 88               | 0.08             |
| 0.00     | 98               | 98               | -0.1             | 93               | 0.04             |
| 0.25     | 91               | 100              | -0.4             | 97               | -0.02            |
| 0.50     | 65               | 100              | -0.6             | 99               | -0.06            |
| 0.75     | 21               | 100              | -0.7             | 100              | -0.06            |
| 1.00     | 4                | 100              | -0.7             | 100              | -0.10            |

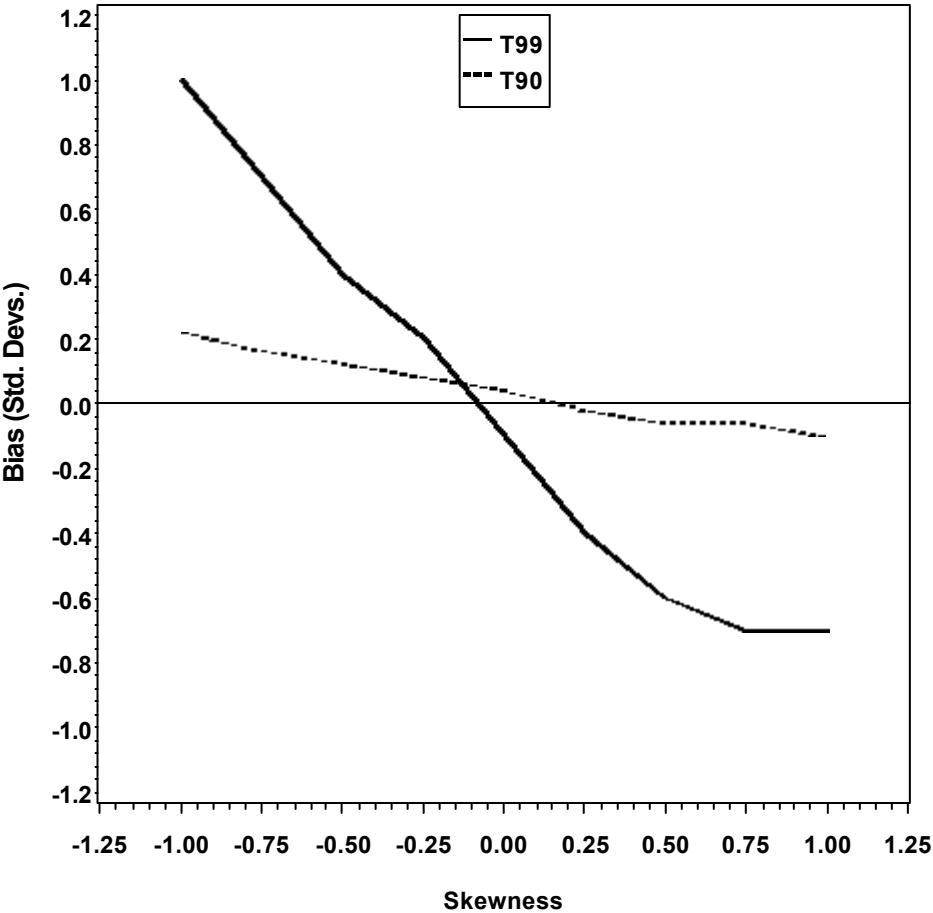


Figure 9.2.6.1. Estimated Bias of  $T_{99}$  and  $T_{90}$  Using Normal Method on Skewed Data.

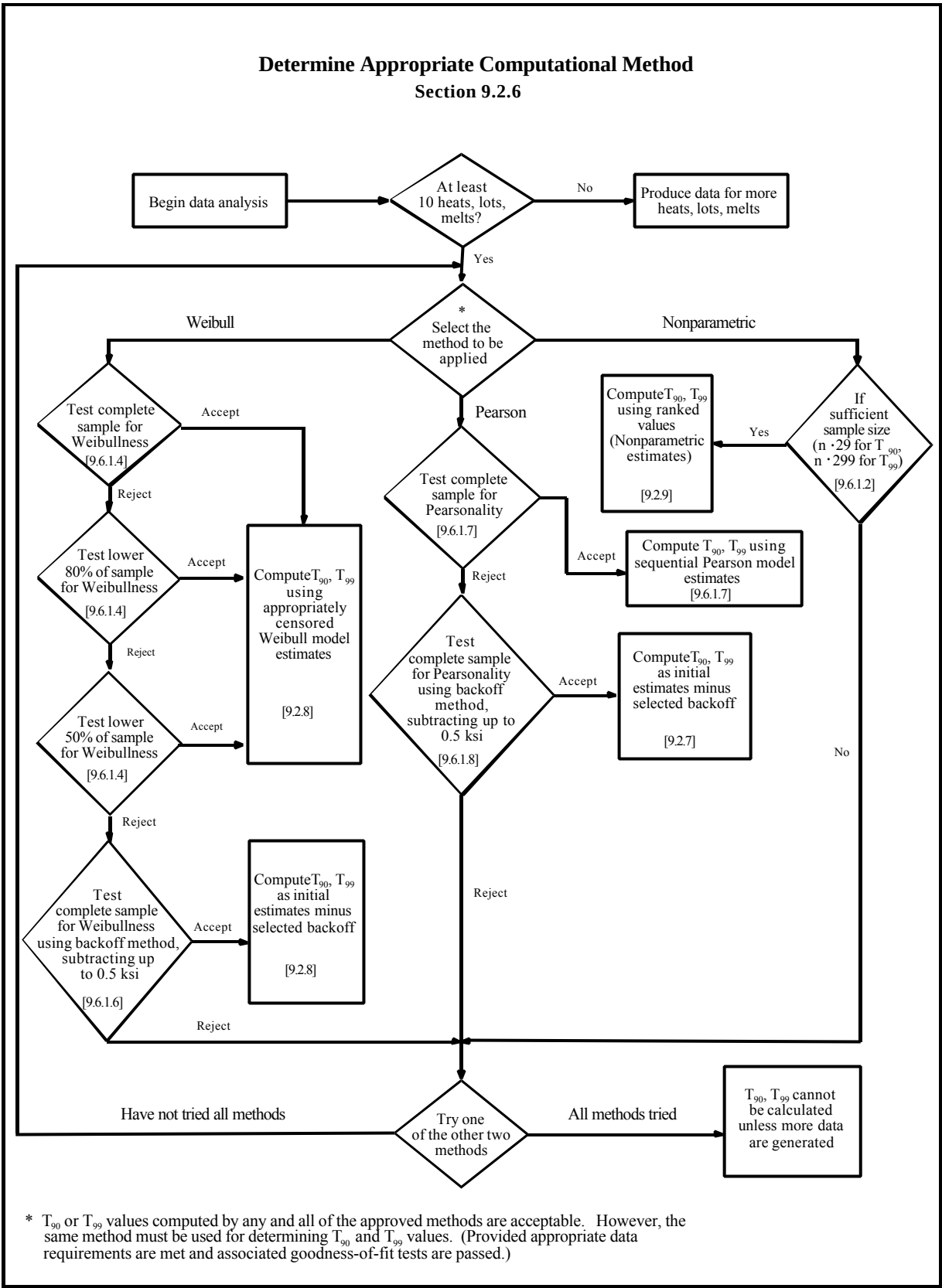


**Figure 9.2.6(a). Procedures for computation of  $T_{99}$  and  $T_{90}$ . (Go to Figure 9.2.6(b) for guidance on conversion of  $T_{99}$  and  $T_{90}$  values to A and B values.)**

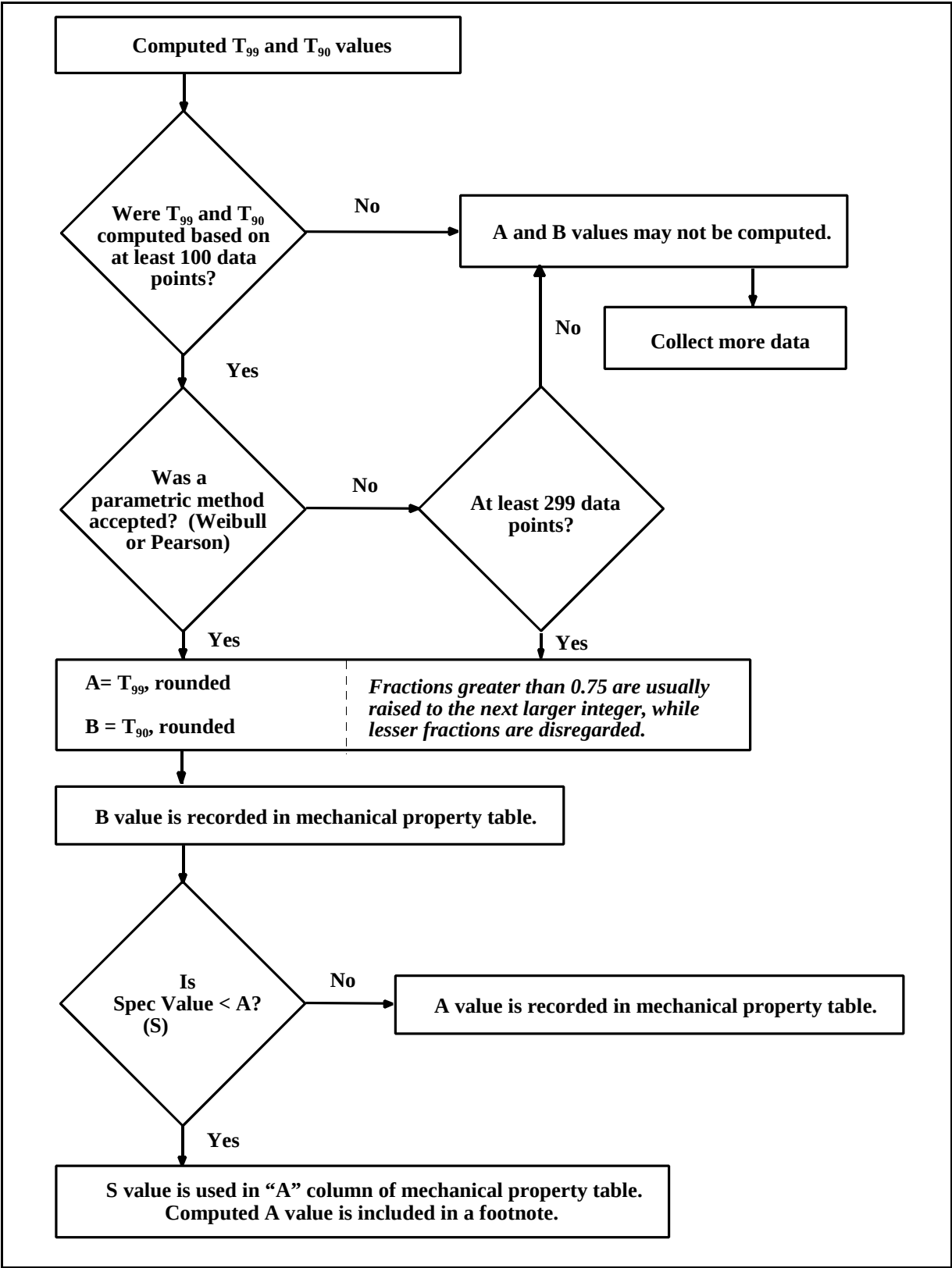


Figure 9.2.6(b). Procedure for Converting  $T_{99}$  and  $T_{90}$  values [from Figure 9.2.6(a)] to A and B Values, and Mechanical Property Table Values.

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In what follows, certain procedures require artificial censoring of the measured data. That is, because the real engineering interest for design lies in lower percentiles of the distribution of a material's properties, some of the following procedures ignore a portion of the observations in the upper tail. Specifically, we use the notation  $X_{(1)} \leq X_{(2)} \leq \dots \leq X_{(n)}$  to denote the ordered sample, and will frequently refer to the censored sample:

$$X_{(1)} \leq X_{(2)} \leq \dots \leq X_{(r)},$$

where  $r/n$  represents the proportion of the sample which is uncensored. Alternatively,  $(1-r/n)$  represents the proportion of the sample which is censored. The terms  $r$  and  $n$  will be used throughout subsequent sections without redefinition. In the case of uncensored data,  $r=n$ .

When the sequential Weibull procedure is applied, a modified Anderson-Darling goodness-of-fit-test is conducted as described in 9.6.1.4 for the uncensored sample. If the assumption of Weibullness is not rejected, the lower tolerance bound should be computed using methods described in Section 9.2.8 for complete samples. (The risk that one may conclude erroneously that a true Weibull distribution is non-Weibull is set at 5 percent.) If the assumption of Weibullness is rejected for the complete sample, then the next step is to test the lower 80 percent of the data for Weibullness by trimming the top 20 percent of the measurements and applying a censored version of the Anderson-Darling test. Use the version of the test described in Section 9.6.1.4 for 20 percent censoring. If this test is not rejected, then the lower tolerance bounds should be computed using the methods described in 9.2.8 for 20 percent censoring. If the assumption of Weibullness is rejected here, then 50 percent censoring should be attempted, in the same manner as described for 20 percent censoring.

If the Weibull model is still rejected with 50 percent censoring, then a last resort conservative Weibull method should be attempted. This method decreases the initial Weibull threshold estimate while holding the shape and scale parameters constant, until the percentiles of the resulting model are sufficiently less than the sample percentiles. To avoid accepting an extremely inadequate fit, the decrease is limited to 0.5 ksi.

Section 9.6.1.6 describes the method for identifying a proper backoff (the decrease from the initial Weibull threshold estimate), denoted by  $\tau_{\text{backoff}}$ , for this method. If the appropriate backoff is less than or equal to 0.5 ksi, the lower tolerance bounds should be calculated by first computing bounds based on the complete sample as specified in Section 9.2.8, and then subtracting the  $\tau_{\text{backoff}}$  value. If an appropriate backoff less than or equal to 0.5 ksi is not identified, then the nonparametric procedures described in 9.2.9, or the adjusted normal procedure described in Section 9.2.7, should be considered.

If the sequential Pearson analysis procedure is applied, the first step is to perform an Anderson-Darling goodness-of-fit test for Pearsonality as described in Section 9.6.1.7. If the assumption of normality is not rejected, the lower tolerance bounds may be computed using the methods described in Section 9.2.7. If the assumption of Pearsonality is rejected, then the Pearson backoff method should be attempted. This method decreases the estimate of the mean, while holding the standard deviation and skewness estimates constant, until the percentiles of the resulting model are sufficiently less than the sample percentiles. To avoid accepting an extremely inadequate fit, the decrease in the mean is limited to 0.5 ksi.

Section 9.6.1.8 describes the method for identifying a proper backoff, denoted by  $\tau_{\text{backoff}}$ , for the sequential Pearson method. If the appropriate backoff is less than or equal to 0.5 ksi, the lower tolerance bounds should be calculated by first computing bounds based on the complete sample as specified in Section 9.2.7, and then subtracting  $\tau_{\text{backoff}}$ . If an appropriate backoff less than or equal to 0.5 ksi is not identified, then the sequential Weibull procedures described in Section 9.2.8 or the nonparametric procedure described in Section 9.2.9 should be considered.

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In those cases where sufficient data is available, one may choose to calculate the lower tolerance bounds by the nonparametric procedure. A  $T_{99}$  bound requires 299 data values and a  $T_{90}$  bound requires 29 data values.\* The nonparametric procedure is described in Section 9.2.9. If the sample size is too small for the nonparametric method, the sequential Weibull procedure described in Section 9.2.8 or the sequential Pearson procedure described in Section 9.2.7, should be considered.

In those cases where sample sizes are insufficient to apply the nonparametric method, and the goodness-of-fit tests will not allow application of the sequential Weibull or sequential Pearson procedures, the lower tolerance bounds cannot be calculated.

**9.2.7 DIRECT COMPUTATION BY THE SEQUENTIAL PEARSON PROCEDURE** — This procedure should be used when a lower tolerance bound ( $T_{99}$ ,  $T_{90}$ ) is to be computed directly (not paired with another property for computational purposes) and the population may be interpreted to signify either the property measured (TUS, etc.) or some transformation of the measured value that is normally distributed. This procedure is applicable to  $F_{tu}$  and  $F_{ty}$ . It may also be used for  $F_{cy}$ ,  $F_{su}$ ,  $F_{bru}$ , and  $F_{bry}$  if sufficient quantity of data is available.

**9.2.7.1 Data Requirements** — Direct calculation of  $T_{99}$  and  $T_{90}$  values requires adequate data to determine (1) the form of distribution and (2) reliable estimates of the population mean and standard deviation. Prior experience with the material under consideration will help in determining sample size requirements. For a material, each population should be represented by a sample containing at least 100 observations. The sample shall include multiple lots, representing at least ten production heats, casts, or melts, from a majority of important producers. See Section 9.1.6.2 for definitions of lot, heat, cast, and melt. The sample should be distributed somewhat evenly over the size range applicable to the tolerance bound for the mechanical property. In order to avoid an undesirable biasing of the sample in favor of lots represented by more observations than other lots, the number of observations from each lot must be nearly equal.

Grouped data may be “ungrouped” and analyzed as described below, if grouped data are reported in intervals of 1 ksi or less. The uniform smoothing method for ungrouping grouped data should be used. For the uniform smoothing method, observations in an interval are spread uniformly over that interval. The  $i$ th observation in an interval is set equal to

$$a_i = L + \frac{i}{n + 1} (U - L) \quad i = 1, 2, \dots, n$$

where

- $n$  = the number of observations in the interval
- $L$  = the lower end point of the interval
- $U$  = the upper end point of the interval.

**9.2.7.2 Computational Procedure** — To compute lower tolerance bounds for a population from the Pearson Type III (or gamma) family of distributions, it is necessary to have estimates of the mean, standard deviation, and skewness of the population. In what follows, these are denoted respectively by  $\bar{X}$ ,  $S$ , and  $q$ . These estimates are also necessary for applying the Anderson-Darling (AD) test for Pearsonity (described in 9.6.1.2) and for the backoff part of the test (described in 9.6.1.7).

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\* However, according to current guidelines, a  $T_{90}$  value cannot be calculated for inclusion in MIL-HDBK-5 with fewer than 100 data values. See Section 9.2.9.1.

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In what follows,  $X_{(1)}, X_{(2)}, \dots, X_{(n)}$  represent the sorted observations, from smallest to largest. Calculate the sample mean and sample standard deviation as usual:

$$\bar{X} = \frac{1}{n} \sum_{i=1}^n X_i$$

$$S = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (X_i - \bar{X})^2}$$

The skewness is calculated as follows. First calculate the sample skewness:

$$Q = \sqrt{\frac{n}{(n-1)^3}} \cdot \frac{\sum_{i=1}^n (X_i - \bar{X})^3}{S^3}$$

If  $Q = 0$ , then let  $q = 0$ . If  $Q \neq 0$ , calculate the estimated threshold

$$T = \bar{X} - 2 \bullet S / Q$$

and use the following rules to define  $q$ :

- a. If  $Q > 0$  and  $X_{(1)} < T$ , then let  $q = 2 \bullet S / (\bar{X} - 0.99999 X_{(1)})$ .
- b. If  $Q < 0$  and  $X_{(n)} > T$ , then let  $q = 2 \bullet S / (\bar{X} - 1.00001 X_{(n)})$ .
- c. Otherwise,  $q = Q$ .

If the data are not rejected by the Anderson-Darling test for Pearsonality (described in 9.6.1.2), then  $T_{99}$  and  $T_{90}$  should be calculated by the following formulae:

$$T_{99} = \bar{X} - k_{99}(q, n) \cdot S$$

$$T_{90} = \bar{X} - k_{90}(q, n) \cdot S$$

where

$$k_{99}(q, n) = z_{99}(q) + \exp[2.556 - 1.229q + 0.987q^2 - 0.6542 \cdot \ln(n) + 0.0897q \cdot \ln(n) - 0.1864q^2 \cdot \ln(n)]$$

$$k_{90}(q, n) = z_{90}(q) + \exp[1.541 - 0.943q - 0.6515q^2 - 0.6004 \cdot \ln(n) + 0.0684q \cdot \ln(n) + 0.0864q^2 \cdot \ln(n)]$$

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$$z_{99}(q) = \frac{2}{q} \left[ 1 - \left( 1 - \frac{q^2}{36} - 2.326348 \cdot \frac{q}{6} \right)^3 \right] - 0.013133 q^2 - 0.003231 q^3 + 0.003139 q^4 + 0.001007 q^5$$

$$z_{90}(q) = \frac{2}{q} \left[ 1 - \left( 1 - \frac{q^2}{36} - 1.281552 \cdot \frac{q}{6} \right)^3 \right] + 0.003814 q^2 - 0.002466 q^3 - 0.000633 q^4 + 0.000122 q^5$$

The above formulas for  $z_{99}(q)$  and  $z_{90}(q)$  should be used for  $q \neq 0$ . If  $q = 0$ , then  $z_{99}(q) = 2.326348$  and  $z_{90}(q) = 1.281552$ .

If the data are rejected by the Anderson-Darling test for Pearsonality, but accepted under the backoff option of the test (9.6.1.7) with a reduction in the mean of  $\tau_{\text{backoff}}$ , then the above formulas should be applied to compute then  $T_{99}$  and  $T_{90}$  with the following slight modification:

$$T_{99} = \bar{X} - k_{99}(q, n) \cdot S - \tau_{\text{backoff}},$$

$$T_{90} = \bar{X} - k_{90}(q, n) \cdot S - \tau_{\text{backoff}}.$$

**9.2.8 DIRECT COMPUTATION BY THE SEQUENTIAL WEIBULL PROCEDURE**— This procedure should be used when a mechanical property value is to be computed directly (not paired with another property for computational purposes) and the population may be interpreted to signify either the property measured (TUS, etc.) or some transformation of the measured value that follows a three-parameter Weibull distribution. This procedure is applicable to  $F_{tu}$  and  $F_{ty}$ . It may also be used for  $F_{cy}$ ,  $F_{su}$ ,  $F_{bru}$ , and  $F_{bry}$  if a sufficient quantity of data is available.

**9.2.8.1 Data Requirements** — Direct calculation of the lower tolerance bounds ( $T_{99}$ ,  $T_{90}$ ) requires adequate data to determine (1) form of the distribution and (2) reliable estimates of population threshold, shape, and scale parameters. Prior experience with the material under consideration will help determine sample size requirements. For a material, each population should be represented by a sample containing at least 100 observations that are distributed (parametrically) according to a three-parameter Weibull distribution. The sample should include multiple lots, representing at least ten production heats, casts, or melts, from a majority of important producers. The sample should be distributed somewhat evenly over the size range applicable to the property. In order to avoid an undesirable biasing of the sample in favor of lots represented by more observations than other lots, the number of observations from each lot must be nearly equal.

Grouped data may be “ungrouped” and analyzed as described below, if grouped data are reported in intervals of 1 ksi or less. The uniform smoothing method for ungrouping grouped data should be used. For the uniform smoothing method, observations in an interval are spread uniformly over that interval. The  $i$ th observation in an interval is set equal to



$$a_i = L + \frac{i}{n + 1} (U - L) \quad i = 1, 2, \dots, n$$

where

- n = the number of observations in the interval
- L = the lower end point of the interval
- U = the upper end point of the interval.

**9.2.8.2. Computational Procedures** — In order to compute the lower tolerance bounds for a three-parameter Weibull population, it is necessary to have (1) an estimate of population threshold, (2) estimates of population shape and scale parameters, and (3) tables of one-sided tolerance limit factors for the three-parameter Weibull distribution. The method for estimating the population threshold based on complete or censored data (20 or 50 percent censoring) is presented in Section 9.6.5.1, and Section 9.6.5.2 contains the method for estimating population shape and scale parameters. Both of these procedures permit estimation with complete or censored data (20 or 50 percent censoring). A tabulation of tolerance limit factors by sample size, censoring level, and population proportion covered by the tolerance interval is presented in Table 9.6.4.8. For further information on these procedures and tabled values, see References 9.2.8(a) and 9.2.8(b).

Let  $X_1, \dots, X_n$  denote sample observations in any order and let  $X_{(1)}, \dots, X_{(n)}$  denote sample observations ordered from smallest to largest. The first step in calculating  $T_{99}$  and  $T_{90}$  for a three-parameter Weibull population is to obtain an estimate of the population threshold. The population threshold is theoretically the minimum achievable value for the property being measured. However, the real population is being empirically modeled by some Weibull population with a threshold. Since this empirical model is not perfect, there may be a small percentage of observations in the population that fall below the model threshold. Separate threshold estimates, denoted by  $\tau_{99}$  and  $\tau_{90}$ , will be obtained for  $T_{99}$  and  $T_{90}$  using the methods described in Section 9.6.5.1.

The second step in calculating mechanical properties for a three-parameter Weibull population is to obtain estimates of population shape and scale parameters for each property. Shape parameter estimates will be denoted by  $\beta_{99}$  and  $\beta_{90}$  and scale parameter estimates will be denoted by  $\alpha_{99}$  and  $\alpha_{90}$ . Estimation of shape and scale parameters is performed using a maximum likelihood procedure for the two-parameter Weibull distribution, after subtracting off the estimated threshold. (The two-parameter Weibull is equivalent to the three-parameter Weibull with threshold zero.)

Using the method outlined in Section 9.6.5.2, compute the maximum likelihood estimates of the shape and scale parameters for the censored or uncensored sample  $\{X_{(i)} - \tau_{99} : i=1, \dots, r\}$ , where  $r$  equals  $n$  for uncensored data and  $r$  represents the smallest integer greater than or equal to  $4n/5$  for 20 percent censoring and  $n/2$  for 50 percent censoring. Denote these estimates by  $\beta_{99}$  and  $\alpha_{99}$ , respectively. Using the same procedure, compute estimates  $\beta_{90}$  and  $\alpha_{90}$  based on the sample  $\{X_{(i)} - \tau_{90} : i=1, \dots, r\}$ .

With population parameter estimates discussed above at hand, the computation of the lower tolerance bounds is carried out by use of the formulas:

$$T_{99} = \tau_{99} + Q_{99} \exp \left[ - V_{99} / (\beta_{99} \sqrt{n}) \right],$$

$$T_{90} = \tau_{90} + Q_{90} \exp \left[ - V_{90} / (\beta_{90} \sqrt{n}) \right],$$

where

$$Q_{99} = \alpha_{99} (0.01005)^{1/\beta_{99}}$$

$$Q_{90} = \alpha_{90} (0.10536)^{1/\beta_{90}}$$

$$V_{99} = \text{the value in the } V_{99} \text{ column of Table 9.6.4.8 corresponding to a sample of size } n \text{ and the appropriate degree of censoring, and}$$

$$V_{90} = \text{the value in the } V_{90} \text{ column of Table 9.6.4.8 corresponding to a sample of size } n \text{ and the appropriate degree of censoring.}$$

Note that the level of censoring used in estimating the threshold, shape, and scale parameters must be used in determining  $V_{99}$  and  $V_{90}$ . Also, because this censoring level is determined by the goodness-of-fit test (9.6.1.4), the same censoring level is used for both  $T_{99}$  and  $T_{90}$ .

If the property that follows a three-parameter Weibull distribution represents a transformation, the lower tolerance bounds ( $T_{99}$ ,  $T_{90}$ ) computed by the above formulas must be transformed back to the original units in which the mechanical property is conventionally reported. When the computed  $T_{99}$  or  $T_{90}$  value results in a fractional number, the mechanical property used in the room temperature tables is determined by rounding. Fractions greater than 0.75 usually are raised to the next larger integer while lesser decimal fractions are disregarded. However, the rounded  $T_{99}$  value is replaced in the mechanical property tables with the  $S$  value if the  $S$  value is lower. In that case the rounded  $T_{99}$  value is included in a footnote.

**9.2.9 DIRECT COMPUTATION FOR AN UNKNOWN DISTRIBUTION** — This procedure should be used when a mechanical-property value is to be computed directly (not paired with another property for computational purposes) and the form of the distribution of population is unknown (not normal or three-parameter Weibull). Distribution should not be considered unknown (1) if tests show it to be nearly normal or three-parameter Weibull, (2) if it can be transformed to a nearly normal or three-parameter Weibull distribution, or (3) if it can be separated into nearly normal or three-parameter Weibull subpopulations. This procedure is applicable to  $F_{tu}$  and  $F_{ty}$ . It may also be used for  $F_{cy}$ ,  $F_{su}$ ,  $F_{bru}$ , and  $F_{bry}$  if sufficient quantity of data is available.

**9.2.9.1 Data Requirements** — Data must be adequate to assure that the sample is representative of the population. Although censoring is highly undesirable, parametric techniques will

“tolerate” a limited degree of censoring. In contrast, nonparametric techniques will not “tolerate” censoring. Determination of a  $T_{99}$  value requires at least 299 individual observations that represents 10 heats, casts, or melts, but additional data is very desirable. The selection of the number 299 is not arbitrary. Rather, 299 represents the smallest sample for which the lowest observation is a tolerance bound,  $T_{99}$ . For smaller samples,  $T_{99}$  is below the lowest observation and thus cannot be determined without knowledge of the form of population distribution. The lowest of 29 observations is a tolerance bound. The  $T_{90}$  value can be computed with a minimum of 29 observations provided these observations represent 10 heats, casts, or melts. However, the B-basis property is not included in the Handbook without the A-basis property. The requirement for number of heats or lots for the sample is comparable to that required for a parametric analysis.

**9.2.9.2 Computational Procedure** — Nonparametric (or distribution-free) data analysis assumes a random selection of test points and uses only the ranks of individual test points and the total number of test points. If test points have been deleted from a sample, the random basis is violated; consequently, this procedure must not be used when there is reason to suspect that the sample may have been censored.

As an example, assume that a sample consists of 299 test points selected in a random manner. The test point having the lowest value has rank 1, the test point having the next lowest value has rank 2, etc. Thus, an array of ranked test points might appear as follows:

| <u>Rank of Test Point</u> | <u>Value of Test Point, ksi</u> |
|---------------------------|---------------------------------|
| 1                         | 73.3                            |
| 2                         | 74.1                            |
| 3                         | 75.2                            |
| 4                         | 75.3                            |
| 5                         | 75.6                            |
| 299                       | 85.7                            |

For each rank from a sample of size,  $n$ , it is possible to predict, with 0.95 confidence, the least fraction of population that exceeds the value of the test point having rank  $r$ . Since only two fractions, or probabilities, are of interest in determination of  $T_{99}$  and  $T_{90}$  values, only the ranks of test points having the probability and confidence of  $T_{99}$  and  $T_{90}$  values are presented in Table 9.6.4.2. To use this table with a sample size of 299, for example, one would designate the value of the lowest ( $r=1$ ) test measurement as  $T_{99}$  and the 22nd lowest ( $r=22$ ) test measurement as  $T_{90}$ . For sample sizes between tabulated values, interpolation is permissible. For sample sizes smaller than 299,  $T_{99}$  is smaller than the value of the lowest point and cannot be determined in this manner.

When the lower tolerance bound ( $T_{99}$  or  $T_{90}$ ) results in a fractional number, the actual mechanical property value used in the room temperature tables is determined by rounding. Fractions greater than 0.75 usually are raised to the next larger integer while less decimal fractions are disregarded. *However, the rounded  $T_{99}$  value is replaced in the mechanical property tables with the  $S$  value if the  $S$  value is lower.* In that case the rounded  $T_{99}$  value is included in a footnote.

**9.2.1.0 COMPUTATION OF DERIVED PROPERTIES**— Ideally, it is desirable to determine  $F_{cy}$ ,  $F_{su}$ ,  $F_{bru}$ ,  $F_{bry}$ , as well as  $F_{tu}$  and  $F_{ty}$  in other than specified test direction by direct computation as described in Sections 9.2.7 through 9.2.9, and, if sufficient quantity of data is available, direct computation procedures shall be used. Unfortunately, the cost of generating required data for these properties is usually prohibitive. Consequently, this section describes an indirect method of computation to determine the mechanical property values.

A derived property is a mechanical property value determined by its relationship to an established tensile property ( $F_{tu}$  or  $F_{ty}$ , A, B, or S-basis). This indirect method of computation is applicable to  $F_{tu}$  and  $F_{ty}$  in grain directions other than the specified testing direction, as delineated in the applicable material specification, and for all grain directions for  $F_{cy}$ ,  $F_{su}$ ,  $F_{bru}$ , and  $F_{bry}$ .

The procedure involves pairing of TUS, SUS, or BUS measurements with TUS measurements for which  $F_{tu}$  has been established or the pairing of TYS, CYS, and BYS measurements with TYS measurements for which  $F_{ty}$  has been established. Average values for each lot shall be used when more than one measurement per lot is available.

This technique is based on the premise that the mean ratio of paired observations representing related properties provides an estimate of the ratio of corresponding population means. The ratio consists of measurements of the property to be derived as the numerator and measurement of the established tensile property as the denominator. Thus, TUS or TYS in the specified testing direction always appears in the denominator of the ratio of observed values.

Grain direction to be used for the denominator is the specified test direction as delineated in the applicable material specification. For most materials, routine quality control (certification) tests are usually conducted only in one grain direction even though the specification may contain mechanical property requirements for two or three grain directions. For guidance, specified or primary test direction for different product forms of each alloy system is shown in Table 9.2.10.

Table 9.2.10. Primary<sup>a</sup> Testing Direction for Various Alloy Systems

| Product Form    | Carbon and Low Alloy Steels | Non-Heat Treat-able Alum. Alloys | Heat Treatable Alum. Alloys | Magnesium Alloys | Titanium Alloys | Corrosion and Heat Resistant Alloys | Other Alloys |
|-----------------|-----------------------------|----------------------------------|-----------------------------|------------------|-----------------|-------------------------------------|--------------|
| Sheet and Plate | LT                          | L                                | LT                          | L                | <sup>d</sup>    | LT                                  | <sup>b</sup> |
| Bar             | L                           | L                                | L                           | L                | <sup>d</sup>    | L                                   | <sup>b</sup> |
| Tubing          | L                           | L                                | L                           | L                | L               | L                                   | <sup>b</sup> |
| Extrusion       | L                           | L                                | L                           | L                | <sup>d</sup>    | L                                   | <sup>b</sup> |
| Die Forging     | <sup>b</sup>                | L                                | L <sup>c</sup>              | L                | <sup>d</sup>    | <sup>b</sup>                        | <sup>b</sup> |
| Hand Forging    | <sup>b</sup>                | LT                               | LT                          | LT               | <sup>d</sup>    | <sup>b</sup>                        | <sup>b</sup> |

- a Although material specifications may contain mechanical-property requirements for two or three grain directions, the primary test direction indicates the grain direction which is tested regularly.
- b See applicable material specification.
- c Although material specifications require testing in both L and T directions, the T direction by definition includes all orientations not within  $\pm 15^\circ$  of parallel to grain flow. Hence, the L direction is preferred for analytical purposes.
- d Since there is no primary test direction for titanium alloys, mechanical property ratios shall be formed using strength values which represent the same grain directions in the numerator and denominator. The design allowable is computed as the product of the reduced ratio and the  $F_{ty}$  or  $F_{tu}$  value for the grain direction represented by the reduced ratio.

**9.2.10.1 Data Requirements** — Computation of a derived value for each significant test direction requires at least ten paired measurements from ten lots of material obtained from at least two production heats, casts, or melts for each product form and heat-treat condition or temper. See Section 9.1.6.2 for definitions of lot, heat, cast, and melt. If two lots are from the same heat, cast, or melt and have the same product form and thickness, they must be heat-treated separately in order to constitute two lots.

Therefore, it is recommended that two lots with the same product form and thickness come from a different heat, cast, or melt.

The thicknesses of the ten lots shall span the thickness range of product form covered by the material specification. Test specimens for paired ratios shall be located in close proximity and shall be taken from the same sheet, plate, bar, extrusion, forging, or casting. If coupons or specimens are machined prior to heat treatment, all coupons or specimens from the same lot shall be heat treated simultaneously in the same heat-treat load through all heat-treating operations. Some or all of the lots may be heat treated together provided they are of the same product form that represent different thicknesses or heats, casts, or melts.

In the cases where multiple observations are available from a single lot, the average of those observations shall be treated as an individual observation. Since some variation in strength may be expected from one specimen location to another, use of lot averages minimizes the effect of this variable.

Dimensionally discrepant castings or special test configurations, as approved by the MIL-HDBK-5 Coordination Group, may be used for a test program to obtain mechanical properties for determination of derived values, providing these castings meet the requirements of the applicable material specification. Separately cast bars are not acceptable for use in obtaining mechanical properties.

**9.2.10.2 Procedure**— Four basic steps are involved in determining design allowable properties by indirect computation:

- (1) Determine the ratios of paired observations for each lot of material.
- (2) Compute the statistics,  $\bar{r}$  and  $s$ , for the ratios of paired observations.
- (3) Determine the lower confidence interval estimate (reduced ratio) for the mean ratio.
- (4) Use the reduced ratio as the ratio of the derived to the established design allowable.

The ratio of two paired observations is obtained by dividing the measurement of the property to be derived [for example, CYS (LT) for heat-treatable aluminum sheet] by the measurement for established tensile property [for example, TYS (LT)] in the specified testing direction. Equations for computing average and standard deviation of the ratios are the same as those in Section 9.2.2.3.

The ratio of the two population means [for CYS (LT) and TYS (LT), respectively] is expected to exceed the lower confidence limit defined as

$$\bar{r} - t_{1-\alpha} s / \sqrt{n} \quad [9.2.10.2(a)]$$

where

- $n$  is the number of ratios
- $\bar{r}$  is the average of  $n$  ratios
- $s$  is the standard deviation of the ratios
- $t_{1-\alpha}$  is the  $1-\alpha$  fractile of the  $t$  distribution for  $n - 1$  degrees of freedom. At the risk level of  $\alpha = 0.05$ , the appropriate  $t$  value is  $t_{0.95}$ .

Since the lower confidence interval estimate is used as the ratio between the design allowable properties, the reduced ratio,  $R$ , may be defined as

$$R = \bar{r} - t_{0.95} s / \sqrt{n} \quad [9.2.10.2(b)]$$

Values of  $t_{0.95}$  for various degrees of freedom,  $n - 1$ , are tabulated in Table 9.6.4.5.

The reduced ratio may now be used to establish the design allowable for the property to be derived using the example of aluminum sheet,

$$R = \frac{F_{cy}(LT)}{F_{ty}(LT)} = \frac{\text{allowable to be derived}}{\text{established allowable in specified test direction}} .$$

The derived allowable property is computed by cross multiplying:

$$F_{cy}(LT) = R F_{ty}(LT) .$$

The basis (A, B, or S) for computed or derived property is assumed to be the same as the basis for  $F_{ty}$  or  $F_{tu}$  tensile property in the right-hand side of the equation. If only the S-basis (integer) properties are available to compute the derived properties, these values must be used. However, the unrounded S-basis  $F_{ty}$  or  $F_{tu}$  values computed with the method in Section 9.1.6.8 must be used to compute the derived properties if there are 100 or more observations representing 10 heats, casts, or melts. When there are 100 or more observations, and the  $T_{99}$  and  $T_{90}$  values can be computed for  $F_{ty}$  or  $F_{tu}$ , these unrounded values must be used to compute the derived property values to ensure the proper statistical confidence in the derived values. The lower of either the S-basis value computed from Section 9.1.6.8 or the  $T_{99}$  value must be used to compute the A-basis derived properties.

In a sample of ratios for a given product, effect of thickness on the ratio should be examined. If there is no effect of thickness, ratios for the various thicknesses can be pooled to compute the average and reduced ratio. If there is an effect of thickness, then a regression with thickness should be computed and the average and reduced ratios determined from the regression. See Section 9.2.11.2 for procedure.

When the computed design allowable results in a fractional number, actual design allowable value used in room temperature tables is determined in the following manner. Fractions greater than 0.75 usually are raised to the next larger integer while lesser decimal fractions are disregarded.

**9.2.10.3 Treatment of Grain Direction** — Tensile properties are usually listed according to grain direction in material specifications although some specifications do not indicate a grain direction, which implies isotropy. For MIL-HDBK-5, it is recommended that tension properties be shown for each grain direction. When the material is shown to be isotropic, then the same properties should be shown for each direction.

Compression properties are shown by grain direction similar to tension properties. An example of computing compression properties for heat treatable plate is shown below. The reduced ratio,  $R$ , for longitudinal grain direction, is determined from ratios,  $r$ , formed from paired observations for each lot of material,  $CYS(L)/TYS(LT)$ . Although a longitudinal ratio is being obtained, the divisor is long transverse because this is the specified testing direction (refer to Table 9.2.10). The reduced ratio,  $R$ , for long transverse grain direction, is determined from ratios,  $r$ , formed from paired observations for each lot of material,  $CYS(LT)/TYS(LT)$ . Similarly the reduced ratios,  $R$ , for short transverse grain direction, are determined from ratios,  $r$ , formed from paired observations for each lot of material,  $CYS(ST)/TYS(LT)$ . The ratios,  $r$ , determined in the above manner are used in conjunction with Equation 9.2.10.2(b) to obtain a reduced ratio,  $R$ , for each grain direction. Equating the reduced ratios, design property values are determined from the resulting relationships,

$$R = \frac{F_{cy}(L)}{F_{ty}(LT)}$$

$$\text{or} \quad F_{cy}(L) = RF_{ty}(LT)$$

$$\text{similarly} \quad F_{cy}(LT) = RF_{ty}(LT)$$

$$\text{and} \quad F_{cy}(ST) = RF_{ty}(LT) \quad .$$

Shear and bearing properties are usually shown without reference to grain direction. These properties shall be analyzed according to grain direction, and design properties shall be based on the lowest reduced ratio obtained for longitudinal, long transverse and short transverse (when applicable) directions. An exception is aluminum hand forgings for which shear values shall be presented according to grain direction.

In computing wrought product derived properties, paired ratios representing different grain directions shall not be combined in the determination of a reduced ratio. This is based on the premise that, if the ratio for two paired measurements is to provide an estimate of population mean ratio, then paired measurements must represent the same grain direction as that of the corresponding population means.

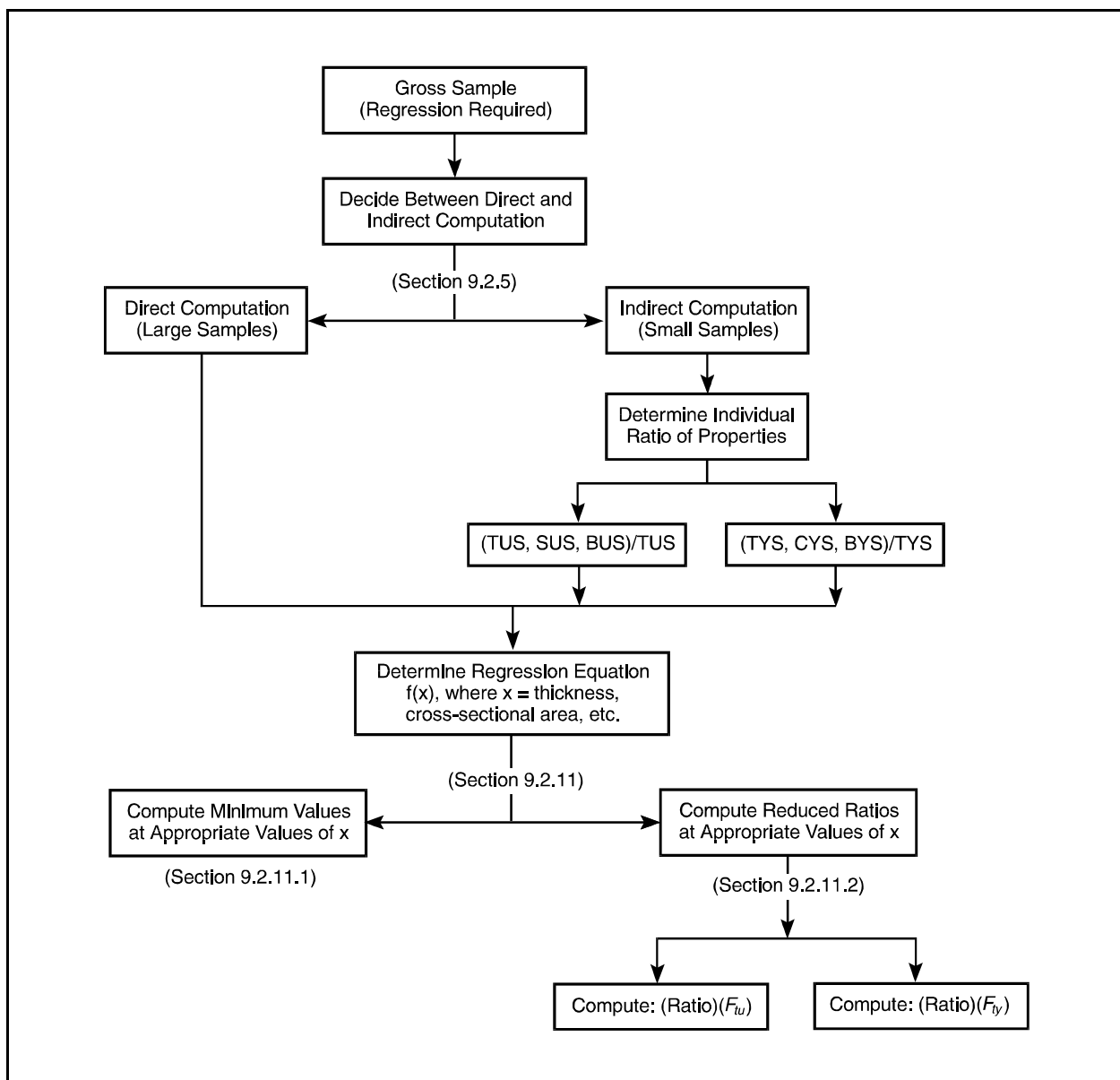
For aluminum die forgings, the longitudinal grain direction is defined as orientations parallel, within  $\pm 15^\circ$ , to the predominate grain flow. The long transverse grain direction is defined as perpendicular, within  $\pm 15^\circ$ , to the longitudinal (predominate) grain direction and parallel, within  $\pm 15^\circ$ , to the parting plane. (Both conditions must be met.) The short transverse grain direction is defined as perpendicular, within  $\pm 15^\circ$ , to the longitudinal (predominate) grain direction and perpendicular, within  $\pm 15^\circ$ , to the parting plane. (Both conditions must be met.) When possible, compression, bearing, and shear tests for three grain directions shall be conducted.

**9.2.10.4 Treatment of Test Specimen Location** — Testing specifications require a change in test specimen location from  $t/2$  for  $\leq 1.500$ - to  $t/4$  for  $> 1.500$ -inch thickness for certain products. Although this change in specimen location may result in  $t/4$  mechanical property ratios which are significantly different from  $t/2$  ratios (different populations), as for aluminum plate, the  $t/2$  and  $t/4$  mechanical property ratios should be treated together for analysis to determine derived properties.

**9.2.10.5 Treatment of Clad Aluminum Alloy Plate** — For clad aluminum alloy plate, 0.500 inch and greater in thickness, tensile properties are determined using round tensile specimens; consequently, tensile properties represent core material. To present design values which represent the average tensile properties across the thickness of the clad plate, an adjustment must be made in the tensile yield and ultimate strength values (S- or A- and B-basis), representing core strength, in the primary test direction(s). These strengths shall be reduced by a factor equal to twice the percentage of the nominal cladding thickness per side. These adjustments in the tensile yield and ultimate strengths shall be made prior to the computation of derived properties, except for short transverse properties. The following footnote, flagged to the appropriate thickness ranges, shall be incorporated into the design allowable table: "These values, except in the ST direction, have been adjusted to represent the average properties across the whole section, including X percent per side nominal cladding thickness."

**9.2.10.6 Proposals** — Proposals presented to the MIL-HDBK-5 Coordination Group should include (1) proposed new or revised table of room-temperature allowables, (2) raw data used in the analysis, and (3) analysis for the proposed design values.

**9.2.11 DETERMINING DESIGN ALLOWABLES BY REGRESSION ANALYSIS** — Procedures used to determine design allowables by regression analysis vary from sample to sample and all involve a number of decisions. These decisions are illustrated by a flowchart in Figure 9.2.11. Before employing regression



### 9.2.11. General procedures for determining design allowables when regression is required.

analysis in the determination of material properties, one must ascertain that the average of property to be regressed varies continuously and linearly or quadratically with some dimensional parameter  $x$  (such as  $x = t$ ,  $1/t$ , etc., where  $t$  is thickness). If the variation of average is attributable to other causes, regression should not be used.

Regression analysis, as described herein, also assumes that residuals are normally distributed about the regression line. Residuals are the differences between observed data values and the values which are predicted by the fitted regression equation. Validity of this normality assumption should be evaluated by performing the Anderson-Darling test presented in Section 9.6.1.2.

The procedure for fitting a regression equation of the form,

$$TUS = a + bx,$$



or

$$(SUS/TUS) = a + bx,$$

or

$$(SUS/TUS) = a + bx + cx^2,$$

to  $n$  data points is described in Section 9.6.3. In addition to estimates for  $a$  and  $b$  (and possibly  $c$ ), this procedure produces two  $F$  statistics. One statistic ( $F_1$ ) tests the significance of regression. The other statistic ( $F_2$ ) tests the adequacy of a linear model for describing the relationship between the material property and the dimensional parameter. If  $F_2$  indicates a lack of fit of the model to the data, a transformation of the data may account for the nonlinearity. If  $F_1$  indicates an insignificant regression, one of the other appropriate analysis techniques, as described in Sections 9.2.7, 9.2.8, 9.2.9, or 9.2.10, should be used.

The steps involved in determining design allowables by regression analysis are as follows:

- (1) Express the property as a simple linear (or quadratic) function of the dimensional parameter and obtain estimates of the coefficient using the least squares regression procedure in Section 9.6.3.1 (or Section 9.6.3.2); for example

$$TUS = a + bx$$

or

$$(SUS/TUS) = a + bx + cx^2$$

where  $x$  is thickness or area and  $a$ ,  $b$ , and  $c$  are constants from the least squares equation.

- (2) Determine the root mean square error of regression ( $s_y$ ). A convenient equation for computing the root mean square error from large quantities of data is shown in Section 9.6.3.1.
- (3) At selected values of  $x$ , determine the allowable for the property by the procedures described in Sections 9.2.11.1 or 9.2.11.2.

The procedures described in this section permit the determination of design allowables only for specific values of  $x$ . When it is desired to present a single allowable covering a range of product thickness (for example, 1.001- to 2.000-inch plate), the lowest allowable for the range should be used. Thus, if  $TUS(LT)$  decreases continuously with increasing thickness, the  $TUS(LT)$  corresponding to  $x = 2.000$  inches would be presented in MIL-HDBK-5. If the decrease is large, a decrease in product thickness interval can be made: for example, by splitting the 1.001- to 2.000-inch interval into two intervals of 1.001 to 1.500 and 1.501 to 2.000 inches.

When the computed design allowable results in a fractional number, actual design allowable value used in room temperature tables is determined in the following manner. Fractions greater than 0.75 usually are raised to the next larger integer while lesser decimal fractions are disregarded.

**9.2.11.1 Direct Computational Procedure** — The direct computational procedure takes into account errors in the model estimates. If a linear relationship has been determined, compute  $T_{99}$  for  $F_{tu}$  at  $x = x_0$ , using Equation [9.2.11.1(a)]

$$T_{99} = a + bx_0 - k'_{99}s_y \quad [9.2.11.1(a)]$$

where  $a$ ,  $b$ , and  $s_y$  are computed in the regression of  $TUS$  data,  $k'_{99}$  is  $\sqrt{(1+\Delta)/n}$  times the 95th percentile of the noncentral  $t$  distribution with noncentrality parameter  $2.326/\sqrt{(1+\Delta)/n}$  and  $n - 2$  degrees of freedom, and

$$\Delta = \frac{(x_o - \Sigma x/n)^2}{\Sigma(x - \Sigma x/n)^2/n} \quad [9.2.11.1(b)]$$

The equation for computing a  $T_{90}$  is similar with  $k'_{90}$  being used in place of  $k'_{99}$ .  $k'_{90}$  is  $\sqrt{(1+\Delta)/n}$  times the 95th percentile of the noncentral t distribution with noncentrality parameter  $1.282/\sqrt{(1+\Delta)/n}$  and  $n - 2$  degrees of freedom, where  $\Delta$  is defined above. If calculation of the appropriate noncentral t percentile is not possible, the following approximations to  $k'_{99}$  and  $k'_{90}$  may be used:

$$k'_{99} = 2.326 + \exp\{0.659 - 0.514 \ln(n) + (0.481 - 1.42/n)\ln(3.71 + \Delta) + 6.58/n\} \quad [9.2.11.1(c)]$$

$$k'_{90} = 1.282 + \exp\{0.595 - 0.508 \ln(n) + (0.486 - 0.986/n)\ln(1.82 + \Delta) + 4.62/n\}. \quad [9.2.11.1(d)]$$

These approximations are accurate to within 1.0 percent for  $n \geq 10$  and  $\Delta \leq 10$ . The square root of  $\Delta$  is the number of standard deviations between  $x_o$  and the arithmetic mean of the  $x$ -values. Thus, a  $\Delta$  value of 10 would represent an extreme  $x_o$  value, which is more than three standard deviations from the mean  $x$ -value.

If a quadratic relationship has been determined, calculate  $T_{99}$  for  $F_{tu}$  at  $x = x_o$  using Equation [9.2.11.1(e)]

$$T_{99} = a + bx_o + cx_o^2 - \left( t_{0.95, n-3, \frac{2.326}{\sqrt{Q}}} \right) \sqrt{Q} s_y \quad [9.2.11.1(e)]$$

where  $a$ ,  $b$ ,  $c$ ,  $s_y$ , and  $Q$  are computed by quadratic regression, and the factor  $t_{0.95, n-3, \frac{2.326}{\sqrt{Q}}}$  is the 95th percentile of the noncentral t distribution with noncentrality parameter  $2.326/\sqrt{Q}$  and  $n-3$  degrees of freedom.

To calculate  $T_{90}$  in the presence of a quadratic relationship, use Equation 9.2.11.1(f)

$$T_{90} = a + bx_o + cx_o^2 - \left( t_{0.95, n-3, \frac{1.282}{\sqrt{Q}}} \right) \sqrt{Q} s_y \quad [9.2.11.1(f)]$$

where  $a$ ,  $b$ ,  $c$ ,  $s_y$ , and  $Q$  are computed by quadratic regression, and the factor  $t_{0.95, n-3, \frac{1.282}{\sqrt{Q}}}$  is the 95th percentile of the noncentral t distribution with noncentrality parameter  $1.282/\sqrt{Q}$  and  $n-3$  degrees of freedom.\*

**9.2.11.2 Reduced Ratio Computational Procedure** — Regression may also be used to determine reduced ratios when an allowable for a property, such as SUS, is computed indirectly from an already established allowable for TUS. The following assumptions are inherent to the reduced ratio procedure:

- (1) The two properties must be distributed according to a bivariate normal distribution.
- (2) The coefficient of variation must be the same for the two properties within particular bounds.
- (3) The average of the ratio of the two properties must be well described by a linear function of the independent variable.

---

\* Note that critical values for the noncentral t distribution are not tabulated in MIL-HDBK-5.

It is also important that paired data be available over the entire range of the dimensional parameter for which there is data for the direct property (TUS). Note that the confidence level associated with allowables computed using the reduced ratio technique may be somewhat below 95 percent.

To compute the reduced ratio at  $x = x_0$ , in the case of linear regression, use Equation [9.2.11.2(a)],

$$\text{Reduced Ratio} = a + bx_0 - (t_{0.95, n-2}) s_y \sqrt{\frac{1+\Delta}{n}} \quad [9.2.11.2(a)]$$

where  $\Delta$  is defined in Equation 9.2.11.1(b),  $a$ ,  $b$ , and  $s_y$  are computed in the regression of SUS/TUS data, and  $t_{0.95, n-2}$  is selected from Table 9.6.4.5 corresponding to  $n-2$  degrees of freedom. The allowable for  $F_{su}$  at  $x_0$  is then computed as the product of the reduced ratio and the established allowable for  $F_{tu}$ :

$$F_{su} = (\text{Reduced Ratio})(F_{tu}) .$$

To compute the reduced ratio at  $x = x_0$ , in the case of quadratic regression, use Equation [9.2.11.2(b)],

$$\text{Reduced Ratio} = a + bx_0 + cx_0^2 - t_{0.95, n-3} s_y \sqrt{Q} \quad [9.2.11.2(b)]$$

where  $a$ ,  $b$ ,  $c$ ,  $s_y$ , and  $Q$  are computed in the quadratic regression of SUS/TUS data, and  $t_{0.95, n-3}$  is selected from Table 9.6.4.5 corresponding to  $n-3$  degrees of freedom.

The allowable for  $F_{su}$  at  $x_0$  is then computed as the product of the reduced ratio and the established allowable for  $F_{tu}$ :

$$F_{su} = (\text{Reduced Ratio})(F_{tu}) .$$

**9.2.12 EXAMPLES OF COMPUTATIONAL PROCEDURES** — It is appropriate to review computational procedures described in Sections 9.2.4 through 9.2.11. To do so, a hypothetical set of input data has been invented. In progressing through this example, flow charts of Figures 9.2.3, 9.2.4, 9.2.6, and 9.2.11 have been followed, and appropriate references to specific sections of the guidelines have been made.

It is assumed for this example that a quantity of quality assurance test data has been amassed, representing one long transverse tensile test per lot, plus other tests from a portion of the lots, at a frequency of one test per lot.

The example problems presented fall into two major categories. Problems I through VII illustrate techniques based on an assumed underlying normal distribution. Problems VIII through XII provide illustrations of techniques based on an assumed underlying three-parameter Weibull distribution.

The input data for these example problems are described below. Because entire data sets (as opposed to means and standard deviations) are required for Problems VIII through XII, the data points for groups (1) through (4) and group (6) have been reported in Tables 9.2.12(a) through (c).

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**Table 9.2.12(a). Group (1) Data Set for Example Problems in Section 9.2.12**

| Group (1) |         |         |         |         |
|-----------|---------|---------|---------|---------|
| 139.608   | 146.534 | 147.442 | 151.229 | 153.792 |
| 140.638   | 146.651 | 147.489 | 151.234 | 153.844 |
| 140.711   | 146.667 | 147.497 | 151.283 | 153.846 |
| 140.988   | 146.699 | 147.653 | 151.323 | 153.855 |
| 141.873   | 146.710 | 147.752 | 151.388 | 153.914 |
| 141.940   | 146.714 | 147.765 | 151.425 | 153.992 |
| 142.105   | 146.766 | 147.785 | 151.428 | 154.021 |
| 142.478   | 146.825 | 147.803 | 151.433 | 154.064 |
| 142.597   | 146.857 | 147.911 | 151.471 | 154.068 |
| 142.694   | 146.876 | 147.942 | 151.557 | 154.077 |
| 143.309   | 146.941 | 147.952 | 151.599 | 154.110 |
| 143.502   | 146.944 | 147.961 | 151.609 | 154.128 |
| 143.620   | 146.970 | 147.980 | 151.628 | 154.149 |
| 143.644   | 147.087 | 148.001 | 151.641 | 154.219 |
| 143.674   | 147.198 | 148.012 | 151.670 | 154.242 |
| 143.720   | 147.284 | 148.029 | 151.785 | 154.297 |
| 143.844   | 147.291 | 148.038 | 151.837 | 154.359 |
| 143.865   | 147.326 | 148.048 | 151.876 | 154.382 |
| 143.867   | 147.334 | 148.049 | 151.962 | 154.508 |
| 143.997   | 147.353 | 148.051 | 151.992 | 154.541 |
| 144.221   | 148.686 | 148.059 | 152.015 | 154.571 |
| 144.320   | 148.691 | 148.074 | 152.037 | 154.781 |
| 144.463   | 148.695 | 148.091 | 152.081 | 154.858 |
| 144.508   | 148.701 | 148.118 | 152.101 | 155.012 |
| 144.612   | 148.714 | 148.122 | 152.143 | 155.077 |
| 144.651   | 148.724 | 148.197 | 152.150 | 155.102 |
| 144.837   | 148.854 | 148.201 | 152.151 | 155.116 |
| 144.864   | 148.868 | 148.236 | 152.157 | 155.231 |
| 144.890   | 148.884 | 148.267 | 152.199 | 155.267 |
| 144.973   | 148.891 | 148.292 | 152.207 | 155.311 |
| 145.076   | 148.919 | 148.304 | 152.270 | 155.336 |
| 145.110   | 148.952 | 148.334 | 152.332 | 155.359 |
| 145.122   | 148.957 | 148.339 | 152.352 | 155.386 |
| 145.165   | 148.982 | 148.355 | 152.448 | 155.422 |
| 145.214   | 149.016 | 148.368 | 152.656 | 155.469 |
| 145.229   | 149.045 | 148.567 | 152.736 | 155.604 |
| 145.270   | 149.103 | 148.584 | 152.802 | 155.627 |
| 145.277   | 149.107 | 148.620 | 152.840 | 155.641 |
| 145.325   | 149.158 | 148.678 | 152.882 | 155.785 |
| 145.399   | 149.180 | 148.684 | 152.907 | 155.823 |
| 145.416   | 149.183 | 150.194 | 152.920 | 155.863 |
| 145.577   | 149.187 | 150.310 | 152.929 | 155.904 |
| 145.600   | 149.321 | 150.315 | 153.007 | 156.078 |
| 145.693   | 149.416 | 150.340 | 153.029 | 156.088 |
| 145.709   | 149.473 | 150.377 | 153.049 | 156.379 |
| 145.721   | 149.571 | 150.415 | 153.102 | 156.616 |
| 145.741   | 149.581 | 150.423 | 153.118 | 156.716 |
| 145.872   | 149.605 | 150.427 | 153.206 | 156.740 |
| 145.921   | 149.605 | 150.459 | 153.279 | 156.924 |
| 145.925   | 149.606 | 150.579 | 153.286 | 157.053 |
| 145.966   | 149.653 | 150.722 | 153.296 | 157.341 |
| 145.978   | 149.707 | 150.731 | 153.298 | 157.357 |
| 146.069   | 149.731 | 150.739 | 153.478 | 157.614 |
| 146.136   | 149.755 | 150.773 | 153.504 | 157.763 |
| 146.220   | 149.798 | 150.830 | 153.543 | 157.980 |
| 146.285   | 149.810 | 151.019 | 153.576 | 158.021 |
| 146.301   | 149.812 | 151.042 | 153.648 | 158.154 |
| 146.367   | 149.894 | 151.075 | 153.695 | 158.518 |
| 146.479   | 149.996 | 151.111 | 153.707 | 159.377 |
| 146.500   | 150.124 | 151.211 | 153.715 | 162.717 |

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**Table 9.2.12(b). Group (3) Data Set for Example Problems in Section 9.2.12**

| Group (3) |         |         |         |         |
|-----------|---------|---------|---------|---------|
| 121.438   | 126.276 | 128.823 | 131.254 | 133.841 |
| 121.614   | 126.342 | 128.846 | 131.325 | 133.843 |
| 121.757   | 126.388 | 128.868 | 131.388 | 133.893 |
| 122.077   | 126.430 | 128.966 | 131.439 | 133.898 |
| 122.109   | 126.449 | 128.983 | 131.444 | 133.912 |
| 122.494   | 126.535 | 128.989 | 131.469 | 133.922 |
| 122.503   | 126.606 | 129.029 | 131.477 | 133.934 |
| 122.543   | 126.665 | 129.035 | 131.677 | 133.948 |
| 122.632   | 126.668 | 129.052 | 131.690 | 134.089 |
| 123.082   | 126.673 | 129.083 | 131.731 | 134.134 |
| 123.101   | 126.696 | 129.117 | 131.754 | 134.179 |
| 123.193   | 126.727 | 129.136 | 131.786 | 134.194 |
| 123.238   | 126.822 | 129.148 | 131.808 | 134.249 |
| 123.296   | 126.863 | 129.321 | 131.816 | 134.339 |
| 123.474   | 126.877 | 129.413 | 131.906 | 134.351 |
| 123.527   | 126.907 | 129.434 | 131.975 | 134.361 |
| 123.616   | 126.919 | 129.546 | 131.977 | 134.689 |
| 123.694   | 126.972 | 129.560 | 132.138 | 134.747 |
| 123.755   | 126.999 | 129.596 | 132.189 | 134.776 |
| 123.770   | 127.114 | 129.654 | 132.223 | 134.779 |
| 123.825   | 127.140 | 129.709 | 132.282 | 134.873 |
| 124.025   | 127.203 | 129.715 | 132.286 | 134.874 |
| 124.055   | 127.300 | 129.784 | 132.296 | 134.883 |
| 124.083   | 127.322 | 129.788 | 132.380 | 134.890 |
| 124.105   | 127.337 | 129.891 | 132.393 | 134.969 |
| 124.121   | 127.383 | 129.899 | 132.436 | 135.027 |
| 124.171   | 127.387 | 129.938 | 132.470 | 135.064 |
| 124.176   | 127.420 | 129.940 | 132.482 | 135.191 |
| 124.223   | 127.474 | 130.007 | 132.511 | 135.499 |
| 124.373   | 127.579 | 130.020 | 132.514 | 135.513 |
| 124.681   | 127.607 | 130.070 | 132.558 | 135.518 |
| 124.691   | 127.677 | 130.206 | 132.564 | 135.532 |
| 124.718   | 127.695 | 130.225 | 132.595 | 135.545 |
| 124.778   | 127.710 | 130.237 | 132.703 | 135.661 |
| 124.793   | 127.741 | 130.351 | 132.718 | 135.754 |
| 124.920   | 127.761 | 130.427 | 132.762 | 135.836 |
| 124.934   | 127.811 | 130.457 | 132.805 | 135.920 |
| 125.000   | 127.841 | 130.499 | 132.849 | 135.921 |
| 125.018   | 127.859 | 130.526 | 132.851 | 135.944 |
| 125.070   | 127.859 | 130.528 | 132.869 | 136.027 |
| 125.070   | 127.889 | 130.586 | 132.952 | 136.030 |
| 125.150   | 127.946 | 130.599 | 133.024 | 136.032 |
| 125.152   | 128.010 | 130.624 | 133.031 | 136.050 |
| 125.247   | 128.016 | 130.684 | 133.049 | 136.112 |
| 125.279   | 128.153 | 130.710 | 133.096 | 136.149 |
| 125.295   | 128.203 | 130.765 | 133.159 | 136.154 |
| 125.350   | 128.288 | 130.772 | 133.166 | 136.160 |
| 125.370   | 128.309 | 130.797 | 133.224 | 136.204 |
| 125.433   | 128.323 | 130.895 | 133.438 | 136.217 |
| 125.531   | 128.332 | 131.003 | 133.441 | 136.348 |
| 125.535   | 128.341 | 131.008 | 133.508 | 136.855 |
| 125.714   | 128.452 | 131.040 | 133.581 | 136.883 |
| 125.717   | 128.640 | 131.103 | 133.592 | 137.087 |
| 125.801   | 128.672 | 131.104 | 133.595 | 137.115 |
| 125.915   | 128.699 | 131.125 | 133.622 | 137.163 |
| 126.083   | 128.719 | 131.158 | 133.683 | 137.484 |
| 126.128   | 128.723 | 131.175 | 133.749 | 137.618 |
| 126.129   | 128.752 | 131.176 | 133.763 | 137.653 |
| 126.194   | 128.795 | 131.192 | 133.768 | 138.335 |
| 126.276   | 128.819 | 131.195 | 133.774 | 139.141 |

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**Table 9.2.12(c). Groups (2), (4), and (6) Data Sets for Example Problems in Section 9.2.12**

| <u>Group (2)</u> | <u>Group (4)</u> | <u>Group (6)</u> |         |
|------------------|------------------|------------------|---------|
| 141.914          | 120.487          | 135.373          | 145.061 |
| 143.980          | 122.271          | 135.500          | 145.072 |
| 145.110          | 124.167          | 135.775          | 145.082 |
| 145.681          | 124.622          | 136.450          | 145.082 |
| 145.829          | 124.672          | 137.114          | 145.331 |
| 145.919          | 125.280          | 137.241          | 145.460 |
| 145.981          | 125.862          | 137.900          | 145.606 |
| 148.412          | 126.332          | 138.916          | 145.626 |
| 148.694          | 128.860          | 139.158          | 145.754 |
| 148.772          | 129.158          | 139.307          | 145.785 |
| 148.831          | 129.179          | 139.626          | 145.802 |
| 148.965          | 130.238          | 139.827          | 145.876 |
| 149.197          | 130.782          | 139.839          | 146.091 |
| 149.761          | 130.985          | 140.022          | 146.096 |
| 150.150          | 131.612          | 140.461          | 146.159 |
| 151.472          | 131.642          | 140.957          | 146.302 |
| 151.746          | 132.129          | 141.083          | 146.303 |
| 152.089          | 132.147          | 141.149          | 146.447 |
| 152.564          | 132.812          | 141.435          | 146.797 |
| 152.737          | 133.388          | 141.473          | 146.937 |
| 152.798          | 133.716          | 141.518          | 146.967 |
| 153.857          | 134.127          | 141.582          | 147.149 |
| 153.930          | 135.787          | 141.592          | 147.224 |
| 154.012          | 135.836          | 141.731          | 147.305 |
| 154.024          | 136.235          | 141.937          | 147.500 |
| 154.153          | 136.770          | 142.125          | 147.657 |
| 155.637          | 137.068          | 142.138          | 147.675 |
| 157.118          | 137.901          | 142.298          | 147.833 |
| 162.241          | 137.919          | 142.441          | 148.084 |
| 164.426          | 138.017          | 142.785          | 148.556 |
|                  |                  | 142.838          | 148.708 |
|                  |                  | 142.859          | 148.954 |
|                  |                  | 143.141          | 148.988 |
|                  |                  | 143.180          | 149.082 |
|                  |                  | 143.397          | 149.123 |
|                  |                  | 143.426          | 149.590 |
|                  |                  | 143.444          | 149.831 |
|                  |                  | 143.558          | 149.974 |
|                  |                  | 143.722          | 150.325 |
|                  |                  | 143.886          | 151.484 |
|                  |                  | 144.200          | 151.523 |
|                  |                  | 144.276          | 151.605 |
|                  |                  | 144.313          | 152.086 |
|                  |                  | 144.418          | 152.467 |
|                  |                  | 144.465          | 152.646 |
|                  |                  | 144.650          | 152.852 |
|                  |                  | 144.672          | 153.164 |
|                  |                  | 144.847          | 153.675 |
|                  |                  | 144.901          | 155.492 |
|                  |                  | 144.924          | 157.944 |

INFORMATION FOR EXAMPLE PROBLEMS

Material Identification: Alloy X sheet, annealed.  
Specified Testing Direction: Long Transverse (LT)  
Specified Properties:  
    ≤ 0.125 inch —  
     $F_{tu}$  (LT) = 140 ksi,  $F_{ty}$  (LT) = 115 ksi;  
    0.126-0.249 inch —  
     $F_{tu}$  (LT) = 135 ksi,  $F_{ty}$  (LT) = 110 ksi.  
Available Test Results:

- Group (1). 300 observations of TUS(LT) for thickness range 0.020-0.125 inch from Supplier A; no variation with thickness. Go to Problems I, III, VIII, and X.
- Group (2). 30 observations of TUS(LT) for thickness range 0.020-0.125 inch from Supplier B; no variation with thickness. Go to Problems I and VIII.
- Group (3). 300 observations of TYS(LT) for thickness range 0.020-0.125 inch from Supplier A; no variation with thickness. Go to Problems II and IX.
- Group (4). 30 observations of TYS(LT) for thickness range 0.020-0.125 inch from Supplier B; no variation with thickness. Go to Problems II and IX.
- Group (5). 30 observations of SUS(LT) for thickness range 0.020-0.249 inch; apparent decrease in SUS(LT) on increasing thickness; observations may be paired with TUS(LT) if desired. Go to Problem VII.
- Group (6). 100 observations of TUS(LT) for thickness range 0.126-0.249 inch; no variation with thickness. Go to Problems III and X.

EXAMPLE PROBLEMS BASED ON AN  
ASSUMED UNDERLYING NORMAL DISTRIBUTION\*

PROBLEM I

*Should the data in Groups (1) and (2) be combined?*

Other Information: Neither property varies with thickness. Sample statistics are:

| Subpopulation                      | n   | $\overline{X}$ , ksi | s, ksi |
|------------------------------------|-----|----------------------|--------|
| Group (1) TUS (LT), 0.020 to 0.125 | 300 | 150.0                | 4.00   |
| Group (2) TUS (LT), 0.020 to 0.125 | 30  | 151.0                | 5.00   |

(Refer to Sections 9.2.4 and 9.6.2.)

\* The statistical tests described in Problems I through III apply specifically to the case where normality can be assumed. The more general Anderson-Darling procedure described in Problem IV can be applied to normal as well as nonnormal distributions.

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*Prob. I—Step 1. Test to determine whether the variances differ significantly:*

$$F = (s_1)^2/(s_2)^2 = (4.00)^2/(5.00)^2 = 0.64$$

Degrees of freedom, numerator =  $n_1 - 1 = 300 - 1 = 299$ .

Degrees of freedom, denominator =  $n_2 - 1 = 30 - 1 = 29$ .

$$F_{0.975}(299,29df) \text{ from Table 9.6.4.4} = 1.87 \text{ (approximately)}$$

$$1/F_{0.975}(29,299df) = 1/1.69 = 0.59$$

Since the computed value of  $F(0.64)$  lies within the 0.95 confidence interval (0.59 to 1.87), conclude the variances do not differ significantly.

*Prob. I—Step 2. Test to determine whether the averages differ significantly:*

Difference between averages  $D_{\bar{X}} = 150.0 - 151.0 = 1.0 \text{ ksi}$

$$u = t_{0.975} S_p \sqrt{\frac{n_1 + n_2}{n_1 n_2}}$$

Degrees of freedom =  $n_1 + n_2 - 2 = 300 + 30 - 2 = 328$

$t_{0.975}$  (328 df) from Table 9.6.4.5 = 1.969

$$S_p = \sqrt{\frac{(n_1 - 2) s_1^2 + (n_2 - 1) s_2^2}{n_1 + n_2 - 2}} = \sqrt{\frac{(300 - 1)(4.00)^2 + (30 - 1)(5.00)^2}{300 + 30 - 2}} = 4.10 \text{ ksi}$$

$$u = 1.969 \times 4.10 \times \sqrt{\frac{n_1 + n_2}{n_1 n_2}} = 1.969 \times 4.10 \times \sqrt{\frac{300 + 30}{300 \times 30}} = 1.54 \text{ ksi}$$

Since the observed difference between the averages,  $\bar{X}$  (1.0 ksi), is less than  $u$  (1.54 ksi), conclude the averages do not differ significantly.

*Prob. I—Step 3. Since there is no reason to conclude that the subpopulations represented by Groups (1) and (2) do not belong to the same population, combine these groups.*

| Subpopulation                                        | $\bar{n}$ | $\bar{X}$ , ksi | $s$ , ksi |
|------------------------------------------------------|-----------|-----------------|-----------|
| Group (1&2) TUS (LT), 0.020-0.125, Suppliers A and B | 330       | 150.1           | 4.10      |

Go to Problem IV.



PROBLEM II

Should the data in Groups (3) and (4) be combined?

Other Information: Neither property varies with thickness. Sample statistics are:

| Subpopulation                               | n   | $\overline{X}$ , ksi | s, ksi |
|---------------------------------------------|-----|----------------------|--------|
| Group (3) TYS (LT), 0.020-0.125, Supplier A | 300 | 130.0                | 4.00   |
| Group (4) TYS (LT), 0.020-0.125, Supplier B | 30  | 131.0                | 5.00   |

The steps involved in this problem are identical to those in Problem I and similar conclusions were obtained from the input, namely, that Groups (3) and (4) should be combined. The sample statistics for the combined groups are:

| Subpopulation                                        | n   | $\overline{X}$ , ksi | s, ksi |
|------------------------------------------------------|-----|----------------------|--------|
| Group (3&4) TYS (LT), 0.020-0.125, Suppliers A and B | 330 | 130.1                | 4.10   |

Go to Problem V.

PROBLEM III

Should the data in Groups (1) and (6) be combined?

Other Information: Neither property varies with thickness. Sample statistics are:

| Subpopulation                   | n   | $\overline{X}$ , ksi | s, ksi |
|---------------------------------|-----|----------------------|--------|
| Group (1) TUS (LT), 0.020-0.125 | 300 | 150.0                | 4.00   |
| Group (6) TUS (LT), 0.126-0.249 | 100 | 145.0                | 4.47   |

Prob. III—Step 1. Test to determine whether the variances differ significantly.

$$F = (s_1)^2/(s_2)^2 = (4.00)^2/(4.47)^2 = 0.80$$

$$\text{Degrees of freedom, numerator} = n_1 - 1 = 300 - 1 = 299.$$

$$\text{Degrees of freedom, denominator} = n_6 - 1 = 100 - 1 = 99.$$

$$F_{0.975}(299,99\text{df}) \text{ from Table 9.6.4.4} = 1.46 \text{ (approximately)}$$

$$1/F_{0.975}(99,299\text{df}) = 1/1.43 = 0.700.$$

Since the computed value of F (0.80) lies within the 0.95 confidence interval (0.700 to 1.46), conclude that the variances do not differ significantly.

*Prob. III—Step 2. Test to determine whether the averages differ significantly.*

Difference between averages,  $D_{\bar{x}} = (150.0 - 145.0) = 5.0$  ksi

$$u = t_{0.975} S_p \sqrt{\frac{n_1 + n_6}{n_1 n_6}}$$

Degrees of freedom =  $n_1 + n_6 - 2 = 300 + 100 - 2 = 398$ .

$t_{0.975}$  (398 df) from Table 9.6.4.5 = 1.968.

$$S_p = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_6 - 1)s_6^2}{n_1 + n_6 - 2}} = \sqrt{\frac{(300 - 1)(4.00)^2 + (100 - 1)(4.47)^2}{300 + 100 - 2}} = 4.20 \text{ ksi}$$

$$u = (1.968)(4.20) \sqrt{\frac{n_1 + n_6}{n_1 n_6}} = (1.968)(4.20) \sqrt{\frac{300 + 100}{(300)(100)}} = 0.95 \text{ ksi}$$

Since the observed difference between the averages  $D_{\bar{x}}$  (5.0 ksi) is greater than  $u$  (0.95 ksi), conclude that the averages differ significantly and that the subpopulations represented by Groups (1) and (6) do not belong to the same population.

*Prob. III—Step 3. Do not combine the sample statistics for these groups.*

Go to Problem VI.

## PROBLEM IV

*What computational method should be used for the combined observations of Groups (1) and (2)?*

Other Information: This property does not vary with thickness. Sample statistics for the combined observations are:

| Population                        | n   | $\bar{X}$ , ksi | s, ksi |
|-----------------------------------|-----|-----------------|--------|
| Group (1&2) TUS (LT), 0.020-0.125 | 330 | 150.1           | 4.10   |

Form of the distribution has not been determined. (Refer to Sections 9.2.5, 9.2.6, 9.2.7, and 9.6.1.)

The sample is large enough to permit direct computation of A and B values. Consequently, the computational method will be determined by whether or not the observations are normally distributed.

*Prob. IV—Step 1. Test to determine whether the distribution is normal.* The Anderson-Darling test for normality will be employed in this example (see 9.6.1.2). Use the formula:

$$Z_{(i)} = (X_{(i)} - 150.1)/4.10,$$

the values of  $Z_{(1)}, \dots, Z_{(330)}$  must be calculated. The first three values are  $Z_{(1)} = -2.56$ ,  $Z_{(2)} = -2.31$ , and  $Z_{(3)} = -2.29$ . Now  $F_0(Z_{(1)}), \dots, F_0(Z_{(330)})$  must be calculated by finding the area under the standard normal curve to the left of each  $Z$  value. The first three values are  $F_0(Z_{(1)}) = 0.0052$ ,  $F_0(Z_{(2)}) = 0.0104$ , and  $F_0(Z_{(3)}) = 0.0110$ .

The Anderson-Darling test statistic is then calculated as

$$AD = \left[ \sum_{i=1}^{330} \frac{1 - 2i}{330} [\ln(F_0(Z_{(i)})) + \ln(1 - F_0(Z_{(331-i)}))] \right] - 330 = 0.693.$$

The computed value of the test statistic is then compared to the critical value

$$0.750 = 0.752/[1 + 0.75/330 + 2.25/(330)^2]$$

Since the computed value of 0.693 is less than the critical value of 0.750, the hypothesis of normality is not rejected.

*Prob. IV—Step 2. Compute  $F_{tu}(LT)$ , 0.020 to 0.125, for Alloy X, using procedures for the normal distribution.*

| Population                           | n   | $\bar{X}$ , ksi | s, ksi |
|--------------------------------------|-----|-----------------|--------|
| Group (1&2) TUS (LT), 0.020 to 0.125 | 330 | 150.1           | 4.10   |

$$k_A = 2.512$$

$$k_B = 1.410$$

$$F_{tu}(LT), A \text{ basis} = X - k_A s = 150.1 - 2.512 \times 4.10 = 139.8 \text{ or } 140 \text{ ksi (rounded per Section 9.2.10.2)}$$

$$F_{tu}(LT), B \text{ basis} = X - k_B s = 150.1 - 1.410 \times 4.10 = 144.3 \text{ or } 144 \text{ ksi (rounded per Section 9.2.10.2)}$$

### PROBLEM V

*What computational method should be used for the combined observations of Groups (3) and (4)?*

Other Information: This property does not vary with thickness. Sample statistics for the combined observations are:

| Population                         | n   | $\bar{X}$ , ksi | s, ksi |
|------------------------------------|-----|-----------------|--------|
| Group (3&4) TYS(LT), 0.20 to 0.125 | 330 | 130.1           | 4.10   |

Form of the distribution has not been determined. (Refer to Sections 9.2.5, 9.2.6, 9.2.9, and 9.6.1.)

The sample is large enough to permit direct computation of A and B-values. Consequently, the computational method to be used will be determined by whether or not the observations are normally distributed.

*Prob. V—Step 1. Test to determine whether or not the distribution is normal.* The value of the Anderson-Darling test statistic for normality is 1.315 for Group (3&4). Since 1.315 is greater than the critical value of 0.750, the underlying distribution cannot be assumed to be normal. Thus, the underlying distribution will be treated as a three-parameter Weibull or an unknown distributional form.

*Prob. V—Step 2. Compute  $F_{ty}(LT)$ , 0.020-0.125, using procedures for the unknown distribution.* This procedure requires the ranking of observations from lowest to highest. Referring to Table 9.6.4.2, it is found that for a sample size of 330, the lowest observation (rank = 1) is an A-value and the 24th lowest (rank = 24) is a B-value. The 24 lowest observations are shown below:

| Rank | TYS, ksi | Rank | TYS, ksi | Rank | TYS, ksi |
|------|----------|------|----------|------|----------|
| 1    | 120.5    | 9    | 122.5    | 17   | 123.5    |
| 2    | 121.4    | 10   | 122.5    | 18   | 123.5    |
| 3    | 121.6    | 11   | 122.6    | 19   | 123.6    |
| 4    | 121.8    | 12   | 123.1    | 20   | 123.7    |
| 5    | 122.1    | 13   | 123.1    | 21   | 123.8    |
| 6    | 122.1    | 14   | 123.2    | 22   | 123.8    |
| 7    | 122.3    | 15   | 123.2    | 23   | 123.8    |
| 8    | 122.5    | 16   | 123.3    | 24   | 124.0    |

Consequently, from these data the following allowables have been computed for Alloy X:

$F_{ty}(LT)$ , A-basis = 120.5 ksi.  
 $F_{ty}(LT)$ , B-basis = 124.0 ksi.

PROBLEM VI

*What computational procedure should be used for the observations in Group (6)?* The data in Group (6) represent a borderline situation. They cannot be combined with data for lesser thicknesses because there is significant difference between the TUS(LT) averages for the two thickness ranges, as shown in Problem III. The sample size is just barely adequate for direct computation if the distribution is found to be normal. If the distribution is not normal, the properties for this product would be presented on an S-basis, pending the accumulation of more data. The test for normality would be conducted as described in Problem IV, and will not be illustrated here.

PROBLEM VII

*What computational procedure should be used for the observations in Group (5)?*

Other Information: SUS(LT) decreases with increasing thickness, while TUS(LT) does not vary with thickness. Sample statistics are:

| Population                        | n  | $\overline{X}$ , ksi | s, ksi |
|-----------------------------------|----|----------------------|--------|
| Group (5) SUS(LT), 0.020 to 0.249 | 30 | not determined       |        |

The sample size for these data is too small to permit direct computation. Thus, the procedure that should be used is indirect computation by pairing observations of SUS(LT) with observations of TUS(LT). Also, since a thickness effect was suspected in the original data, a regression against thickness should be made and checked for significance. (Refer to Sections 9.2.10, 9.2.11, and 9.6.3.)

Prob. VII—Step 1. Pair SUS(LT) with TUS(LT).

Ratios of SUS(LT)/TUS(LT) are as follows:

| SUS(LT)/TUS(LT) | Thickness,<br>inch | SUS(LT)/TUS(LT) | Thickness,<br>inch |
|-----------------|--------------------|-----------------|--------------------|
| 0.700           | 0.020              | 0.640           | 0.090              |
| 0.680           | 0.020              | 0.650           | 0.090              |
| 0.660           | 0.020              | 0.660           | 0.090              |
| 0.660           | 0.030              | 0.630           | 0.100              |
| 0.670           | 0.030              | 0.650           | 0.100              |
| 0.680           | 0.030              | 0.670           | 0.100              |
| 0.650           | 0.040              | 0.640           | 0.150              |
| 0.670           | 0.040              | 0.630           | 0.150              |
| 0.690           | 0.040              | 0.620           | 0.150              |
| 0.650           | 0.060              | 0.610           | 0.180              |
| 0.660           | 0.060              | 0.630           | 0.180              |
| 0.670           | 0.060              | 0.650           | 0.180              |
| 0.640           | 0.070              | 0.600           | 0.240              |
| 0.660           | 0.070              | 0.610           | 0.240              |
| 0.680           | 0.070              | 0.620           | 0.240              |

Prob. VII—Step 2. Determine regression equation in the form  $[SUS(LT)/TUS(LT)]' = r' = a + bx$ , where  $x$  = thickness, using least-squares techniques. (Note—in this example, the letter  $r$ , rather than  $y$ , is used to denote the dependent variable and the prime (') is used to indicate that the ratio is determined by regression.) The following sums were obtained from analysis of the ratios plotted in Figure 9.2.12.

Number of ratios,  $n = 30$

|              |           |                    |            |
|--------------|-----------|--------------------|------------|
| $\sum(x)$    | = 2.94    | $(\sum r)^2$       | = 381.4209 |
| $\sum(x^2)$  | = 0.4260  | $(\sum x)(\sum r)$ | = 57.4182  |
| $\sum(r)$    | = 19.53   | $S_{xx}$           | = 0.1379   |
| $\sum(r^2)$  | = 12.7319 | $S_{xr}$           | = 0.0416   |
| $\sum(xr)$   | = 1.8723  | $S_{rr}$           | = 0.0179   |
| $(\sum x)^2$ | = 8.6436  |                    |            |

Referring to the equations presented in Section 9.6.3:

Slope,  $b = \frac{S_{xr}}{S_{xx}} = \frac{-0.0416}{0.1379} = -0.302$

Intercept,  $a = \frac{\sum r - b(\sum x)}{n} = \frac{19.53 - (-0.302)(2.94)}{30} = 0.6806$

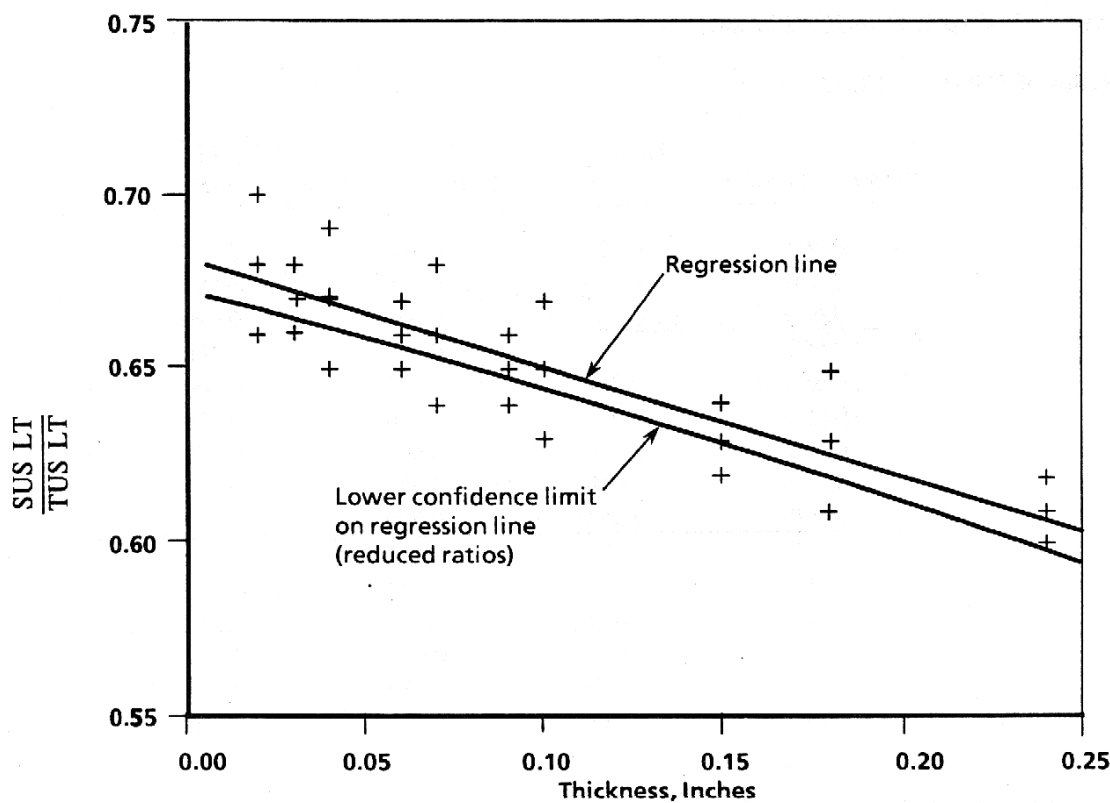


Figure 9.2.12. Ratios of input data for Problem VII.

Standard Error of Estimate,

$$S_r \dots \sqrt{\frac{S_{rr} \dots b^2 S_{xx}}{(n \dots 2)}} \\ \dots \sqrt{\frac{0.0179 \dots (\dots 0.302)^2 (0.1379)}{(30 \dots 2)}} \\ E \dots 0.014$$

The equation of the regression line is  $r \dots = 0.6806 - 0.302x$ .

The regression line is shown in Figure 9.2.12.

*Prob. VII—Step 3. Perform an analysis of variance to check the significance and linearity of the regression.*

Since there are 30 ratios, the analysis of variance approach rather than the method involving the computation of confidence limits on the slope term can be used to evaluate linearity.

The only information missing from Step 2 required for the analysis of variance is the values of T, or the summed values of r for each x. They are as follows:

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| $x_1$ | $T_1$ | $x_1$ | $T_1$ |
|-------|-------|-------|-------|
| 0.02  | 2.04  | 0.09  | 1.95  |
| 0.03  | 2.01  | 0.10  | 1.95  |
| 0.04  | 2.01  | 0.15  | 1.89  |
| 0.06  | 1.98  | 0.18  | 1.89  |
| 0.07  | 1.98  | 0.24  | 1.83  |

Using these values, the analysis of variance, which is illustrated in Section 9.6.3.2, can be completed as follows:

| Source of Variation | Sum of Squares | Degrees of Freedom | Mean Squares | $F_{calc}$ |
|---------------------|----------------|--------------------|--------------|------------|
| Regression          | 0.0126         | 1                  | 0.0126       | 63.0       |
| Error               | 0.0053         | 28                 | 0.0002       |            |
| <hr/>               |                |                    |              |            |
| Lack of Fit         | 0.0004         | 8                  | 0.00005      | 0.208      |
| Pure Error          | 0.0049         | 20                 | 0.00024      |            |
| <hr/>               |                |                    |              |            |
| Total               | 0.0179         | 29                 |              |            |

The second calculated F statistic of 0.208 with  $k - 2 = 8$  and  $n - k = 20$  degrees of freedom is less than the value of 2.45 from Table 9.6.4.9 corresponding to 8 numerator and 20 denominator degrees of freedom. Thus, the deviation from linearity is not significant. The first F statistic of 63.0 with 1 and 28 degrees of freedom is greater than the value of 4.20 from Table 9.6.4.9 corresponding to 1 numerator and 28 denominator degrees of freedom, so the slope of the regression is found to be significantly different from zero.

*Prob. VII—Step 4. Compute the reduced ratio for SUS(LT)/TUS(LT).* In performing this step, the reduced ratio will be computed at each of four thicknesses (0.020, 0.062, 0.125, and 0.249 inch). This is done by determining the lower confidence limit for the regression line at the desired thicknesses, using the equation from Section 9.2.11. The computation will be worked in detail for  $x_0 = 0.020$  inch:

$$\text{Reduced ratio} = [\text{SUS(LT)/TUS(LT)}]' - t_{0.95} s'_r \sqrt{\frac{1}{n} + \frac{(x_0 - \Sigma x/n)^2}{(\Sigma x^2) - (\Sigma x)^2/n}}$$

$$[\text{SUS(LT)/TUS(LT)}]' = r' = 0.681 - 0.302x_0 \text{ (from Step 2, Problem VII)}$$

$$= 0.681 - 0.302 \times 0.020 = 0.6746.$$

$$t_{0.95} \text{ (for } n - 2 = 30 - 2 = 28 \text{ degrees of freedom)} = 1.701 \text{ (from Table 9.6.4.5)}$$

$$s'_r = 0.014 \text{ (from Step 2)}$$

$$\sqrt{\frac{1}{n} + \frac{(x_0 - \Sigma x/n)^2}{(\Sigma x^2) - (\Sigma x)^2/n}} = \sqrt{\frac{1}{30} + \frac{(0.020 - 2.94/30)^2}{0.4260 - 8.6436/30}} = 0.2783$$

Reduced ratio = 0.6746 - 1.701 x 0.014 x 0.2783 = 0.668.

The corresponding ratios for the other thicknesses are tabulated in Step 5. See Figure 9.2.12 for lower confidence limit curve.

*Prob. VII—Step 5. Compute  $F_{su}$ .* This computation will be illustrated for a thickness of 0.020 inch, using the reduced ratio from Step 4.

From Problem IV,

|                        |   |                              |
|------------------------|---|------------------------------|
| $F_{tu}(LT)$           | = | 140 ksi (A-basis)            |
| $F_{tu}(LT)$           | = | 144 ksi (B-basis)            |
| $F_{su}(LT)$           | = | Reduced Ratio x $F_{tu}(LT)$ |
| $F_{su}(LT)$ (A-Basis) | = | 0.668 x 140 = 93.5 ksi       |
| $F_{su}(LT)$ (B-Basis) | = | 0.668 x 144 = 96.2 ksi.      |

For the four thicknesses listed,

|         |               | $F_{su}(LT)$ , ksi |         |         |
|---------|---------------|--------------------|---------|---------|
| t, inch | Reduced Ratio | A-basis            | B-basis | S-basis |
| 0.020   | 0.668         | 93.5               | 96.2    | ...     |
| 0.062   | 0.657         | 92.0               | 94.6    | ...     |
| 0.125   | 0.638         | 89.3               | 91.9    | ...     |
| 0.249   | 0.595         | ...                | ...     | 80.3    |

Since  $F_{su}$  is shown to decrease with increasing thickness, only the lowest value applicable to the range should be presented in MIL-HDBK-5. By dividing the 0.020 to 0.125 thickness range into two ranges, a somewhat higher  $F_{su}(LT)$  value may be presented for thinner material as shown below.

The results of the computations in Problems I through VII have produced the following results (fractions greater than 0.75 are raised to the next higher ksi, while less fractions are dropped):

|                    |     | Thickness, inch |             |     |             |             |
|--------------------|-----|-----------------|-------------|-----|-------------|-------------|
|                    |     | <0.020          | 0.020-0.062 |     | 0.063-0.125 | 0.126-0.249 |
| Basis              | S   | A               | B           | A   | B           | S           |
| $F_{tu}(LT)$ , ksi | 140 | 140             | 144         | 140 | 144         | 135         |
| $F_{ty}(LT)$ , ksi | 115 | 120             | 124         | 120 | 124         | 110         |
| $F_{su}$ , ksi     | ... | 92              | 94          | 89  | 92          | 80          |

Since SUS(LT) data were not available for thickness <0.020 inch, a design value is not presented for this range.



# EXAMPLE PROBLEMS BASED ON AN ASSUMED UNDERLYING THREE-PARAMETER WEIBULL DISTRIBUTION

## PROBLEM VIII

*Should the data in Groups (1) and (2) be combined?*

Other Information. Neither property varies with thickness. (Refer to Sections 9.2.4 and 9.6.2.)

The k-sample Anderson-Darling test will be employed in this example (see Section 9.6.2.5) to determine whether or not the data in Groups (1) and (2) should be combined. There are 328 distinct values in the combined data from both groups and these are ordered from least to greatest to obtain  $Z_{(1)}, \dots, Z_{(328)}$ . All values of  $h_j$  are equal to 1 except for  $h_{34} = 2$  and  $h_{160} = 2$ . Taking Group (2) to be the first ( $A_1$ )-sample and Group (1) to be the second ( $A_2$ )-sample, the first 24 Z-values are listed in the table below with the corresponding H- and F-values.

| $Z_j$  | $H_j$ | $F_{ij}$ | $Z_j$  | $H_j$ | $F_{ij}$ | $Z_j$  | $H_j$ | $F_{ij}$ |
|--------|-------|----------|--------|-------|----------|--------|-------|----------|
| 139.61 | 0.5   | 0        | 142.48 | 8.5   | 1        | 143.72 | 16.5  | 1        |
| 140.64 | 1.5   | 0        | 142.60 | 9.5   | 1        | 143.84 | 17.5  | 1        |
| 140.71 | 2.5   | 0        | 142.69 | 10.5  | 1        | 143.86 | 18.5  | 1        |
| 140.99 | 3.5   | 0        | 143.31 | 11.5  | 1        | 143.87 | 19.5  | 1        |
| 141.87 | 4.5   | 0        | 143.50 | 12.5  | 1        | 143.98 | 20.5  | 1.5      |
| 141.91 | 5.5   | 0.5      | 143.62 | 13.5  | 1        | 144.00 | 21.5  | 2        |
| 141.94 | 6.5   | 1        | 143.64 | 14.5  | 1        | 144.22 | 22.5  | 2        |
| 142.10 | 7.5   | 1        | 143.67 | 15.5  | 1        | 144.32 | 23.5  | 2        |

The k-sample Anderson-Darling test statistic is calculated as

$$ADK = \frac{1}{330(1)} \left[ \frac{1}{300} \sum_{j=1}^{328} h_j \frac{(330F_{1j} - 300H_j)^2}{H_j(330 - H_j) - 330h_j/4} + \frac{1}{30} \sum_{j=1}^{328} h_j \frac{(330F_{2j} - 30H_j)^2}{H_j(330 - H_j) - 330h_j/4} \right] = 0.821$$

The computed value of the test statistic is compared to the critical value of

$$2.488 = 1 + 0.759 \left( 1.645 + \frac{0.678}{\sqrt{1}} - \frac{0.362}{1} \right) .$$

Since the computed value of 0.821 is less than the critical value of 2.488, the hypothesis that the populations from which these groups were drawn are identical is not rejected. Thus Groups (1) and (2) will be combined for the computation of allowables.

Go to Problem XI.

### PROBLEM IX

*Should the data in Groups (3) and (4) be combined?*

Other Information: Neither property varies with thickness. (Refer to Sections 9.2.4 and 9.6.2.)

The value of the k-sample Anderson-Darling test statistic for Groups (3) and (4) is 2.147. Since 2.147 is less than the critical value of 2.488, the hypothesis that the populations from which these groups were drawn are identical is not rejected. Thus, Groups (3) and (4) will be combined for the computation of allowables.

Go to Problem XII.

### PROBLEM X

*Should the data in Groups (1) and (6) be combined?*

Other Information: Neither property varies with thickness. (Refer to Sections 9.2.4 and 9.6.2.)

The k-sample Anderson-Darling test will be employed in this example (see Section 9.6.2.5). Taking Group (6) to be the first sample ( $A_1$ ) and Group (1) to be the second sample ( $A_2$ ), the k-sample Anderson-Darling test statistic is calculated as:

$$ADK = \frac{1}{400(1)} \left[ \frac{1}{100} \sum_{j=1}^{398} h_j \frac{(400 F_{1j} - 100 H_j)^2}{H_j(400 - H_j) 400 h_j/4} + \frac{1}{300} \sum_{j=1}^{398} h_j \frac{(400 F_{2j} - 300 H_j)^2}{H_j (400 - H_j) - 400 h_j/4} \right] = 44.195$$

Since the computed value of 44.195 is greater than the critical value of

$$2.486 = 1 + 0.758 \left( 1.645 + \frac{0.678}{\sqrt{1}} - \frac{0.362}{1} \right),$$

the hypothesis that the populations from which these groups are drawn are identical is rejected. Thus Groups (1) and (6) will not be combined for the calculation allowables.

### PROBLEM XI

*What computational method should be used for the combined observations of Groups (1) and (2)?*

Other Information: This property does not vary with thickness.

Form of the distribution has not been determined. (Refer to Sections 9.2.5, 9.2.6, 9.2.8, and 9.6.1.4.)

The sample is large enough to permit direct computation of A and B-values. Consequently, the computational method will be determined by whether or not the observations may be assumed to follow a three-parameter Weibull distribution.

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*Prob. XI—Step 1. Test to determine whether the distribution is a three-parameter Weibull distribution. The Anderson-Darling test for three-parameter Weibullness will be employed in this example (see Section 9.6.1.4). Preliminary calculations give*

$$\begin{array}{ll} K &= 88 \\ \overline{X} &= 150.1 \\ X_{(1)} &= 139.608 \\ L &= -259.9 \end{array} \quad \begin{array}{ll} W_{50} &= 0.665 \\ S &= 4.10 \\ H &= 139.6079 \end{array}$$

$$R(\tau) = \frac{\sum_{i=89}^{262} L_i(\tau)}{\sum_{i=1}^{262} L_i(\tau)} \quad .$$

It can be verified that  $R(-259.9) > 0.665$  and  $R(139.6079) < 0.665$ . Solving the equation  $R(\tau) = 0.665$  with the initial interval  $(-259.9, 139.6079)$  gives  $\tau_{50} = 138.70$ . The function  $G_{50}(\beta_{50})$  then becomes

$$G_{50}(\beta_{50}) = \frac{1}{330} \sum_{i=1}^{330} \ln(X_i - 138.70) \left[ \left( \frac{X_i - 138.70}{\alpha_{50}} \right)^{\beta_{50}} - 1 \right] - \frac{1}{\beta_{50}}$$

where

$$\alpha_{50} = 10.53 \left[ \frac{1}{330} \sum_{i=1}^{330} \left( \frac{X_i - 138.70}{10.53} \right)^{1/\beta_{50}} \right]^{\beta_{50}}$$

Solving the equation  $G_{50}(\beta_{50}) = 0$  gives  $\beta_{50} = 3.02$  which in turn gives  $\alpha_{50} = 12.75$ .

The values of  $Z_{(1)}, \dots, Z_{(330)}$  are obtained using the formula

$$Z_i = \left( \frac{X_{(i)} - 138.70}{12.75} \right)^{3.02} \quad .$$

The first three Z-values are  $Z_{(1)} = 0.000345$ ,  $Z_{(2)} = 0.00339$ , and  $Z_{(3)} = 0.00378$ . The Anderson-Darling test statistic is calculated as

$$AD = \sum_{i=1}^{330} \frac{1 - 2i}{330} \left[ \ln(1 - \exp(-Z_{(i)})) + \ln(\exp(-Z_{(331-i)}) \right] - 330 = 0.491 \quad .$$

The computed value of the test statistic is compared to the critical value

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$$0.749 = 0.757 / (1 + 1/5\sqrt{330}) \quad .$$

Since the computed value of 0.491 is less than the critical value of 0.749, the hypothesis that the observations follow a three-parameter Weibull distribution is not rejected.

*Prob. XI—Step 2. Compute  $F_{tu}$  (LT), 0.020-0.125, for Alloy X, using procedures for the three-parameter Weibull distribution. Preliminary calculations give*

$$\begin{array}{ll} K = 88 & W_A = 0.698 \\ W_\beta = 0.678 & \bar{X} = 150.1 \\ S = 4.10 & X_{(1)} = 139.608 \\ H = 139.6079 & L = -259.9 \end{array}$$

$$R(\tau) = \sum_{i=89}^{262} L_i(\tau) / \sum_{i=1}^{262} L_i(\tau)$$

Solving the equation  $R(\tau) = 0.698$  with the interval  $(-259.9, 139.6079)$  gives  $\tau_A = 136.43$ . Solving  $R(\tau) = 0.678$  gives  $\tau_B = 137.98$ .

Solving the equation  $G_A(\beta_A) = 0$  gives  $\beta_A = 3.63$  which in turn gives  $\alpha_A = 15.14$ . Solving the equation  $G_B(\beta_B) = 0$  gives  $\beta_B = 3.22$  which in turn gives  $\alpha_B = 13.52$ .

Using the formulas from 9.2.8.4 the allowables are calculated as follows:

$$\begin{aligned} Q_A &= 15.14 (0.01005)^{1/3.63} = 4.263 \\ Q_B &= 13.52 (0.10536)^{1/3.22} = 6.719 \\ A &= 136.43 + 4.263 \exp(-7.259/3.63 \sqrt{330}) = 140.2 \\ B &= 137.98 + 6.716 \exp(-4.103/3.22 \sqrt{330}) = 144.2 \end{aligned}$$

## PROBLEM XII

*What computational method should be used for the combined observations of Groups (3) and (4)?*

Other Information: This property does not vary with thickness.

Form of the distribution has not been determined. (Refer to Sections 9.2.5, 9.2.6, 9.2.8, and 9.6.1.4.)

The sample is large enough to permit direct computation of A and B values. Consequently, the computational method will be determined by whether or not the observations may be assumed to follow a three-parameter Weibull distribution.

*Prob. XII—Step 1. Test to determine whether the distribution is a three-parameter Weibull distribution. The Anderson-Darling test for three-parameter Weibullness will be employed in this example (see Section 9.6.1.4). Preliminary calculations give*

$$\begin{array}{ll} K = 88 & \\ \bar{X} = 130.1 & W_{50} = 0.665 \\ X_{(1)} = 120.487 & S = 4.10 \\ L = -279.9 & H = 120.4869 \end{array}$$

$$R(\tau) = \sum_{i=89}^{262} L_i(\tau) / \sum_{i=1}^{262} L_i(\tau)$$

Solving the equation  $R(\tau) = 0.665$  with initial interval  $(-279.9, 120.4869)$  gives  $\tau_{50} = 119.58$ . Solving the equation  $G_{50}(\beta_{50}) = 0$  gives  $\beta_{50} = 2.84$  which in turn gives  $\alpha_{50} = 11.81$ .

The values  $Z_{(1)}, \dots, Z_{(330)}$  are obtained using these estimates. The value of the Anderson-Darling test statistic is 1.392. Since the computed value of 1.392 is greater than the critical value of 0.749, the hypothesis that the observations follow a three-parameter Weibull distribution is rejected.

*Prob. XII—Step 2. Compute  $F_y(LT)$ , 0.020 to 0.125, using procedures for an unknown distribution. This computation has been carried out in Problem V, Step 2.*

**9.2.13 MODULUS OF ELASTICITY AND POISSON'S RATIO** — The following room-temperature elasticity values are presented in the room-temperature property tables as typical values:

| Property              | Units           | Symbol | Recommended ASTM Test Procedures |
|-----------------------|-----------------|--------|----------------------------------|
| Modulus of Elasticity |                 |        |                                  |
| In tension            | 1000 ksi        | $E$    | E 111                            |
| In compression        | 1000 ksi        | $E_c$  | E 111                            |
| In shear              | 1000 ksi        | $G$    | E 143                            |
| Poisson's Ratio       | (Dimensionless) | $\mu$  | E 132                            |

If the material is not isotropic, the applicable test direction must be specified. Deviations from isotropy must be suspected if the experimentally determined Poisson's ratio differs from the value computed by the formula

$$\mu = \frac{E}{2G} - 1 \tag{9.2.13(a)}$$

where  $E$  is the average of  $E$  and  $E_c$ .

Given  $E$ ,  $E_c$ , and  $G$ ,  $\mu$  may be computed by this equation. Likewise, given  $E$ ,  $E_c$ , and  $\mu$ ,  $G$  may be computed from the equation:

$$G = \frac{E}{2(\mu + 1)} \tag{9.2.13(b)}$$

In the event  $E_c$  is not available,  $E$  may be substituted for  $E$  in the above equations to provide an estimate of either  $\mu$  or  $G$ .

**9.2.14 PHYSICAL PROPERTIES**—Density, specific heat, thermal conductivity, and mean coefficient of thermal expansion are physical properties normally included in MIL-HDBK-5. Physical properties are presented in the room-temperature property table if they are not presented in effect-of-temperature curves (see Section 9.3.1.4). The basis for physical properties is “typical”. Table 9.2.14 displays units and symbols used in MIL-HDBK-5, and also recommended ASTM test procedures for measuring these properties. Since modifications of procedures are employed in measuring physical properties, methods used for values proposed for inclusion in MIL-HDBK-5 should be reported in the supporting data proposal. For specific heat

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and thermal conductivity values reported in the room temperature property table, the reference temperature of measurement is also shown [for example, for 2017 aluminum the specific heat is 0.23 (at 212·F)]. For tabulated values of mean thermal expansion, temperature range of the coefficient is shown [for example, 12.5 (70 to 212·F)]. The reference temperature of 70·F is established as standard for mean coefficient of thermal expansion curves.

**Table 9.2.14. Units and Symbols Used to Present Physical Property Data and ASTM Test Procedures**

| Property                              | Unit                           | Symbol   | Recommended ASTM Test Procedures |
|---------------------------------------|--------------------------------|----------|----------------------------------|
| Density                               | lb/in. <sup>3</sup>            | $\omega$ | C 693                            |
| Specific heat                         | Btu/lb-·F                      | $C$      | D 2766                           |
| Thermal conductivity                  | Btu(hr-ft <sup>2</sup> -·F/ft) | $K$      | C 714 <sup>a</sup>               |
| Mean coefficient of thermal expansion | 10 <sup>-6</sup> (in./in./ ·F) | $\alpha$ | E 228                            |

a ASTM C 714 is a test for thermal diffusivity from which thermal conductivity can be computed.

**9.2.15 PRESENTATION OF ROOM-TEMPERATURE DESIGN VALUES** — The proposal for the incorporation of design allowables into MIL-HDBK-5 shall contain supporting data and computations for all design properties. Depending on quantity and availability, data may be tabulated, plotted, or referenced (to readily available technical reports, specifications, etc.). Computations should indicate adequately the manner in which design values were computed and shall be presented in an orderly manner. Data sources shall be identified.

All minimum mechanical property data analyses must be performed in English units. Strength data recorded in metric units should be converted to English units, to the nearest 0.01 ksi, before data analyses are undertaken. If desired by the data supplier, metric equivalent tables and figures can be included as part of the working data submitted with a data proposal, but the tables and/or figures proposed for inclusion in MIL-HDBK-5 will contain only English units.

The table of room-temperature design values shall be presented in the format indicated in Figure 9.2.15(a) for conventional metallic materials. This format has been designed to accommodate most of these materials; however, some modifications may be required. For example, the format shown in Figure 9.2.15(b) shall be used for aluminum alloy sheet laminates which are generally anisotropic and have limited ductility. Design values for these hybrid materials are presented for several mechanical properties which differ from those shown for conventional metallic materials. Unused lines (for example, ST properties for sheet) are deleted. Guidance in the use of these formats may be obtained by examining tables throughout this document and by referral to the applicable procurement specification. The following instructions should be followed for the items located in Figure 9.2.15(a):

- (1) Table number: If this is a revision of an existing table, use the same table number; otherwise, use a new table number in the proper sequence.
- (2) Material designation: Use a numeric designation where available (for example, 7075 aluminum alloy). Avoid the use of trade names. Include products following the material designation, except products may be omitted from the title if there are many products covered by the table.
- (3) Specification: Refer to a public specification (industry, Military, or Federal), followed by a type or class designation, if appropriate. Do not refer to proprietary specifications.

Table j . Design Mechanical and Physical Properties of (material designation) k  
(products)

|                                                       |     |       |     |   |
|-------------------------------------------------------|-----|-------|-----|---|
| Specification . . . . .                               | ③   |       |     |   |
| Form . . . . .                                        |     |       |     |   |
| Condition (or Temper) . . . . .                       | ④   |       |     |   |
| Cross-Sectional Area, in. <sup>2</sup> . .            |     | ⑤     |     |   |
| Location Within Casting . . .                         |     | ⑥     |     |   |
| Thickness or Diameter, in. . .                        |     | ⑦     |     |   |
| Basis . . . . .                                       | S   | A     | B ⑧ | S |
| Mechanical Properties:                                |     |       |     |   |
| <i>F<sub>u</sub></i> , ksi:                           |     |       |     |   |
| L . . . . .                                           | 120 | 120   | 124 |   |
| LT (or T) ⑨ . . . . .                                 | ... | ... ⑩ | ... |   |
| ST . . . . .                                          |     |       |     |   |
| <i>F<sub>y</sub></i> , ksi:                           |     |       |     |   |
| L . . . . .                                           |     |       |     |   |
| LT (or T) . . . . .                                   |     |       |     |   |
| ST . . . . .                                          |     |       |     |   |
| <i>F<sub>cy</sub></i> , ksi:                          |     |       |     |   |
| L . . . . .                                           |     |       |     |   |
| LT (or T) . . . . .                                   |     |       |     |   |
| ST . . . . .                                          |     |       |     |   |
| <i>F<sub>su</sub></i> , ksi . . . . .                 |     |       |     |   |
| <i>F<sub>bru</sub></i> , ksi:⑪                        |     |       |     |   |
| (e/D = 1.5) . . . . .                                 |     |       |     |   |
| (e/D = 2.0) . . . . .                                 |     |       |     |   |
| <i>F<sub>bry</sub></i> , ksi:                         |     |       |     |   |
| (e/D = 1.5) . . . . .                                 |     |       |     |   |
| (e/D = 2.0) . . . . .                                 |     |       |     |   |
| <i>e</i> , percent (S-basis):                         |     |       |     |   |
| L . . . . .                                           |     |       |     |   |
| LT (or T) . . . . .                                   |     |       |     |   |
| ST . . . . .                                          |     |       |     |   |
| <i>RA</i> , percent (S-basis):                        |     |       |     |   |
| L . . . . .                                           |     |       |     |   |
| LT (or T) . . . . .                                   |     |       |     |   |
| ST . . . . .                                          |     |       |     |   |
| <i>E</i> , 10 <sup>3</sup> ksi . . . . .              |     |       |     |   |
| <i>E<sub>c</sub></i> , 10 <sup>3</sup> ksi . . . . .  |     |       |     |   |
| <i>G</i> , 10 <sup>3</sup> ksi . . . . .              |     |       |     |   |
| <i>μ</i> . . . . .                                    |     |       |     |   |
| Physical Properties:                                  |     |       |     |   |
| <i>ω</i> , lb/in. <sup>3</sup> . . . . .              | ⑫   |       |     |   |
| <i>C</i> , Btu/(lb)/(°F) . . . . .                    |     |       |     |   |
| <i>K</i> , Btu/[ (hr)(ft <sup>2</sup> )(°F)/ft] . . . |     |       |     |   |
| <i>α</i> , 10 <sup>-6</sup> in./in./°F . . . . .      |     |       |     |   |

⑬ (footnotes)

Figure 9.2.15(a). Format for room temperature property table.

**Table 7.5.X.X(b). Design Mechanical and Physical Properties of (sheet material designation) Aluminum Alloy, Aramid Fiber Reinforced, Sheet Laminate**

|                                             |                                        |       |       |       |
|---------------------------------------------|----------------------------------------|-------|-------|-------|
| Specification .....                         |                                        |       |       |       |
| Form .....                                  | Aramid fiber reinforced sheet laminate |       |       |       |
| Laminate Lay-Up .....                       | 2/1                                    | 3/2   | 4/3   | 5/4   |
| Nominal Thickness, in. ....                 | 0.032                                  | 0.053 | 0.074 | 0.094 |
| Basis .....                                 | S                                      | S     | S     | S     |
| Mechanical Properties <sup>a</sup> :        |                                        |       |       |       |
| <i>F<sub>tu</sub></i> , ksi:                |                                        |       |       |       |
| L .....                                     |                                        |       |       |       |
| LT .....                                    |                                        |       |       |       |
| <i>F<sub>ty</sub></i> , ksi:                |                                        |       |       |       |
| L .....                                     |                                        |       |       |       |
| LT .....                                    |                                        |       |       |       |
| <i>F<sub>cy</sub></i> , ksi:                |                                        |       |       |       |
| L .....                                     |                                        |       |       |       |
| LT .....                                    |                                        |       |       |       |
| <i>F<sub>su</sub></i> , ksi .....           |                                        |       |       |       |
| <i>F<sub>sy</sub></i> , ksi .....           |                                        |       |       |       |
| <i>F<sub>bru</sub></i> , ksi:               |                                        |       |       |       |
| L (e/D = 1.5) .....                         |                                        |       |       |       |
| LT (e/D = 1.5) .....                        |                                        |       |       |       |
| L (e/D = 2.0) .....                         |                                        |       |       |       |
| LT (e/D = 2.0) .....                        |                                        |       |       |       |
| <i>F<sub>bry</sub></i> , ksi:               |                                        |       |       |       |
| L (e/D = 1.5) .....                         |                                        |       |       |       |
| LT (e/D = 1.5) .....                        |                                        |       |       |       |
| L (e/D = 2.0) .....                         |                                        |       |       |       |
| LT (e/D = 2.0) .....                        |                                        |       |       |       |
| <i>ε<sub>p</sub></i> , percent:             |                                        |       |       |       |
| L .....                                     |                                        |       |       |       |
| LT .....                                    |                                        |       |       |       |
| <i>E</i> , 10 <sup>3</sup> ksi:             |                                        |       |       |       |
| L .....                                     |                                        |       |       |       |
| LT .....                                    |                                        |       |       |       |
| <i>E<sub>c</sub></i> , 10 <sup>3</sup> ksi: |                                        |       |       |       |
| L .....                                     |                                        |       |       |       |
| LT .....                                    |                                        |       |       |       |
| <i>G</i> , 10 <sup>3</sup> ksi:             |                                        |       |       |       |
| L .....                                     |                                        |       |       |       |
| LT .....                                    |                                        |       |       |       |
| <i>μ</i> :                                  |                                        |       |       |       |
| L .....                                     |                                        |       |       |       |
| LT .....                                    |                                        |       |       |       |
| Physical Properties:                        |                                        |       |       |       |
| <i>ω</i> , lb/in. <sup>3</sup> .....        |                                        |       |       |       |
| <i>C</i> , <i>K</i> , and <i>α</i> .....    |                                        |       |       |       |

a Design values were computed using nominal thickness of sheet laminate.

**Figure 9.2.15(b). Format for room temperature property table for aluminum alloy fiber reinforced sheet laminate.**



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- (4) Condition: Use a standard temper designation where applicable. Otherwise, use an easily recognized description, including pertinent details if these are not available in the reference specification. Examples: T651, TH1050, Aged (1400°F), Mill Annealed.
- (5) Cross-sectional area: Use only when applicable.
- (6) Location within casting: Applicable only to castings. Specify “Non-designated area,” or “Designated area,” as applicable.
- (7) Design values shall be presented only for the thicknesses covered in the material specification.
- (8) Basis: For each product and size, use two columns covering A- and B-basis properties or one column covering S-basis properties. A-values that are higher than the corresponding S-values are presented only in footnotes to the table. In such instances, A-values are replaced by S-values in the body of the table. When A-values are presented for some properties and S-values are presented for other properties for the same product, values shall be shown in a column labeled A-basis, and individual S-values shall be identified by appropriate footnotes. Elongation, total strain at failure, and reduction of area values are presented on an S-basis only. When other properties are presented on an A- and B-basis, add “(S-basis)” after “e, percent,” or “ $\epsilon_t$  percent” and “RA, percent.” For aluminum alloy die forgings,  $F_{tu}$ ,  $F_{ty}$ , and  $e$  shall be shown on an S-basis only for transverse, T, grain direction. To explain, add the following footnote to these values, “Specification value. T tensile properties are presented on an S-basis only.” Design values for low alloy, quenched and tempered steels shall be presented on an S-basis only.
- (9) Grain direction: Show design values for grain directions “L, LT, and ST” or for grain directions “L and T” for the properties  $F_{tu}$ ,  $F_{ty}$ ,  $F_{cy}$ ,  $e$ , and RA. For anisotropic materials, present design values for grain directions “L, 45°, and LT” for  $F_{tu}$ ,  $F_{ty}$ , and  $F_{cy}$ . For aluminum alloy sheet laminates, show design values for L and LT grain directions of aluminum alloy sheet for all mechanical properties. Grain directions are not applicable to castings.

The T grain direction should be footnoted with the definition used in the specification identified at the top of the mechanical property table. For example, the T grain direction for aluminum die forgings covered in MIL, Federal and some AMS specifications will read as follows: “For die forgings, T indicates any grain direction not within  $\pm 15$  degrees of being parallel to the forging flow lines.” For updated AMS specifications with the preferred narrower definition of the T grain direction, the footnote should read as follows: “For die forgings, T indicates a grain direction within  $\pm 15$  degrees of being perpendicular to the forging flow lines.” Specimens to test the transverse properties should be located as close to the short transverse direction as possible.

Transverse  $F_{cy}$  values for aluminum die forgings shall be shown as  $F_{cy}(T)$ . If the values are based upon short transverse or long transverse test data, add this information to the above footnote.

- (10) Missing values: For table entries that are missing or not applicable, show a series of three dots aligned with the numbers in that column.
- (11) Bearing values: Add footnote “Bearing values are dry pin values per Section 1.4.7.1” when bearing allowables are based on data from clean pin tests. Supporting information supplied with the proposal should describe the bearing test cleaning procedures used in testing.

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- (12) Physical properties: Include a section for physical properties even if properties are not available. If physical property data are presented in an effect-of-temperature curve, use table entry, "See Figure X.X.X.0" to refer to the illustration.
- (13) Footnotes: Use footnotes to indicate anything unusual or restrictive concerning the property description, properties, or individual values; to present supplementary values; or to reference other tables or sections of text. When A-values have been replaced by S-values, the following wording is suggested: "S-basis. The rounded  $T_{99}$  values are as follows: (list values)."

In addition, the proposal shall contain supporting data and computations for all design properties. Depending on quantity and availability, data may be tabulated, plotted (by cumulative-probability curves or histograms), or referenced (to readily available technical reports, specifications, etc.). Computations should indicate adequately the manner in which design values were computed and shall be presented in an orderly manner. Data sources shall be identified.

## APPENDIX A

### A.0 GLOSSARY

#### A.1 ABBREVIATIONS (also see Sections 1.2.1, 9.2.2, 9.3.4.3, 9.3.6.2, 9.4.1.2, 9.5.1.2, and 9.6).

|        |                                                                                                                                                                                                                                                 |
|--------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| a      | — Amplitude; crack or flaw dimension; measure of flaw size, inches.                                                                                                                                                                             |
| $a_c$  | — Critical half crack length.                                                                                                                                                                                                                   |
| $a_o$  | — Initial half crack length.                                                                                                                                                                                                                    |
| A      | — Area of cross section, square inches; ratio of alternating stress to mean stress; subscript “axial”; A basis for mechanical-property values (see Section 1.4.1.1 or Section 9.2.2.1); “A” ratio, loading amplitude/mean load; or area.        |
| $A_e$  | — Strain “A” ratio, strain amplitude/mean strain.                                                                                                                                                                                               |
| $A_i$  | — Model parameter.                                                                                                                                                                                                                              |
| AD     | — Anderson-Darling test statistic, computed in goodness-of-fit tests for normality or Weibullness.                                                                                                                                              |
| AISI   | — American Iron and Steel Institute.                                                                                                                                                                                                            |
| AMS    | — Aerospace Materials Specification (published by Society of Automotive Engineers, Inc.).                                                                                                                                                       |
| Ann    | — Annealed.                                                                                                                                                                                                                                     |
| AN     | — Air Force-Navy Aeronautical Standard.                                                                                                                                                                                                         |
| ASTM   | — American Society for Testing and Materials.                                                                                                                                                                                                   |
| b      | — Width of sections; subscript “bending”.                                                                                                                                                                                                       |
| br     | — Subscript “bearing”.                                                                                                                                                                                                                          |
| B      | — Biaxial ratio (see Equation 1.3.2.8); B-basis for mechanical-property values (see Section 1.4.1.1 or Section 9.2.2.1).                                                                                                                        |
| Btu    | — British thermal unit(s).                                                                                                                                                                                                                      |
| BUS    | — Individual or typical bearing ultimate strength.                                                                                                                                                                                              |
| BYS    | — Individual or typical bearing yield strength.                                                                                                                                                                                                 |
| c      | — Fixity coefficient for columns; subscript “compression”.                                                                                                                                                                                      |
| cpm    | — Cycles per minute.                                                                                                                                                                                                                            |
| C      | — Specific heat; Celsius; Constant.                                                                                                                                                                                                             |
| CEM    | — Consumable electrode melted.                                                                                                                                                                                                                  |
| CRES   | — Corrosion resistant steel (stainless steel).                                                                                                                                                                                                  |
| C(T)   | — Compact tension.                                                                                                                                                                                                                              |
| CYS    | — Individual or typical compressive yield strength.                                                                                                                                                                                             |
| d      | — Mathematical operator denoting differential.                                                                                                                                                                                                  |
| D or d | — Diameter, or Durbin Watson statistic; hole or fastener diameter; dimpled hole.                                                                                                                                                                |
| df     | — Degrees of freedom.                                                                                                                                                                                                                           |
| e      | — Elongation in percent, a measure of the ductility of a material based on a tension test; unit deformation or strain; subscript “fatigue or endurance”; the minimum distance from a hole, center to the edge of the sheet; Engineering strain. |
| $e_e$  | — Elastic strain.                                                                                                                                                                                                                               |
| $e_p$  | — Plastic strain.                                                                                                                                                                                                                               |
| e/D    | — Ratio of edge distance (center of the hole to edge of the sheet) to hole diameter (bearing strength).                                                                                                                                         |
| E      | — Modulus of elasticity in tension or compression; average ratio of stress to strain for stress below proportional limit.                                                                                                                       |
| $E_c$  | — Modulus of elasticity in compression; average ratio of stress to strain below proportional limit.                                                                                                                                             |

|                  |                                                                                                                                                |
|------------------|------------------------------------------------------------------------------------------------------------------------------------------------|
| $E_s$            | — Secant modulus of elasticity, Eq. 9.3.2.5b.                                                                                                  |
| $E_t$            | — Tangent modulus of elasticity.                                                                                                               |
| ELI              | — Extra low interstitial (grade of titanium alloy).                                                                                            |
| ER               | — Equivalent round.                                                                                                                            |
| ESR              | — Electro-slag remelted.                                                                                                                       |
| $f$              | — Internal (or calculated) tension stress; stress applied to the gross flawed section; creep stress.                                           |
| $f_b$            | — Internal (or calculated) primary bending stress.                                                                                             |
| $f_c$            | — Internal (or calculated) compressive stress; maximum stress at fracture: gross stress limit (for screening elastic fracture data).           |
| $f_{pl}$         | — Proportional limit.                                                                                                                          |
| $f_s$            | — Internal (or calculated) shear stress.                                                                                                       |
| $f_t$            | — Internal (or calculated) tensile stress.                                                                                                     |
| ft               | — Foot: feet.                                                                                                                                  |
| F                | — Design stress; Fahrenheit; Ratio of two sample variances.                                                                                    |
| $F_A$            | — Design axial stress.                                                                                                                         |
| $F_b$            | — Design bending stress; modulus of rupture in bending.                                                                                        |
| $F_{bru}$        | — Design ultimate bearing stress.                                                                                                              |
| $F_{bry}$        | — Design bearing yield stress.                                                                                                                 |
| $F_c$            | — Design column stress.                                                                                                                        |
| $F_{cc}$         | — Design crushing or crippling stress (upper limit of column stress for local failure).                                                        |
| $F_{cu}$         | — Design ultimate compressive stress.                                                                                                          |
| $F_{cy}$         | — Design compressive yield stress at which permanent strain equals 0.002.                                                                      |
| $F_H$            | — Design hoop stress.                                                                                                                          |
| $F_s$            | — Design shear stress.                                                                                                                         |
| $F_{sp}$         | — Design proportional limit in shear.                                                                                                          |
| $F_{st}$         | — Design modulus of rupture in torsion.                                                                                                        |
| $F_{su}$         | — Design ultimate stress in pure shear (this value represents the average shear stress over the cross section).                                |
| $F_{sy}$         | — Design shear yield stress.                                                                                                                   |
| $F_{tp}$         | — Design proportional limit in tension.                                                                                                        |
| $F_{tu}$         | — Design tensile ultimate stress.                                                                                                              |
| $F_{ty}$         | — Design tensile yield stress at which permanent strain equals 0.002.                                                                          |
| g                | — Gram(s).                                                                                                                                     |
| G                | — Modulus of rigidity (shear modulus).                                                                                                         |
| Gpa              | — Gigapascal(s).                                                                                                                               |
| hr               | — Hour(s).                                                                                                                                     |
| H                | — Subscript “hoop”.                                                                                                                            |
| HIP              | — Hot isostatically pressed.                                                                                                                   |
| i                | — Slope (due to bending) of neutral plane of a beam, in radians (1 radian = 57.3 degrees).                                                     |
| in.              | — Inch(es).                                                                                                                                    |
| I                | — Axial moment of inertia.                                                                                                                     |
| J                | — Torsion constant (= $I_p$ for round tubes); Joule.                                                                                           |
| k                | — Tolerance limit factor for the normal distribution and the specified probability, confidence, and degrees of freedom; Strain at unit stress. |
| $k_{99}, k_{90}$ | — One-sided tolerance limit factor for $T_{99}$ and $T_{90}$ , respectively (see Section 9.2.7.2).                                             |
| $k_{A,B}$        | — K to A basis or B basis, respectively (see Section 9.2.7.2).                                                                                 |
| ksi              | — Kips (1,000 pounds) per square inch.                                                                                                         |
| K                | — A constant, generally empirical; thermal conductivity; stress intensity; Kelvin; correction factor.                                          |
| $K_{app}$        | — Apparent plane stress fracture toughness or residual strength.                                                                               |

|           |                                                                                                                                                                                                                                 |
|-----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $K_c$     | — Critical plane stress fracture toughness, a measure of fracture toughness at point of crack growth instability.                                                                                                               |
| $K_f$     | — Fatigue notch factor, or fatigue strength reduction factor.                                                                                                                                                                   |
| $K_{Ic}$  | — Plane strain fracture toughness.                                                                                                                                                                                              |
| $K_N$     | — Empirically calculated fatigue notch factor.                                                                                                                                                                                  |
| $K_t$     | — Theoretical stress concentration factor.                                                                                                                                                                                      |
| lb        | — Pound.                                                                                                                                                                                                                        |
| ln        | — Natural (base e) logarithm.                                                                                                                                                                                                   |
| log       | — Base 10 logarithm.                                                                                                                                                                                                            |
| L         | — Length; subscript “lateral”; longitudinal (grain direction).                                                                                                                                                                  |
| LT        | — Long transverse (grain direction).                                                                                                                                                                                            |
| m         | — Subscript “mean”; metre; slope.                                                                                                                                                                                               |
| mm        | — Millimeter(s).                                                                                                                                                                                                                |
| M         | — Applied moment or couple, usually a bending moment.                                                                                                                                                                           |
| Mc        | — Machine countersunk.                                                                                                                                                                                                          |
| Mg        | — Megagram(s).                                                                                                                                                                                                                  |
| MIG       | — Metal-inert-gas (welding).                                                                                                                                                                                                    |
| MPa       | — Megapascal(s).                                                                                                                                                                                                                |
| MS        | — Military Standard.                                                                                                                                                                                                            |
| M.S.      | — Margin of safety.                                                                                                                                                                                                             |
| M(T)      | — Middle tension.                                                                                                                                                                                                               |
| n         | — Number of individual measurements or pairs of measurements; subscript “normal”; cycles applied to failure; shape parameter for the standard stress-strain curve (Ramberg-Osgood parameter); number of fatigue cycles endured. |
| N         | — Fatigue life, number of cycles to failure; Newton; normalized.                                                                                                                                                                |
| $N_f$     | — Fatigue life, cycles to failure.                                                                                                                                                                                              |
| $N_i^*$   | — Fatigue life, cycles to initiation.                                                                                                                                                                                           |
| $N_t^*$   | — Transition fatigue life where plastic and elastic strains are equal.                                                                                                                                                          |
| NAS       | — National Aerospace Standard.                                                                                                                                                                                                  |
| p         | — Subscript “polar”; subscript “proportional limit”.                                                                                                                                                                            |
| psi       | — Pounds per square inch.                                                                                                                                                                                                       |
| P         | — Load; applied load (total, not unit, load); exposure parameter; probability.                                                                                                                                                  |
| $P_a$     | — Load amplitude.                                                                                                                                                                                                               |
| $P_m$     | — Mean load.                                                                                                                                                                                                                    |
| $P_{max}$ | — Maximum load.                                                                                                                                                                                                                 |
| $P_{min}$ | — Minimum load.                                                                                                                                                                                                                 |
| Pu        | — Test ultimate load, pounds per fastener.                                                                                                                                                                                      |
| Py        | — Test yield load, pounds per fastener.                                                                                                                                                                                         |
| q         | — Fatigue notch sensitivity.                                                                                                                                                                                                    |
| Q         | — Static moment of a cross section.                                                                                                                                                                                             |
| Q&T       | — Quenched and tempered.                                                                                                                                                                                                        |
| r         | — Radius; root radius; reduced ratio (regression analysis); ratio of two pair measurements; rank of test point within a sample.                                                                                                 |
| $\bar{r}$ | — average ratio of paired measurements.                                                                                                                                                                                         |
| R         | — Load (stress) ratio, or residual (observed minus predicted value); stress ratio, ratio of minimum stress to maximum stress in a fatigue cycle; reduced ratio.                                                                 |
| $R_b$     | — Stress ratio in bending.                                                                                                                                                                                                      |
| $R_c$     | — Stress ratio in compression; Rockwell hardness - C scale.                                                                                                                                                                     |

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\* Different from ASTM.

|                  |                                                                                                                                                                                  |
|------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $R_{\epsilon}$   | — Strain ratio, $\epsilon_{\min}/\epsilon_{\max}$ .                                                                                                                              |
| $R_s$            | — Stress ratio in shear or torsion; ratio of applied load to allowable shear load.                                                                                               |
| $R_t$            | — Ratio of applied load to allowable tension load.                                                                                                                               |
| RA               | — Reduction of area.                                                                                                                                                             |
| R.H.             | — Relative humidity.                                                                                                                                                             |
| RMS              | — Root-mean-square (surface finish).                                                                                                                                             |
| RT               | — Room temperature.                                                                                                                                                              |
| s                | — Estimated population standard deviation; sample standard deviation; subscript “shear”.                                                                                         |
| $s^2$            | — Sample variance.                                                                                                                                                               |
| S                | — Shear force; nominal engineering stress, fatigue; S-basis for mechanical-property values (see Section 1.4.1.1).                                                                |
| $S_a$            | — Stress amplitude, fatigue.                                                                                                                                                     |
| $S_e$            | — Fatigue limit.                                                                                                                                                                 |
| $S_{eq}^*$       | — Equivalent stress.                                                                                                                                                             |
| $S_f$            | — Fatigue limit.                                                                                                                                                                 |
| $S_m$            | — Mean stress, fatigue.                                                                                                                                                          |
| $S_{\max}$       | — Highest algebraic value of stress in the stress cycle.                                                                                                                         |
| $S_{\min}$       | — Lowest algebraic value of stress in the stress cycle.                                                                                                                          |
| $S_r$            | — Algebraic difference between the maximum and minimum stresses in one cycle.                                                                                                    |
| $S_y$            | — Root mean square error.                                                                                                                                                        |
| SAE              | — Society of Automotive Engineers.                                                                                                                                               |
| SCC              | — Stress-corrosion cracking.                                                                                                                                                     |
| SEE              | — Estimate population standard error of estimate.                                                                                                                                |
| SR               | — Studentized residual.                                                                                                                                                          |
| ST               | — Short transverse (grain direction).                                                                                                                                            |
| STA              | — Solution treated and aged.                                                                                                                                                     |
| SUS              | — Individual or typical shear ultimate strength.                                                                                                                                 |
| SYS              | — Individual or typical shear yield strength.                                                                                                                                    |
| t                | — Thickness; subscript “tension”; exposure time; elapsed time; tolerance factor for the “t” distribution with the specified probability and appropriate degrees of freedom.      |
| T                | — Transverse direction; applied torsional moment; transverse (grain direction); subscript “transverse”.                                                                          |
| $T_F$            | — Exposure temperature.                                                                                                                                                          |
| $T_{90}$         | — Statistically based lower tolerance bound for a mechanical property such that at least 90 percent of the population is expected to exceed $T_{90}$ with 95 percent confidence. |
| $T_{99}$         | — Statistically based lower tolerance bound for a mechanical property such that at least 99 percent of the population is expected to exceed $T_{99}$ with 95 percent confidence. |
| TIG              | — Tungsten-inert-gas (welding).                                                                                                                                                  |
| TUS              | — Individual or typical tensile ultimate strength.                                                                                                                               |
| $TUS (S_u)^*$    | — Tensile ultimate strength.                                                                                                                                                     |
| TYS              | — Individual or typical tensile yield strength.                                                                                                                                  |
| u                | — Subscript “ultimate”.                                                                                                                                                          |
| U                | — Factor of utilization.                                                                                                                                                         |
| $V_{99}, V_{90}$ | — The tolerance limit factor corresponding to $T_{99}$ , $T_{90}$ for the three-parameter Weibull distribution, based on a 95 percent confidence level and a sample of size n.   |
| W                | — Width of center-through-cracked tension panel; Watt.                                                                                                                           |
| $\bar{x}$        | — Distance along a coordinate axis.                                                                                                                                              |
| x                | — Sample mean based upon n observations.                                                                                                                                         |

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\* Different from ASTM.

|   |                                                                                                                                                           |
|---|-----------------------------------------------------------------------------------------------------------------------------------------------------------|
| X | — Value of an individual measurement; average value of individual measurements.                                                                           |
| y | — Deflection (due to bending) of elastic curve of a beam; distance from neutral axis to given fiber; subscript “yield”; distance along a coordinate axis. |
| Y | — Nondimensional factor relating component geometry and flaw size. See Reference 1.4.12.2.1(a) for values.                                                |
| z | — Distance along a coordinate axis.                                                                                                                       |
| Z | — Section modulus, $I/y$ .                                                                                                                                |

**A.2 SYMBOLS** (also see Sections 1.2.1, 9.2.2, 9.3.4.3, 9.3.6.2, 9.4.1.2, 9.5.1.2, and 9.6).

|                                    |                                                                                                                                                                      |
|------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\alpha$                           | — (1) Coefficient of thermal expansion, mean; constant. (2) Significance level; probability (risk of erroneously rejecting the null hypothesis (see Section 9.6.2)). |
| $\alpha_{99}, \alpha_{90}$         | — Shape parameter estimates for a $T_{99}$ or $T_{90}$ value based on an assumed three-parameter Weibull distribution.                                               |
| $\alpha_{50}$                      | — Shape parameter estimate for the Anderson-Darling goodness-of-fit test based on an assumed three-parameter Weibull distribution.                                   |
| $\beta$                            | — Constant.                                                                                                                                                          |
| $\beta_{99}, \beta_{90}$           | — Scale parameter estimate for a $T_{99}$ or $T_{90}$ value based on an assumed three-parameter Weibull distribution.                                                |
| $\beta_{50}$                       | — Scale parameter estimate for the Anderson-Darling goodness-of-fit test based on an assumed three-parameter Weibull distribution.                                   |
| $\Delta\epsilon$ or $\epsilon_r^*$ | — strain range, $\epsilon_{\max} - \epsilon_{\min}$ .                                                                                                                |
| $\Delta\epsilon_e$                 | — Elastic strain range.                                                                                                                                              |
| $\Delta\epsilon_p$                 | — Plastic strain range.                                                                                                                                              |
| $\Delta S (S_r)^*$                 | — Stress range.                                                                                                                                                      |
| $\Delta\sigma$                     | — True or local stress range.                                                                                                                                        |
| $\epsilon$                         | — True or local strain.                                                                                                                                              |
| $\epsilon_{eq}^*$                  | — Equivalent strain.                                                                                                                                                 |
| $\epsilon_m$                       | — Mean strain, $(\epsilon_{\max} + \epsilon_{\min})/2$ .                                                                                                             |
| $\epsilon_{\max}$                  | — Maximum strain.                                                                                                                                                    |
| $\epsilon_{\min}$                  | — Minimum strain.                                                                                                                                                    |
| $\epsilon_t$                       | — Total (elastic plus plastic) strain at failure determined from tensile stress-strain curve.                                                                        |
| $\delta$                           | — Deflection.                                                                                                                                                        |
| $\Phi$                             | — Angular deflection.                                                                                                                                                |
| $\rho$                             | — Radius of gyration; Neuber constant (block length).                                                                                                                |
| $\mu$                              | — Poisson’s ratio.                                                                                                                                                   |
| $\sigma$                           | — True or local stress; or population standard deviation.                                                                                                            |
| $\sigma_x$                         | — Population standard deviation of x.                                                                                                                                |
| $\sigma_x^2$                       | — Population variance of x.                                                                                                                                          |
| $\tau_{99}, \tau_{90}$             | — Threshold estimates for a $T_{99}$ or $T_{90}$ value based on an assumed three-parameter Weibull distribution.                                                     |
| $\tau_{50}$                        | — Threshold estimate for the Anderson-Darling goodness-of-fit test based on an assumed three-parameter Weibull distribution.                                         |
| $\omega$                           | — Density; flank angle.                                                                                                                                              |
| $\infty$                           | — Infinity.                                                                                                                                                          |
| $\Sigma$                           | — The sum of.                                                                                                                                                        |
| '                                  | — Superscript that denotes value determined by regression analysis.                                                                                                  |

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\* Different from ASTM.

**A.3 DEFINITIONS** (also see Sections 1.2.1, 9.2.2, 9.3.6.2, 9.4.1.2, 9.5.1.2 and 9.6).

*A-Basis*.—The lower of either a statistically calculated number, or the specification minimum (S-basis). The statistically calculated number indicates that at least 99 percent of the population of values is expected to equal or exceed the A-basis mechanical design property, with a confidence of 95 percent.

*Alternating Load*.—See Loading Amplitude.

*B-Basis*.—At least 90 percent of the population of values is expected to equal or exceed the B-basis mechanical property allowable, with a confidence of 95 percent.

*Cast*.—Cast consists of the sequential ingots which are melted from a single furnace charge and poured in one or more drops without changes in the processing parameters. (The cast number is for internal identification and is not reported.) (See Table 9.1.6.1).

*Casting*.—One or more parts which are melted from a single furnace charge and poured in one or more molds without changes in the processing parameters. (The cast number is for internal identification and is not reported.) (See Table 9.1.6.1).

*Confidence*.—A specified degree of certainty that at least a given proportion of all future measurements can be expected to equal or exceed the lower tolerance limit. Degree of certainty is referred to as the confidence coefficient. For MIL-HDBK-5, the confidence coefficient is 95 percent which, as related to design properties, means that, in the long run over many future samples, 95 percent of conclusions regarding exceedance of A and B-values would be true.

*Confidence Interval*.—An interval estimate of a population parameter computed so that the statement “the population parameter lies in this interval” will be true, on the average, in a stated proportion of the times such statements are made.

*Confidence Interval Estimate*.—Range of values, computed with the sample that is expected to include the population variance or mean.

*Confidence Level (or Coefficient)*.—The stated portion of the time the confidence interval is expected to include the population parameter.

*Confidence Limits\**.—The two numeric values that define a confidence interval.

*Constant-Amplitude Loading*.—A loading in which all of the peak loads are equal and all of the valley loads are equal.

*Constant-Life Fatigue Diagram*.—A plot (usually on Cartesian coordinates) of a family of curves, each of which is for a single fatigue life,  $N$ —relating  $S$ ,  $S_{\max}$ , and/or  $S_{\min}$  to the mean stress,  $S_m$ . Generally, the constant life fatigue diagram is derived from a family of  $S/N$  curves, each of which represents a different stress ratio (A or R) for a 50 percent probability of survival. NOTE—MIL-HDBK-5 no longer presents fatigue data in the form of constant-life diagrams.

*Creep*.—The time-dependent deformation of a solid resulting from force.

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\* Different from ASTM.



Note 1—Creep tests are usually made at constant load and temperature. For tests on metals, initial loading strain, however defined, is not included.

Note 2—This change in strain is sometimes referred to as creep strain.

*Creep-Rupture Curve.*—Results of material tests under constant load and temperature; usually plotted as strain versus time to rupture. A typical plot of creep-rupture data is shown in Figure 9.3.6.2. The strain indicated in this curve includes both initial deformation due to loading and plastic strain due to creep.

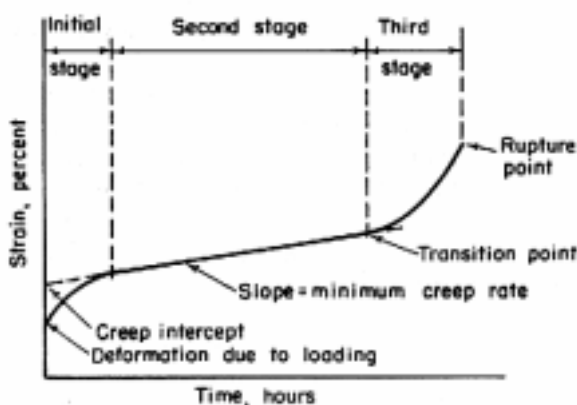


**Figure A.1. Typical creep-rupture curve.**

*Creep-Rupture Strength.*—Stress that will cause fracture in a creep test at a given time, in a specified constant environment. Note: This is sometimes referred to as the stress-rupture strength.

*Creep-Rupture Test.*—A creep-rupture test is one in which progressive specimen deformation and time for rupture are measured. In general, deformation is much larger than that developed during a creep test.

*Creep-Strain.*—The time-dependent part of the strain resulting from stress, excluding initial loading strain and thermal expansion.

*Creep Strength.*—Stress that causes a given creep in a creep test at a given time in a specified constant environment.

*Creep Stress.*—The constant load divided by the original cross-sectional area of the specimen.

*Creep Test.*—A creep test has the objective of measuring deformation and deformation rates at stresses usually well below those which would result in fracture during the time of testing.

*Critical Stress Intensity Factor.*—A limiting value of the stress intensity factor beyond which continued flaw propagation and/or fracture may be expected. This value is dependent on material and may vary with type of loading and conditions of use.

*Cycle.*—Under constant-amplitude loading, the load varies from the minimum to the maximum and then to the minimum load (see Figure 9.3.4.3). The symbol  $n$  or  $N$  (see definition of fatigue life) is used to indicate the number of cycles.

*Deformable Shank Fasteners.*—A fastener whose shank is deformed in the grip area during normal installation processes.

*Degree of Freedom.*—Number of degrees of freedom for  $n$  variables may be defined as number of variables minus number of constraints between them. Since the standard deviation calculation contains one fixed value (the mean) it has  $n - 1$  degrees of freedom.

*Degrees of Freedom.*—Number of independent comparisons afforded by a sample.

*Discontinued Test.*—See Runout.

*Elapsed Time.*—The time interval from application of the creep stress to a specified observation.

*Fatigue.*—The process of progressive localized permanent structural change occurring in a material subjected to conditions that produce fluctuating stresses and strains at some point or points, and which may culminate in cracks or complete fracture after a sufficient number of fluctuations. NOTE—fluctuations in stress and in time (frequency), as in the case of “random vibration”.

*Fatigue Life.*— $N$ —the number of cycles of stress or strain of a specified character that a given specimen sustains before failure of a specified nature occurs.

*Fatigue Limit.*— $S_f$ —the limiting value of the median fatigue strength as  $N$  becomes very large. NOTE—Certain materials and environments preclude the attainment of a fatigue limit. Values tabulated as “fatigue limits” in the literature are frequently (but not always) values of  $S_N$  for 50 percent survival at  $N$  cycles of stress in which  $S_m = 0$ .

*Fatigue Loading.*—Periodic or non-periodic fluctuating loading applied to a test specimen or experienced by a structure in service (also known as cyclic loading).

*Fatigue Notch Factor\**.—The fatigue notch factor,  $K_f$  (also called fatigue strength reduction factor), is the ratio of the fatigue strength of a specimen with no stress concentration to the fatigue strength of a specimen with a stress concentration at the same number of cycles for the same conditions. NOTE—In specifying  $K_f$ , it is necessary to specify the geometry, mode of loading, and the values of  $S_{max}$ ,  $S_m$ , and  $N$  for which it is computed.

*Fatigue Notch Sensitivity.*—The fatigue notch sensitivity,  $q$ , is a measure of the degree of agreement between  $K_f$  and  $K_t$ . NOTE—the definition of fatigue notch sensitivity is  $q = (K_f - 1)/(K_t - 1)$ .

*Heat.*—All material identifiable to a single molten metal source. (All material from a heat is considered to have the same composition. A heat may yield one or more ingots. A heat may be divided into several lots by subsequent processing.)

*Heat.*—Heat is material which, in the case of batch melting, is cast at the same time from the same furnace and is identified with the same heat number; or, in the case of continuous melting, is poured without interruption. (See Table 9.1.6.2)

*Heat.*—Heat is a consolidated (vacuum hot pressed) billet having a distinct chemical composition. (See Table 9.1.6.2)

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\* Different from ASTM.

*Hysteresis Diagram.*—The stress-strain path during a fatigue cycle.

*Isostrain Lines.*—Lines representing constant levels of creep.

*Isothermal Lines.*—Lines of uniform temperature on a creep or stress-rupture curve.

*Interrupted Test\*.*—Tests which have been stopped before failure because of some mechanical problem, e.g., power failure, load or temperature spikes.

*Loading Amplitude.*—The loading amplitude,  $P_a$ ,  $S_a$ , or  $\epsilon_a$  represents one-half of the range of a cycle (see Figure 9.3.4.3). (Also known as alternating load, alternating stress, or alternating strain.)

*Loading Strain.*—Loading strain is the change in strain during the time interval from the start of loading to the instant of full-load application, sometimes called initial strain.

*Loading (Unloading) Rate.*—The time rate of change in the monotonically increasing (decreasing) portion of the load-time function.

*Load Ratio.*—The load ratio,  $R$ ,  $A$ , or  $R_\epsilon$ ,  $A_\epsilon$ , or  $R_\sigma$ ,  $A_\sigma$ , is the algebraic ratio of the two loading parameters of a cycle; the two most widely used ratios are

$$R = \frac{\text{minimum load}}{\text{maximum load}} = \frac{P_{\min}}{P_{\max}}$$

or

$$R_\sigma = \frac{S_{\min}}{S_{\max}}$$

or

$$R_\epsilon = \epsilon_{\min}/\epsilon_{\max}$$

and

$$A = \frac{\text{loading amplitude}}{\text{mean load}} = \frac{P_a}{P_m} \text{ or } \frac{S_a}{S_M}$$

$$A_\epsilon = \frac{\text{strain amplitude}}{\text{mean strain}} = \frac{\epsilon_a}{\epsilon_M} \text{ or } (\epsilon_{\max} - \epsilon_{\min})/(\epsilon_{\max} + \epsilon_{\min}) .$$

NOTE—load ratios  $R$  or  $R_\epsilon$  are generally used in MIL-HDBK-5.

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\* Different from ASTM.

**MIL-HDBK-5H**  
**1 December 1998**

*Longitudinal Direction.*—Parallel to the principal direction of flow in a worked metal. For die forgings this direction is within  $\pm 15^\circ$  of the predominate grain flow.

*Long-Transverse Direction.*—The transverse direction having the largest dimension, often called the “width” direction. For die forgings this direction is within  $\pm 15^\circ$  of the longitudinal (predominate) grain direction and parallel, within  $\pm 15^\circ$ , to the parting plane. (Both conditions must be met.)

*Lot.*—All material from a heat or single molten metal source of the same product type having the same thickness or configuration, and fabricated as a unit under the same conditions. If the material is heat treated, a lot is the above material processed through the required heat-treating operations as a unit.

*Master Creep Equation.*—An equation expressing combinations of stress, temperature, time and creep, or a set of equations expressing combinations of stress, temperature and time for given levels of creep.

*Master Rupture Equation.*—An equation expressing combinations of stress, temperature, and time that cause complete separation (fracture or rupture) of the specimen.

*Maximum Load.*—The maximum load,  $P_{\max}$ ,  $S_{\max}$ ,  $\epsilon_{\max}$  is the load having the greatest algebraic value.

*Mean Load.*—The mean load,  $P_m$ , is the algebraic average of the maximum and minimum loads in constant-amplitude loading:

$$P_m = \frac{P_{\max} + P_{\min}}{2}, \text{ or}$$

$$S_m = \frac{S_{\max} + S_{\min}}{2}, \text{ or}$$

$$\epsilon_m = \frac{\epsilon_{\max} + \epsilon_{\min}}{2},$$

or the integral average of the instantaneous load values.

*Median Fatigue Life.*—The middlemost of the observed fatigue life values (arranged in order of magnitude) of the individual specimens in a group tested under identical conditions. In the case where an even number of specimens are tested, it is the average of the two middlemost values (based on log lives in MIL-HDBK-5). NOTE 1—The use of the sample median instead of the arithmetic mean (that is, the average) is usually preferred. NOTE 2—In the literature, the abbreviated term “fatigue life” usually has meant the median fatigue life of the group. However, when applied to a collection of data without further qualification, the term “fatigue life” is ambiguous.

*Median Fatigue Strength at N Cycles.*—An estimate of the stress level at which 50 percent of the population would survive N cycles. NOTE—The estimate of the median fatigue strength is derived from a particular point of the fatigue-life distribution, since there is no test procedure by which a frequency distribution of fatigue strengths at N cycles can be directly observed. That is, one can not perform constant-life tests.

*Melt*.—Melt is a single homogeneous batch of molten metal for which all processing has been completed and the temperature has been adjusted and made ready to pour castings. (For metal-matrix composites, the molten metal includes unmelted reinforcements such as particles, fibers, or whiskers.) (See Table 9.1.6.2)

*Minimum Load*.—The minimum load,  $P_{\min}$ ,  $S_{\min}$ , or  $\epsilon_{\min}$ , is the load having the least algebraic value.

*Nominal Hole Diameters*.—Nominal hole diameters for deformable shank fasteners shall be according to Table 9.4.1.2(a). When tests are made with hole diameters other than those tabulated, hole sizes used shall be noted in the report and on the proposed joint allowables table.

*Nominal Shank Diameter*.—Nominal shank diameter of fasteners with shank diameters equal to those used for standard size bolts and screws (NAS 618 sizes) shall be the decimal equivalents of stated fractional or numbered sizes. These diameters are those listed in the fourth column of Table 9.4.1.2. Nominal shank diameters for nondeformable shank blind fasteners are listed in the fifth column of Table 9.4.1.2. Nominal shank diameters for other fasteners shall be the average of required maximum and minimum shank diameters.

*Nondeformable Shank Fasteners*.—A fastener whose shank does not deform in the grip area during normal installation processes.

*Outlier\**.—An experimental observation which deviates markedly from other observations in the sample. An outlier is often either an extreme value of the variability in the data, or the result of gross deviation in the material or experimental procedure.

*Peak*.—The point at which the first derivative of the load-time history changes from a positive to a negative sign; the point of maximum load in constant-amplitude loading (see Figure 9.3.4.3).

*Plane Strain*.—The stress state in which all strains occur only in the principal loading plane. No strains occur out of the plane, i.e.,  $\epsilon_z = 0$ , and  $\sigma_z \neq 0$ .

*Plane Stress*.—The stress state in which all stresses occur only in the principal loading plane. No stresses occur out of the plane, i.e.,  $\sigma_z = 0$ , and  $\epsilon_z \neq 0$ .

*Plastic Strain During Loading*.—Plastic strain during loading is the portion of the strain during loading determined as the offset from the linear portion to the end of a stress-strain curve made during load application.

*Plane-Strain Fracture Toughness*.—A generic term now generally adopted for the critical plane-strain stress intensity factor characteristic of plane-strain fracture, symbolically denoted  $K_{Ic}$ . This is because in current fracture testing practices, specification of the slowly increasing load test of specimen materials in the plane-strain stress state and in opening mode (I) has been dominant.

*Plane-Stress and Transitional Fracture Toughness*.—A generic term denoting the critical stress intensity factor associated with fracture behavior under nonplane-strain conditions. Because of plasticity effects and stable crack growth which can be encountered prior to fracture under these conditions, designation of a specific value is dependent on the stage of crack growth detected during testing. Residual strength or apparent fracture toughness is a special case of plane-stress and transitional fracture toughness wherein the reference crack length is the initial pre-existing crack length and subsequent crack growth during the test is neglected.

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\* Different from ASTM.

*Population.*—All potential measurements having certain independent characteristics in common; i.e., “all possible TUS(L) measurements for 17-7PH stainless steel sheet in TH1050 condition”.

*Precision.\**—The degree of mutual agreement among individual measurements. Relative to a method of test, precision is the degree of mutual agreement among individual measurements made under prescribed like conditions. The lack of precision in a measurement may be characterized as the standard deviation of the errors in measurement.

*Primary Creep.*—Creep occurring at a diminishing rate, sometimes called initial stage of creep.

*Probability.*—Ratio of possible number of favorable events to total possible number of equally likely events. For example, if a coin is tossed, the probability of heads is one-half (or 50 percent) because heads can occur one way and the total possible events are two, either heads or tails. Similarly, the probability of throwing a three or greater on a die is 4/6 or 66.7 percent. Probability, as related to design allowables, means that chances of a material-property measurement equaling or exceeding a certain value (the one-sided lower tolerance limit) is 99 percent in the case of a A-basis value and 90 percent in the case of a B-basis value.

*Range.*—Range,  $\Delta P$ ,  $S_r$ ,  $\Delta \epsilon$ ,  $\epsilon_r$ ,  $\Delta \sigma$  is the algebraic difference between successive valley and peak loads (positive range or increasing load range) or between successive peak and valley loads (negative range or decreasing load range), see Figure 9.3.4.3. In constant-amplitude loading, for example, the range is given by  $\Delta P = P_{\max} - P_{\min}$ .

*Rate of Creep.*—The slope of the creep-time curve at a given time determined from a Cartesian plot.

*Residual.\**—The difference between the observed fatigue (log) life and the fatigue (log) life estimated from the fatigue model at a particular stress/strain level.

*Runout.\**—A test that has been terminated prior to failure. Runout tests are usually stopped at an arbitrary life value because of time and economic considerations. NOTE—Runout tests are useful for estimating a pseudo-fatigue-limit for a fatigue data sample.

*Sample.*—A finite number of observations drawn from the population.

*Sample.*—The number of specimens selected from a population for test purposes. NOTE—The method of selecting the sample determines the population about which statistical inferences or generalization can be made.

*Sample Average (Arithmetic Mean).*—The sum of all the observed values in a sample divided by the sample size (number). It is a point estimate of the population mean.

*Sample Mean.*—Average of all observed values in the sample. It is an estimate of population mean. A mean is indicated by a bar over the symbol for the value observed. Thus, the mean of n observations of TUS would be expressed as:

$$\overline{TUS} = \frac{TUS_1 + TUS_2 + \dots + TUS_n}{n} = \frac{\sum_{i=1}^n (TUS_i)}{n}$$

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\* Different from ASTM.

*Sample Median.*—Value of the middle-most observation. If the sample is nearly normally distributed, the sample median is also an estimate of the population mean.

*Sample Median.*—The middle value when all observed values in a sample are arranged in order of magnitude if an odd number of samples are tested. If the sample size is even, it is the average of the two middlemost values. It is a point estimate of the population median, or 50 percentile point.

*Sample Point Deviation.*—The difference between an observed value and the sample mean.

*Sample Standard Deviation.\**—The standard deviation of the sample,  $s$ , is the square root of the sample variance. It is a point estimate of the standard deviation of a population, a measure of the "spread" of the frequency distribution of a population. NOTE—This value of  $s$  provides a statistic that is used in computing interval estimates and several test statistics.

*Sample Variance.\**—Sample variance,  $s^2$ , is the sum of the squares of the differences between each observed value and the sample average divided by the sample size minus one. It is a point estimate of the population variance. NOTE—This value of  $s^2$  provides both an unbiased point estimate of the population variance and a statistic that is used on computing the interval estimates and several test statistics. Some texts define  $s^2$  as "the sum of the squared differences between each observed value and the sample average divided by the sample size", however, this statistic underestimates the population variance, particularly for small sample sizes.

*Sample Variance.*—The sum of the squared deviations, divided by  $n - 1$ , and, based on  $n$  observations of TUS, expressed as

$$S_{TUS}^2 = \frac{\sum_{i=1}^n (TUS_i - \overline{TUS})^2}{n - 1} = \frac{n \sum_{i=1}^n (TUS_i)^2 - \left( \sum_{i=1}^n TUS_i \right)^2}{n(n - 1)}$$

*S-Basis.*—The S-value is the minimum property value specified by the governing industry specification (as issued by standardization groups such as SAE Aerospace Materials Division, ASTM, etc.) or federal or military standards for the material. (See MIL-STD-970 for order of preference for specifications.) For certain products heat treated by the user (for example, steels hardened and tempered to a designated  $F_w$ ), the S-value may reflect a specified quality-control requirement. Statistical assurance associated with this value is not known.

*Secondary Creep.*—Creep occurring at a constant rate, sometimes called second stage creep.

*Short-Transverse Direction.*—The transverse direction having the smallest dimension, often called the "thickness" direction. For die forgings this direction is within  $\pm 15^\circ$  of the longitudinal (predominate) grain direction and perpendicular, within  $\pm 15^\circ$ , to the parting plane. (Both conditions must be met.) When possible, short transverse specimens shall be taken across the parting plane.

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\* Different from ASTM.

*Significance Level (As Used Here).*—Risk of concluding that two samples were drawn from different populations when, in fact, they were drawn from the same population. A significance level of  $\alpha = 0.05$  is employed through these Guidelines.\*

*Significance Level.*—The stated probability (risk) that a given test of significance will reject the hypothesis that a specified effect is absent when the hypothesis is true.

*Significant (Statistically Significant).*—An effect or difference between populations is said to be present if the value of a test statistic is significant, that is, lies outside of predetermined limits. NOTE—An effect that is statistically significant may not have engineering importance.

*S/N Curve for 50 Percent Survival.\*\**—A curve fitted to the median values of fatigue life at each of several stress levels. It is an estimate of the relationship between applied stress and the number of cycles-to-failure that 50 percent of the population would survive. NOTE 1—This is a special case of the more general definition of S/N curve for P percent survival. NOTE 2—In the literature, the abbreviated term “S/N Curve” usually has meant either the S/N curve drawn through the mean (averages) or through the medians (50 percent values) for the fatigue life values. Since the term “S/N Curve” is ambiguous, it should be used only when described appropriately. NOTE 3—Mean S/N curves (based on log lives) are shown in MIL-HDBK-5.

*S/N Diagram.*—A plot of stress against the number of cycles to failure. The stress can be  $S_{\max}$ ,  $S_{\min}$ , or  $S_a$ . The diagram indicates the S/N relationship for a specified value of  $S_m$ , A, or R and a specified probability of survival. Typically, for N, a log scale (base 10) is used. Generally, for S, a linear scale is used, but a log scale is used occasionally. NOTE— $S_{\max}$ -versus-log N diagrams are used commonly in MIL-HDBK-5.

*Standard Deviation.*—An estimate of the population standard deviation; the square root of the variance, or

$$S_{TUS} = \sqrt{\frac{\sum_{i=1}^n (TUS_i - \overline{TUS})^2}{n - 1}} = \sqrt{\frac{n \sum_{i=1}^n (TUS_i)^2 - \sum_{i=1}^n (TUS_i)^2}{n(n - 1)}}$$

*Stress Intensity Factor.*—A physical quantity describing the severity of a flaw in the stress field of a loaded structural element. The gross stress in the material and flaw size are characterized parametrically by the stress intensity factor,

$$K = f\sqrt{a} Y, \text{ ksi} \cdot \text{in.}^{1/2} \quad [9.5.1.2]$$

*Stress-Rupture Test*—A stress-rupture test is one in which time for rupture is measured, no deformation measurement being made during the test.

*Tertiary Creep.*—Creep occurring at an accelerating rate, sometimes called third stage creep.

*Theoretical Stress Concentration Factor (or Stress Concentration Factor).*—This factor,  $K_t$ , is the ratio of the nominal stress to the greatest stress in the region of a notch (or other stress concentrator) as determined

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\* This is appropriate, since a confidence level of  $1 - \alpha = 0.95$  is used in establishing A and B-values.

\*\* Different from ASTM.



by the theory of elasticity (or by experimental procedures that give equivalent values). NOTE—The theory of plasticity should not be used to determine  $K_t$ .

*Tolerance Interval.*—An interval computed so that it will include at least a stated percentage of the population with a stated probability.

*Tolerance Level.*—The stated probability that the tolerance interval includes at least the stated percentage of the population. It is not the same as a confidence level, but the term confidence level is frequently associated with tolerance intervals.

*Tolerance Limits.*—The two statistics that define a tolerance interval. (One value may be “minus infinity” or “plus infinity”.)

*Total Plastic Strain.*—Total plastic strain at a specified time is equal to the sum of plastic strain during loading plus creep.

*Total Strain.*—Total strain at any given time, including initial loading strain (which may include plastic strain in addition to elastic strain) and creep strain, but not including thermal expansion.

*Transition Fatigue Life.\**—The point on a strain-life diagram where the elastic and plastic strains are equal.

*Transverse Direction.*—Perpendicular to the principal direction of flow in a worked metal; may be defined as T, LT or ST.

*Typical Basis.*—A typical property value is an average value and has no statistical assurance associated with it.

*Waveform.*—The shape of the peak-to-peak variation of a controlled mechanical test variable (for example, load, strain, displacement) as a function of time.

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\* Different from ASTM.

A.4 Conversion of U.S. Units of Measure Used in MIL-HDBK-5 to SI Units

| Quantity or Property           | To Convert From U. S. Unit                                                                             | Multiply by <sup>a</sup> | SI Unit <sup>b</sup>                                                       |
|--------------------------------|--------------------------------------------------------------------------------------------------------|--------------------------|----------------------------------------------------------------------------|
| Area                           | in. <sup>2</sup>                                                                                       | 645.16 <sup>c</sup>      | Millimeter <sup>2</sup> (mm <sup>2</sup> )                                 |
| Force                          | lb                                                                                                     | 4.4482                   | Newton (N)                                                                 |
| Length                         | in.                                                                                                    | 25.4 <sup>c</sup>        | Millimeter (mm)                                                            |
| Stress                         | ksi                                                                                                    | 6.895                    | Megapascal (MPa) <sup>d</sup>                                              |
| Stress intensity factor        | ksi $\sqrt{\text{in.}}$                                                                                | 1.0989                   | Megapascal $\sqrt{\text{meter}}$<br>(MPa · m <sup>1/2</sup> ) <sup>d</sup> |
| Modulus                        | 10 <sup>3</sup> ksi                                                                                    | 6.895                    | Gigapascal (GPa) <sup>d</sup>                                              |
| Temperature                    | °F                                                                                                     | $\frac{F + 459.67}{1.8}$ | Kelvin (K)                                                                 |
| Density ( $\omega$ )           | lb/in. <sup>3</sup>                                                                                    | 27.680                   | Megagram/meter <sup>3</sup><br>(Mg/m <sup>3</sup> )                        |
| Specific heat (C)              | Btu/lb·F<br>(or Btu·lb <sup>-1</sup> ·F <sup>-1</sup> )                                                | 4.1868 <sup>c</sup>      | Joule/(gram·Kelvin)<br>(J/g·K) or (J·g <sup>-1</sup> ·K <sup>-1</sup> )    |
| Thermal conductivity (K)       | Btu/[(hr)(ft <sup>2</sup> )(F)/ft]<br>(or Btu·hr <sup>-1</sup> ·ft <sup>-2</sup> ·F <sup>-1</sup> ·ft) | 1.7307                   | Watt/(meter·Kelvin)<br>W/(m·K) or (W·m <sup>-1</sup> ·K <sup>-1</sup> )    |
| Thermal expansion ( $\alpha$ ) | in./in./F<br>(or in.·in. <sup>-1</sup> ·F <sup>-1</sup> )                                              | 1.8                      | Meter/meter/Kelvin<br>m/(m·K) or (m·m <sup>-1</sup> ·K <sup>-1</sup> )     |

a Conversion factors to give significant figures are as specified in ASTM E 380, NASA SP-7012, second revision. NBS Special Publication 330, and *Metals Engineering Quarterly*. Note: Multiple conversions between U.S. and SI units should be avoided because significant round-off errors may result.

|          |                 |                 |                  |
|----------|-----------------|-----------------|------------------|
| b Prefix | Multiple        | Prefix          | Multiple         |
| giga (G) | 10 <sup>9</sup> | milli (m)       | 10 <sup>-3</sup> |
| mega (M) | 10 <sup>6</sup> | micro ( $\mu$ ) | 10 <sup>-6</sup> |
| kilo (k) | 10 <sup>3</sup> |                 |                  |

c Conversion factor is exact.

d One Pascal (Pa) = one Newton/meter<sup>2</sup>.

## ***APPENDIX B***

### **B.0 Alloy Index**

| <b>Alloy Name</b> | <b>Form</b>                          | <b>Specification</b> | <b>Section</b> |
|-------------------|--------------------------------------|----------------------|----------------|
| 250               | Bar                                  | AMS 6512             | 2.5.1          |
| 250               | Sheet and Plate                      | AMS 6520             | 2.5.1          |
| 354.0             | Casting                              | AMS-A-21180          | 3.9.1          |
| 355.0             | Permanent Mold Casting               | AMS 4281             | 3.9.2          |
| 356.0             | Sand Casting                         | AMS 4217             | 3.9.4          |
| 356.0             | Investment Casting                   | AMS 4260             | 3.9.4          |
| 356.0             | Permanent Mold Casting               | AMS 4284             | 3.9.4          |
| 359.0             | Casting                              | AMS-A-21180          | 3.9.8          |
| 2014              | Bare Sheet and Plate                 | AMS 4028             | 3.2.1          |
| 2014              | Bare Sheet and Plate                 | AMS 4029             | 3.2.1          |
| 2014              | Bar and Rod, Rolled or Cold Finished | AMS 4121             | 3.2.1          |
| 2014              | Forging                              | AMS 4133             | 3.2.1          |
| 2014              | Extrusion                            | AMS 4153             | 3.2.1          |
| 2014              | Forging                              | AMS-A-22771          | 3.2.1          |
| 2014              | Extruded Bar, Rod and Shapes         | AMS-QQ-A-200/2       | 3.2.1          |
| 2014              | Rolled or Drawn Bar, Rod and Shapes  | AMS-QQ-A-225/4       | 3.2.1          |
| 2014              | Clad Sheet and Plate                 | AMS-QQ-A-250/3       | 3.2.1          |
| 2014              | Forging                              | AMS-QQ-A-367         | 3.2.1          |
| 2017              | Bar and Rod, Rolled or Cold-Finished | AMS 4118             | 3.2.2          |
| 2017              | Rolled Bar and Rod                   | AMS-QQ-A-225/5       | 3.2.2          |
| 2024              | Bare Sheet and Plate                 | AMS 4035             | 3.2.3          |
| 2024              | Bare Sheet and Plate                 | AMS 4037             | 3.2.3          |
| 2024              | Tubing, Hydraulic, Seamless, Drawn   | AMS 4086             | 3.2.3          |
| 2024              | Bar and Rod, Rolled or Cold-Finished | AMS 4120             | 3.2.3          |
| 2024              | Extrusion                            | AMS 4152             | 3.2.3          |
| 2024              | Extrusion                            | AMS 4164             | 3.2.3          |
| 2024              | Extrusion                            | AMS 4165             | 3.2.3          |
| 2024              | Extruded Bar, Rod and Shapes         | AMS-QQ-A-200/3       | 3.2.3          |
| 2024              | Rolled or Drawn Bar, Rod and Wire    | AMS-QQ-A-225/6       | 3.2.3          |
| 2024              | Bare Sheet and Plate                 | AMS-QQ-A-250/4       | 3.2.3          |
| 2024              | Clad Sheet and Plate                 | AMS-QQ-A-250/5       | 3.2.3          |
| 2024              | Tubing                               | AMS-WW-T-700/3       | 3.2.3          |
| 2025              | Die Forging                          | AMS 4130             | 3.2.4          |
| 2090              | Sheet                                | AMS 4251             | 3.2.5          |
| 2124              | Plate                                | AMS 4101             | 3.2.6          |
| 2124              | Plate                                | AMS-QQ-A-250/29      | 3.2.6          |
| 2219              | Sheet and Plate                      | AMS 4031             | 3.2.7          |
| 2219              | Hand Forging                         | AMS 4144             | 3.2.7          |
| 2219              | Extrusion                            | AMS 4162             | 3.2.7          |
| 2219              | Extrusion                            | AMS 4163             | 3.2.7          |
| 2219              | Sheet and Plate                      | AMS-QQ-A-250/30      | 3.2.7          |
| 2424              | Sheet (Clad)                         | AMS 4270             | 3.2.8          |
| 2424              | Sheet (Bare)                         | AMS 4273             | 3.2.8          |
| 2519              | Plate                                | MIL-A-46192          | 3.2.9          |

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Key: Underline indicates inactive for new design.

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| <b>Alloy Name</b> | <b>Form</b>                          | <b>Specification</b> | <b>Section</b> |
|-------------------|--------------------------------------|----------------------|----------------|
| 2524              | Sheet and Plate                      | AMS 4296             | 3.2.10         |
| 2618              | Die and Hand Forgings                | AMS 4132             | 3.2.11         |
| 2618              | Die Forging                          | AMS-A-22771          | 3.2.11         |
| 2618              | Forging                              | AMS-QQ-A-367         | 3.2.11         |
| 4130              | Bar and Forging                      | AMS 6348             | 2.3.1          |
| 4130              | Sheet, Strip and Plate               | AMS 6350             | 2.3.1          |
| 4130              | Sheet, Strip and Plate               | AMS 6351             | 2.3.1          |
| 4130              | Tubing                               | AMS 6361             | 2.3.1          |
| 4130              | Tubing                               | AMS 6362             | 2.3.1          |
| 4130              | Bar and Forging                      | AMS 6370             | 2.3.1          |
| 4130              | Tubing                               | AMS 6371             | 2.3.1          |
| 4130              | Tubing                               | AMS 6373             | 2.3.1          |
| 4130              | Tubing                               | AMS 6374             | 2.3.1          |
| 4130              | Bar and Forging                      | AMS 6528             | 2.3.1          |
| 4130              | Sheet, Strip and Plate               | AMS-S-18729          | 2.3.1          |
| 4130              | Bar and Forging                      | AMS-S-6758           | 2.3.1          |
| 4130              | Tubing                               | AMS-T-6736           | 2.3.1          |
| 4135              | Sheet, Strip and Plate               | AMS 6352             | 2.3.1          |
| 4135              | Tubing                               | AMS 6365             | 2.3.1          |
| 4135              | Tubing                               | AMS 6372             | 2.3.1          |
| 4135              | Tubing                               | AMS-T-6735           | 2.3.1          |
| 4140              | Bar and Forging                      | AMS 6349             | 2.3.1          |
| 4140              | Tubing                               | AMS 6381             | 2.3.1          |
| 4140              | Bar and Forging                      | AMS 6382             | 2.3.1          |
| 4140              | Sheet, Strip and Plate               | AMS 6395             | 2.3.1          |
| 4140              | Bar and Forging                      | AMS 6529             | 2.3.1          |
| 4140              | Bar and Forging                      | MIL-S-5626           | 2.3.1          |
| 4340              | Sheet, Strip and Plate               | AMS 6359             | 2.3.1          |
| 4340              | Bar and Forging                      | AMS 6414             | 2.3.1          |
| 4340              | Tubing                               | AMS 6414             | 2.3.1          |
| 4340              | Bar and Forging                      | AMS 6415             | 2.3.1          |
| 4340              | Tubing                               | AMS 6415             | 2.3.1          |
| 4340              | Sheet, Strip and Plate               | AMS 6454             | 2.3.1          |
| 4340              | Bar and Forging                      | MIL-S-5000           | 2.3.1          |
| 5052              | Sheet and Plate                      | AMS 4015             | 3.5.1          |
| 5052              | Sheet and Plate                      | AMS 4016             | 3.5.1          |
| 5052              | Sheet and Plate                      | AMS 4017             | 3.5.1          |
| 5052              | Sheet and Plate                      | AMS-QQ-A-250/8       | 3.5.1          |
| 5083              | Bare Sheet and Plate                 | AMS 4056             | 3.5.2          |
| 5083              | Extruded Bar, Rod and Shapes         | AMS-QQ-A-200/4       | 3.5.2          |
| 5083              | Bare Sheet and Plate                 | AMS-QQ-A-250/6       | 3.5.2          |
| 5086              | Extruded Bar, Rod and Shapes         | AMS-QQ-A-200/5       | 3.5.3          |
| 5086              | Sheet and Plate                      | AMS-QQ-A-250/7       | 3.5.3          |
| 5454              | Extruded Bar, Rod and Shapes         | AMS-QQ-A-200/6       | 3.5.4          |
| 5454              | Sheet and Plate                      | AMS-QQ-A-250/10      | 3.5.4          |
| 5456              | Extruded Bar, Rod and Shapes         | AMS-QQ-A-200/7       | 3.5.5          |
| 5456              | Sheet and Plate                      | AMS-QQ-A-250/9       | 3.5.5          |
| 6061              | Sheet and Plate                      | AMS 4025             | 3.6.2          |
| 6061              | Sheet and Plate                      | AMS 4026             | 3.6.2          |
| 6061              | Sheet and Plate                      | AMS 4027             | 3.6.2          |
| 6061              | Tubing Seamless, Drawn               | AMS 4080             | 3.6.2          |
| 6061              | Tubing Seamless, Drawn               | AMS 4082             | 3.6.2          |
| 6061              | Bar and Rod, Rolled or Cold Finished | AMS 4115             | 3.6.2          |

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Key: Underline indicates inactive for new design.

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| <b>Alloy Name</b> | <b>Form</b>                          | <b>Specification</b> | <b>Section</b> |
|-------------------|--------------------------------------|----------------------|----------------|
| 6061              | Bar and Rod, Cold Finished           | AMS 4116             | 3.6.2          |
| 6061              | Bar and Rod, Rolled or Cold Finished | AMS 4117             | 3.6.2          |
| 6061              | Forging                              | AMS 4127             | 3.6.2          |
| 6061              | Extrusion                            | AMS 4160             | 3.6.2          |
| 6061              | Extrusion                            | AMS 4161             | 3.6.2          |
| 6061              | Extrusion                            | AMS 4172             | 3.6.2          |
| 6061              | Hand Forging                         | AMS 4248             | 3.6.2          |
| 6061              | Forging                              | AMS-A-22771          | 3.6.2          |
| 6061              | Pipe                                 | MIL-P-25995          | 3.6.2          |
| 6061              | Extruded Rod, Bar Shapes and Tubing  | AMS-QQ-A-200/8       | 3.6.2          |
| 6061              | Rolled Bar, Rod and Shapes           | AMS-QQ-A-225/8       | 3.6.2          |
| 6061              | Sheet and Plate                      | AMS-QQ-A-250/11      | 3.6.2          |
| 6061              | Forging                              | AMS-QQ-A-367         | 3.6.2          |
| 6061              | Tubing Seamless, Drawn               | AMS-WW-T-700/6       | 3.6.2          |
| 6151              | Die Forging                          | AMS 4125             | 3.6.3          |
| 6151              | Forging                              | AMS-A-22771          | 3.6.3          |
| 7010              | Plate                                | AMS 4204             | 3.7.1          |
| 7010              | Plate                                | AMS 4205             | 3.7.1          |
| 7040              | Plate                                | AMS 4211             | 3.7.2          |
| 7050              | Bare Plate                           | AMS 4050             | 3.7.4          |
| 7050              | Die Forging                          | AMS 4107             | 3.7.4          |
| 7050              | Hand Forging                         | AMS 4108             | 3.7.4          |
| 7050              | Bare Plate                           | AMS 4201             | 3.7.4          |
| 7050              | Die Forging                          | AMS 4333             | 3.7.4          |
| 7050              | Extruded Shape                       | AMS 4340             | 3.7.4          |
| 7050              | Extruded Shape                       | AMS 4341             | 3.7.4          |
| 7050              | Extruded Shape                       | AMS 4342             | 3.7.4          |
| 7050              | Forging                              | AMS-A-22771          | 3.7.4          |
| 7055              | Plate                                | AMS 4206             | 3.7.5          |
| 7055              | Extrusion                            | AMS 4337             | 3.7.5          |
| 7075              | Bare Sheet and Plate                 | AMS 4044             | 3.7.6          |
| 7075              | Bare Sheet and Plate                 | AMS 4045             | 3.7.6          |
| 7075              | Clad Sheet and Plate                 | AMS 4049             | 3.7.6          |
| 7075              | Bare Plate                           | AMS 4078             | 3.7.6          |
| 7075              | Bar and Rod, Rolled or Cold Finished | AMS 4122             | 3.7.6          |
| 7075              | Bar and Rod, Rolled or Cold Finished | AMS 4123             | 3.7.6          |
| 7075              | Bar and Rod, Rolled or Cold Finished | AMS 4124             | 3.7.6          |
| 7075              | Forging                              | AMS 4126             | 3.7.6          |
| 7075              | Die Forging                          | AMS 4141             | 3.7.6          |
| 7075              | Forging                              | AMS 4147             | 3.7.6          |
| 7075              | Bar and Rod, Rolled or Cold Finished | AMS 4186             | 3.7.6          |
| 7075              | Bar and Rod, Rolled or Cold Finished | AMS 4187             | 3.7.6          |
| 7075              | Forging                              | AMS-A-22771          | 3.7.6          |
| 7075              | Extruded Bar, Rod and Shapes         | AMS-QQ-A-200/11, 15  | 3.7.6          |
| 7075              | Rolled or Drawn Bar and Rod          | AMS-QQ-A-225/9       | 3.7.6          |
| 7075              | Bare Sheet and Plate                 | AMS-QQ-A-250/12, 24  | 3.7.6          |
| 7075              | Clad Sheet and Plate                 | AMS-QQ-A-250/13, 25  | 3.7.6          |
| 7075              | Forging                              | AMS-QQ-A-367         | 3.7.6          |
| 7150              | Bare Plate                           | AMS 4252 (T7751)     | 3.7.7          |
| 7150              | Bare Plate                           | AMS 4306 (T6151)     | 3.7.7          |
| 7150              | Extrusion                            | AMS 4307 (T61511)    | 3.7.7          |
| 7150              | Extrusion                            | AMS 4345 (T77511)    | 3.7.7          |
| 7175              | Die Forging                          | AMS 4148 (T66)       | 3.7.8          |

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Key: Underline indicates inactive for new design.

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| <b>Alloy Name</b>               | <b>Form</b>                             | <b>Specification</b> | <b>Section</b> |
|---------------------------------|-----------------------------------------|----------------------|----------------|
| 7175                            | Die and Hand Forging                    | AMS 4149 (T74)       | 3.7.8          |
| 7175                            | Hand Forging                            | AMS 4179 (T7452)     | 3.7.8          |
| 7175                            | Extrusion                               | AMS 4344 (T73511)    | 3.7.8          |
| 7175                            | Forging                                 | AMS-A-22771          | 3.7.8          |
| 7249                            | Hand Forging                            | AMS 4334             | 3.7.9          |
| 7475                            | Bare Sheet                              | AMS 4084 (T61)       | 3.7.10         |
| 7475                            | Bare Sheet                              | AMS 4085 (T761)      | 3.7.10         |
| 7475                            | Bare Plate                              | AMS 4089 (T7651)     | 3.7.10         |
| 7475                            | Bare Plate                              | AMS 4090 (T651)      | 3.7.10         |
| 7475                            | Clad Sheet                              | AMS 4100 (T761)      | 3.7.10         |
| 7475                            | Bare Plate                              | AMS 4202 (T7351)     | 3.7.10         |
| 7475                            | Clad Sheet                              | AMS 4207 (T61)       | 3.7.10         |
| 8630                            | Bar and Forging                         | AMS 6280             | 2.3.1          |
| 8630                            | Tubing                                  | AMS 6281             | 2.3.1          |
| 8630                            | Sheet, Strip and Plate                  | MIL-S-18728          | 2.3.1          |
| 8630                            | Bar and Forging                         | MIL-S-6050           | 2.3.1          |
| 8735                            | Tubing                                  | AMS 6282             | 2.3.1          |
| 8735                            | Bar and Forging                         | AMS 6320             | 2.3.1          |
| 8735                            | Sheet, Strip and Plate                  | AMS 6357             | 2.3.1          |
| 8740                            | Bar and Forging                         | AMS 6322             | 2.3.1          |
| 8740                            | Tubing                                  | AMS 6323             | 2.3.1          |
| 8740                            | Bar and Forging                         | AMS 6327             | 2.3.1          |
| 8740                            | Sheet, Strip and Plate                  | AMS 6358             | 2.3.1          |
| 8740                            | Bar and Forging                         | AMS-S-6049           | 2.3.1          |
| 15-5PH                          | Investment Casting                      | AMS 5400             | 2.6.6          |
| 15-5PH                          | Bar, Forging, Ring and Extrusion (CEVM) | AMS 5659             | 2.6.6          |
| 15-5PH                          | Sheet, Strip and Plate (CEVM)           | AMS 5862             | 2.6.6          |
| 17-4PH                          | Investment Casting (H1100)              | AMS 5342             | 2.6.8          |
| 17-4PH                          | Investment Casting (H1000)              | AMS 5343             | 2.6.8          |
| 17-4PH                          | Investment Casting (H900)               | AMS 5344             | 2.6.8          |
| 17-4PH                          | Sheet, Strip and Plate                  | AMS 5604             | 2.6.8          |
| 17-4PH                          | Bar, Forging and Ring                   | AMS 5643             | 2.6.8          |
| 17-7PH                          | Plate, Sheet and Strip                  | AMS 5528             | 2.6.9          |
| 17-7PH                          | Plate, Sheet and Strip                  | MIL-S-25043          | 2.6.9          |
| 2024-T3 ARAMID Fiber Reinforced | Sheet Laminate                          | AMS 4254             | 7.5.1          |
| 280 (300)                       | Bar                                     | AMS 6514             | 2.5.1          |
| 280 (300)                       | Sheet and Plate                         | AMS 6521             | 2.5.1          |
| 300M (0.42C)                    | Bar and Forging                         | AMS 6257             | 2.3.1          |
| 300M (0.42C)                    | Tubing                                  | AMS 6257             | 2.3.1          |
| 300M (0.42C)                    | Bar and Forging                         | AMS 6419             | 2.3.1          |
| 300M (0.42C)                    | Tubing                                  | AMS 6419             | 2.3.1          |
| 300M (0.4C)                     | Bar and Forging                         | AMS 6417             | 2.3.1          |
| 300M (0.4C)                     | Tubing                                  | AMS 6417             | 2.3.1          |
| 4130 - N                        | Tubing                                  | AMS 6360             | 2.3.1          |
| 4330V                           | Bar and Forging                         | AMS 6411             | 2.3.1          |
| 4330V                           | Tubing                                  | AMS 6411             | 2.3.1          |
| 4330V                           | Bar and Forging                         | AMS 6427             | 2.3.1          |
| 4330V                           | Tubing                                  | AMS 6427             | 2.3.1          |
| 4335V                           | Bar and Forging                         | AMS 6429             | 2.3.1          |
| 4335V                           | Tubing                                  | AMS 6429             | 2.3.1          |
| 4335V                           | Bar and Forging                         | AMS 6430             | 2.3.1          |
| 4335V                           | Tubing                                  | AMS 6430             | 2.3.1          |
| 4335V                           | Sheet, Strip and Plate                  | AMS 6433             | 2.3.1          |

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Key: Underline indicates inactive for new design.

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| <b>Alloy Name</b>                 | <b>Form</b>                      | <b>Specification</b> | <b>Section</b> |
|-----------------------------------|----------------------------------|----------------------|----------------|
| 4335V                             | Sheet, Strip and Plate           | AMS 6435             | 2.3.1          |
| 5Cr-Mo-V                          | Sheet, Strip and Plate           | AMS 6437             | 2.4.1          |
| 5Cr-Mo-V                          | Bar and Forging (CEVM)           | AMS 6487             | 2.4.1          |
| 5Cr-Mo-V                          | Bar and Forging                  | AMS 6488             | 2.4.1          |
| 6013-T4                           | Sheet                            | AMS 4216             | 3.6.1          |
| 6013-T6                           | Sheet                            | AMS 4347             | 3.6.1          |
| 7049/7149                         | Forging                          | AMS 4111             | 3.7.3          |
| 7049/7149                         | Extrusion                        | AMS 4157             | 3.7.3          |
| 7049/7149                         | Plate                            | AMS 4200             | 3.7.3          |
| 7049/7149                         | Forging                          | AMS 4320             | 3.7.3          |
| 7049/7149                         | Extrusion                        | AMS 4343             | 3.7.3          |
| 7049/7149                         | Forging                          | AMS-A-22771          | 3.7.3          |
| 7049/7149                         | Forging                          | AMS-QQ-A-367         | 3.7.3          |
| 7475-T761 ARAMID Fiber Reinforced | Sheet Laminate                   | AMS 4302             | 7.5.2          |
| 9Ni-4Co-0.20C                     | Sheet, Strip and Plate           | AMS 6523             | 2.4.2          |
| 9Ni-4Co-0.20C                     | Sheet, Strip and Plate           | AMS 6524             | 2.4.3          |
| 9Ni-4Co-0.20C                     | Bar and Forging, Tubing          | AMS 6526             | 2.4.3          |
| A201.0                            | Casting (T7 Temper)              | AMS-A-21180          | 3.8.1          |
| A-286                             | Sheet, Strip and Plate           | AMS 5525             | 6.2.1          |
| A-286                             | Bar, Forging, Tubing and Ring    | AMS 5731             | 6.2.1          |
| A-286                             | Bar, Forging, Tubing and Ring    | AMS 5732             | 6.2.1          |
| A-286                             | Bar, Forging and Tubing          | AMS 5734             | 6.2.1          |
| A-286                             | Bar, Forging and Tubing          | AMS 5737             | 6.2.1          |
| A356.0                            | Casting                          | AMS 4218             | 3.9.5          |
| A356.0                            | Casting                          | AMS-A-21180          | 3.9.5          |
| A357.0                            | Casting                          | AMS-A-21180          | 3.9.6          |
| AerMet 100                        | Bar and Forging                  | AMS 6478             | 2.5.3          |
| AerMet 100                        | Bar and Forging                  | AMS 6532             | 2.5.3          |
| AF1410                            | Bar and Forging                  | AMS 6527             | 2.5.2          |
| AISI 1025                         | Sheet, Strip, and Plate          | AMS 5046             | 2.2.1          |
| AISI 1025                         | Bar                              | ASTM A 108           | 2.2.1          |
| AISI 1025                         | Sheet and Strip                  | AMS-S-7952           | 2.2.1          |
| AISI 1025                         | Tubing                           | AMS 5077             | 2.2.1          |
| AISI 1025 - N                     | Seamless Tubing                  | AMS 5075             | 2.2.1          |
| AISI 1025 - N                     | Tubing                           | AMS 5077             | 2.2.1          |
| AISI 1025 - N                     | Tubing                           | AMS-T-5066           | 2.2.1          |
| AISI 301                          | Sheet and Strip                  | AMS 5517             | 2.7.1          |
| AISI 301                          | Sheet and Strip                  | AMS 5518             | 2.7.1          |
| AISI 301                          | Sheet and Strip                  | AMS 5519             | 2.7.1          |
| AISI 301                          | Sheet, Strip and Plate           | AMS 5901             | 2.7.1          |
| AISI 301                          | Sheet and Strip (175 ksi)        | AMS 5902             | 2.7.1          |
| AISI 302                          | Sheet, Strip and Plate           | AMS 5516             | 2.7.1          |
| AISI 302                          | Sheet and Strip (125 ksi)        | AMS 5903             | 2.7.1          |
| AISI 302                          | Sheet and Strip (150 ksi)        | AMS 5904             | 2.7.1          |
| AISI 302                          | Sheet and Strip (175 ksi)        | AMS 5905             | 2.7.1          |
| AISI 302                          | Sheet and Strip (185 ksi)        | AMS 5906             | 2.7.1          |
| AISI 304                          | Sheet and Strip                  | AMS 5913             | 2.7.1          |
| AISI 304                          | Sheet, Strip and Plate (125 ksi) | AMS 5910             | 2.7.1          |
| AISI 304                          | Sheet and Strip (150 ksi)        | AMS 5911             | 2.7.1          |
| AISI 304                          | Sheet and Strip (175 ksi)        | AMS 5912             | 2.7.1          |
| AISI 304                          | Sheet and Strip (185 ksi)        | AMS 5913             | 2.7.1          |
| AISI 316                          | Sheet and Strip                  | AMS 5924             | 2.7.1          |
| AISI 316                          | Sheet, Strip and Plate (125 ksi) | AMS 5907             | 2.7.1          |

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| <b>Alloy Name</b> | <b>Form</b>                                      | <b>Specification</b> | <b>Section</b> |
|-------------------|--------------------------------------------------|----------------------|----------------|
| Alloy 188         | Sheet and Plate                                  | AMS 5608             | 6.4.2          |
| Alloy 188         | Bar and Forging                                  | AMS 5772             | 6.4.2          |
| AM100A            | Investment Casting                               | AMS 4455             | 4.3.1          |
| AM100A            | Permanent Mold Casting                           | AMS 4483             | 4.3.1          |
| AM100A            | Casting                                          | MIL-M-46062          | 4.3.1          |
| AM-350            | Sheet and Strip                                  | AMS 5548             | 2.6.1          |
| AM-355            | Sheet and Strip                                  | AMS 5547             | 2.6.2          |
| AM-355            | Plate                                            | AMS 5549             | 2.6.2          |
| AM-355            | Bar, Forging and Forging Stock                   | AMS 5743             | 2.6.2          |
| AZ31B             | Sheet and Plate                                  | AMS 4375             | 4.2.1          |
| AZ31B             | Plate                                            | AMS 4376             | 4.2.1          |
| AZ31B             | Sheet and Plate                                  | AMS 4377             | 4.2.1          |
| AZ31B             | Forging                                          | ASTM B 91            | 4.2.1          |
| AZ31B             | Extrusion                                        | ASTM B 107           | 4.2.1          |
| AZ61A             | Extrusion                                        | AMS 4350             | 4.2.2          |
| AZ61A             | Forging                                          | ASTM B 91            | 4.2.2          |
| AZ91C/AZ91E       | Sand Casting                                     | AMS 4437             | 4.3.2          |
| AZ91C/AZ91E       | Sand Casting                                     | AMS 4446             | 4.3.2          |
| AZ91C/AZ91E       | Investment Casting                               | AMS 4452             | 4.3.2          |
| AZ91C/AZ91E       | Casting                                          | MIL-M-46062          | 4.3.2          |
| AZ92A             | Sand Casting                                     | AMS 4434             | 4.3.3          |
| AZ92A             | Permanent Mold Casting                           | AMS 4484             | 4.3.3          |
| AZ92A             | Casting                                          | MIL-M-46062          | 4.3.3          |
| C355.0            | Casting                                          | AMS-A-21180          | 3.9.3          |
| Copper Beryllium  | Strip (TB00)                                     | AMS 4530             | 7.3.2          |
| Copper Beryllium  | Strip (TD02)                                     | AMS 4532             | 7.3.2          |
| Copper Beryllium  | Bar and Rod (TF00)                               | AMS 4533             | 7.3.2          |
| Copper Beryllium  | Bar and Rod (TH04)                               | AMS 4534             | 7.3.2          |
| Copper Beryllium  | Mechanical tubing (TF00)                         | AMS 4535             | 7.3.2          |
| Copper Beryllium  | Bar, Rod, Shapes and Forging (TB00)              | AMS 4650             | 7.3.2          |
| Copper Beryllium  | Bar and Rod (TD04)                               | AMS 4651             | 7.3.2          |
| Copper Beryllium  | Sheet (TB00, TD01, TD02, TD04)                   | ASTM B 194           | 7.3.2          |
| CP Titanium       | Sheet, Strip and Plate                           | AMS 4900             | 5.2.1          |
| CP Titanium       | Sheet, Strip and Plate                           | AMS 4901             | 5.2.1          |
| CP Titanium       | Sheet, Strip and Plate                           | AMS 4902             | 5.2.1          |
| CP Titanium       | Bar                                              | AMS 4921             | 5.2.1          |
| CP Titanium       | Extruded Bars and Shapes                         | AMS-T-81556          | 5.2.1          |
| CP Titanium       | Sheet, Strip and Plate                           | AMS-T-9046           | 5.2.1          |
| CP Titanium       | Bar                                              | MIL-T-9047           | 5.2.1          |
| Custom 450        | Bar, Forging, Tubing, Wire and Ring (air melted) | AMS 5763             | 2.6.3          |
| Custom 450        | Bar, Forging, Tubing, Wire and Ring (CEM)        | AMS 5773             | 2.6.3          |
| Custom 455        | Tubing (welded)                                  | AMS 5578             | 2.6.4          |
| Custom 455        | Bar and Forging                                  | AMS 5617             | 2.6.4          |
| D357.0            | Sand Composite Casting                           | AMS 4241             | 3.9.7          |
| D6AC              | Bar and Forging                                  | AMS 6431             | 2.3.1          |
| D6AC              | Tubing                                           | AMS 6431             | 2.3.1          |
| D6AC              | Bar and Forging                                  | AMS 6439             | 2.3.1          |
| D6AC              | Sheet, Strip and Plate                           | AMS 6439             | 2.3.1          |
| EZ33A             | Sand Casting                                     | AMS 4442             | 4.3.4          |
| Hastelloy X       | Sheet and Plate                                  | AMS 5536             | 6.3.1          |
| Hastelloy X       | Bar and Forging                                  | AMS 5754             | 6.3.1          |
| Haynes®230®       | Plate, Sheet, and Strip                          | AMS 5878             | 6.3.9          |
| Haynes®230®       | Bar and Forging                                  | AMS 5891             | 6.3.9          |

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| <b>Alloy Name</b>                | <b>Form</b>                                 | <b>Specification</b> | <b>Section</b> |
|----------------------------------|---------------------------------------------|----------------------|----------------|
| Hy-Tuf                           | Bar and Forging                             | AMS 6425             | 2.3.1          |
| Hy-Tuf                           | Tubing                                      | AMS 6425             | 2.3.1          |
| Inconel 718                      | Investment Casting                          | AMS 5383             | 6.3.5          |
| Inconel 718                      | Tubing; Creep Rupture                       | AMS 5589             | 6.3.5          |
| Inconel 718                      | Tubing; Short-Time                          | AMS 5590             | 6.3.5          |
| Inconel 718                      | Sheet, Strip and Plate; Creep Rupture       | AMS 5596             | 6.3.5          |
| Inconel 718                      | Sheet, Strip and Plate; Short-Time          | AMS 5597             | 6.3.5          |
| Inconel 718                      | Bar and Forging; Creep Rupture              | AMS 5662             | 6.3.5          |
| Inconel 718                      | Bar and Forging; Creep Rupture              | AMS 5663             | 6.3.5          |
| Inconel 718                      | Bar and Forging; Short-Time                 | AMS 5664             | 6.3.5          |
| Inconel Alloy 600                | Plate, Sheet and Strip                      | AMS 5540             | 6.3.2          |
| Inconel Alloy 600                | Tubing, Seamless                            | AMS 5580             | 6.3.2          |
| Inconel Alloy 600                | Bar and Rod                                 | ASTM B 166           | 6.3.2          |
| Inconel Alloy 600                | Forging                                     | ASTM B 564           | 6.3.2          |
| Inconel Alloy 625                | Sheet, Strip and Plate                      | AMS 5599             | 6.3.3          |
| Inconel Alloy 625                | Bar, Forging and Ring                       | AMS 5666             | 6.3.3          |
| Inconel Alloy 706                | Sheet, Strip and Plate                      | AMS 5605             | 6.3.4          |
| Inconel Alloy 706                | Sheet, Strip and Plate                      | AMS 5606             | 6.3.4          |
| Inconel Alloy 706                | Bar, Forging and Ring                       | AMS 5701             | 6.3.4          |
| Inconel Alloy 706                | Bar, Forging and Ring                       | AMS 5702             | 6.3.4          |
| Inconel Alloy 706                | Bar, Forging and Ring                       | AMS 5703             | 6.3.4          |
| Inconel Alloy X-750              | Sheet, Strip and Plate; Annealed            | AMS 5542             | 6.3.6          |
| Inconel Alloy X-750              | Bar and Forging; Equalized                  | AMS 5667             | 6.3.6          |
| L-605                            | Sheet                                       | AMS 5537             | 6.4.1          |
| L-605                            | Bar and Forging                             | AMS 5759             | 6.4.1          |
| Manganese Bronzes                | Casting                                     | AMS 4860             | 7.3.1          |
| Manganese Bronzes                | Casting                                     | AMS 4862             | 7.3.1          |
| MP159 Alloy                      | Bar (solution treated and cold drawn)       | AMS 5842             | 7.4.2          |
| MP159 Alloy                      | Bar (solution treated, cold drawn and aged) | AMS 5843             | 7.4.2          |
| MP35N Alloy                      | Bar (solution treated and cold drawn)       | AMS 5844             | 7.4.1          |
| MP35N Alloy                      | Bar (solution treated, cold drawn and aged) | AMS 5845             | 7.4.1          |
| N-155                            | Sheet                                       | AMS 5532             | 6.2.2          |
| N-155                            | Tubing (welded)                             | AMS 5585             | 6.2.2          |
| N-155                            | Bar and Forging                             | AMS 5768             | 6.2.2          |
| N-155                            | Bar and Forging                             | AMS 5769             | 6.2.2          |
| PH13-8Mo                         | Bar, Forging Ring and Extrusion (VIM+CEVM)  | AMS 5629             | 2.6.5          |
| PH15-7Mo                         | Plate, Sheet and Strip                      | AMS 5520             | 2.6.7          |
| QE22A Magnesium                  | Sand Casting                                | AMS 4418             | 4.3.5          |
| QE22A Magnesium                  | Sand Casting                                | MIL-M-46062          | 4.3.5          |
| René 41                          | Plate, Sheet and Strip                      | AMS 5545             | 6.3.7          |
| René 41                          | Bar and Forging                             | AMS 5713             | 6.3.7          |
| René 41 - STA                    | Bar and Forging                             | AMS 5712             | 6.3.7          |
| Standard Grade Beryllium         | Sheet and Plate                             | AMS 7902             | 7.2.1          |
| Standard Grade Beryllium         | Bar, Rod, Tubing and Machined Shapes        | AMS 7906             | 7.2.1          |
| Ti-10V-2Fe-3Al (Ti-10-2-3)       | Forging                                     | AMS 4983             | 5.5.3          |
| Ti-10V-2Fe-3Al (Ti-10-2-3)       | Forging                                     | AMS 4984             | 5.5.3          |
| Ti-10V-2Fe-3Al (Ti-10-2-3)       | Forging                                     | AMS 4986             | 5.5.3          |
| Ti-13V-11Cr-3Al                  | Sheet, Strip and Plate                      | AMS-T-9046           | 5.5.1          |
| Ti-13V-11Cr-3Al                  | Bar                                         | MIL-T-9047           | 5.5.1          |
| Ti-15V-3Cr-3Sn-3Al (Ti-15-3-3-3) | Sheet and Strip                             | AMS 4914             | 5.5.2          |
| Ti-4.5Al-3V-2Fe-2Mo              | Sheet                                       | AMS 4899             | 5.4.3          |
| Ti-5Al-2.5Sn                     | Sheet, Strip and Plate                      | AMS 4910             | 5.3.1          |
| Ti-5Al-2.5Sn                     | Bar                                         | AMS 4926             | 5.3.1          |

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| <b>Alloy Name</b>  | <b>Form</b>             | <b>Specification</b> | <b>Section</b> |
|--------------------|-------------------------|----------------------|----------------|
| Ti-5Al-2.5Sn       | Forging                 | AMS 4966             | 5.3.1          |
| Ti-5Al-2.5Sn       | Extruded Bar and Shapes | AMS-T-81556          | 5.3.1          |
| Ti-5Al-2.5Sn       | Sheet, Strip and Plate  | AMS-T-9046           | 5.3.1          |
| Ti-5Al-2.5Sn       | Bar                     | MIL-T-9047           | 5.3.1          |
| Ti-6Al-2Sn-4Zr-2Mo | Sheet, Strip and Plate  | AMS 4919             | 5.3.3          |
| Ti-6Al-2Sn-4Zr-2Mo | Bar                     | AMS 4975             | 5.3.3          |
| Ti-6Al-2Sn-4Zr-2Mo | Forging                 | AMS 4976             | 5.3.3          |
| Ti-6Al-2Sn-4Zr-2Mo | Sheet and Strip         | AMS-T-9046           | 5.3.3          |
| Ti-6Al-4V          | Sheet, Strip and Plate  | AMS 4911             | 5.4.1          |
| Ti-6Al-4V          | Die Forging             | AMS 4920             | 5.4.1          |
| Ti-6Al-4V          | Bar and Die Forging     | AMS 4928             | 5.4.1          |
| Ti-6Al-4V          | Extrusion               | AMS 4934             | 5.4.1          |
| Ti-6Al-4V          | Extrusion               | AMS 4935             | 5.4.1          |
| Ti-6Al-4V          | Casting                 | AMS 4962             | 5.4.1          |
| Ti-6Al-4V          | Bar                     | AMS 4967             | 5.4.1          |
| Ti-6Al-4V          | Sheet, Strip and Plate  | AMS-T-9046           | 5.4.1          |
| Ti-6Al-4V          | Bar                     | MIL-T-9047           | 5.4.1          |
| Ti6Al-6V-2Sn       | Sheet, Strip and Plate  | AMS 4918             | 5.4.2          |
| Ti6Al-6V-2Sn       | Bar and Forging         | AMS 4971             | 5.4.2          |
| Ti6Al-6V-2Sn       | Bar and Forging         | AMS 4978             | 5.4.2          |
| Ti6Al-6V-2Sn       | Bar and Forging         | AMS 4979             | 5.4.2          |
| Ti6Al-6V-2Sn       | Extruded Bar and Shapes | AMS-T-81556          | 5.4.2          |
| Ti6Al-6V-2Sn       | Sheet, Strip and Plate  | AMS-T-9046           | 5.4.2          |
| Ti-8Al-1Mo-1V      | Sheet, Strip and Plate  | AMS 4915             | 5.3.2          |
| Ti-8Al-1Mo-1V      | Sheet, Strip and Plate  | AMS 4916             | 5.3.2          |
| Ti-8Al-1Mo-1V      | Forging                 | AMS 4973             | 5.3.2          |
| Ti-8Al-1Mo-1V      | Sheet, Strip and Plate  | AMS-T-9046           | 5.3.2          |
| Ti-8Al-1Mo-1V      | Bar                     | MIL-T-9047           | 5.3.2          |
| Waspaloy           | Plate, Sheet and Strip  | AMS 5544             | 6.3.8          |
| Waspaloy           | Forging                 | AMS 5704             | 6.3.8          |
| Waspaloy           | Bar, Forgings and Ring  | AMS 5706             | 6.3.8          |
| Waspaloy           | Bar, Forgings and Ring  | AMS 5707             | 6.3.8          |
| Waspaloy           | Bar, Forgings and Ring  | AMS 5708             | 6.3.8          |
| Waspaloy           | Bar, Forgings and Ring  | AMS 5709             | 6.3.8          |
| ZE41A Magnesium    | Sand Casting            | AMS 4439             | 4.3.6          |
| ZK60A-F            | Extrusion               | ASTM B 107           | 4.2.3          |
| ZK60A-T5           | Extrusion               | AMS 4352             | 4.2.3          |
| ZK60A-T5           | Die and Hand Forging    | AMS 4362             | 4.2.3          |

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## APPENDIX C

### C.0 Specification Index

| Specification    | Alloy Name | Form/Application                     | Section |
|------------------|------------|--------------------------------------|---------|
| AMS 4015         | 5052       | Sheet and Plate                      | 3.5.1   |
| AMS 4016         | 5052       | Sheet and Plate                      | 3.5.1   |
| AMS 4017         | 5052       | Sheet and Plate                      | 3.5.1   |
| AMS 4025         | 6061       | Sheet and Plate                      | 3.6.2   |
| AMS 4026         | 6061       | Sheet and Plate                      | 3.6.2   |
| AMS 4027         | 6061       | Sheet and Plate                      | 3.6.2   |
| AMS 4028         | 2014       | Bare Sheet and Plate                 | 3.2.1   |
| AMS 4029         | 2014       | Bare Sheet and Plate                 | 3.2.1   |
| AMS 4031         | 2219       | Sheet and Plate                      | 3.2.7   |
| AMS 4035         | 2024       | Bare Sheet and Plate                 | 3.2.3   |
| AMS 4037         | 2024       | Bare Sheet and Plate                 | 3.2.3   |
| AMS 4044         | 7075       | Bare Sheet and Plate                 | 3.7.6   |
| AMS 4045         | 7075       | Bare Sheet and Plate                 | 3.7.6   |
| AMS 4049         | 7075       | Clad Sheet and Plate                 | 3.7.6   |
| AMS 4050         | 7050       | Bare Plate                           | 3.7.4   |
| AMS 4056         | 5083       | Bare Sheet and Plate                 | 3.5.2   |
| AMS 4078         | 7075       | Bare Plate                           | 3.7.6   |
| AMS 4080         | 6061       | Tubing Seamless, Drawn               | 3.6.2   |
| AMS 4082         | 6061       | Tubing Seamless, Drawn               | 3.6.2   |
| AMS 4084 (T61)   | 7475       | Bare Sheet                           | 3.7.10  |
| AMS 4085 (T761)  | 7475       | Bare Sheet                           | 3.7.10  |
| AMS 4086         | 2024       | Tubing, Hydraulic, Seamless, Drawn   | 3.2.3   |
| AMS 4089 (T7651) | 7475       | Bare Plate                           | 3.7.10  |
| AMS 4090 (T651)  | 7475       | Bare Plate                           | 3.7.10  |
| AMS 4100 (T761)  | 7475       | Clad Sheet                           | 3.7.10  |
| AMS 4101         | 2124       | Plate                                | 3.2.6   |
| AMS 4107         | 7050       | Die Forging                          | 3.7.4   |
| AMS 4108         | 7050       | Hand Forging                         | 3.7.4   |
| AMS 4111         | 7049/7149  | Forging                              | 3.7.3   |
| AMS 4115         | 6061       | Bar and Rod, Rolled or Cold Finished | 3.6.2   |
| AMS 4116         | 6061       | Bar and Rod, Cold Finished           | 3.6.2   |
| AMS 4117         | 6061       | Bar and Rod, Rolled or Cold Finished | 3.6.2   |
| AMS 4118         | 2017       | Bar and Rod, Rolled or Cold-Finished | 3.2.2   |
| AMS 4120         | 2024       | Bar and Rod, Rolled or Cold-Finished | 3.2.3   |
| AMS 4121         | 2014       | Bar and Rod, Rolled or Cold Finished | 3.2.1   |
| AMS 4122         | 7075       | Bar and Rod, Rolled or Cold Finished | 3.7.6   |
| AMS 4123         | 7075       | Bar and Rod, Rolled or Cold Finished | 3.7.6   |
| AMS 4124         | 7075       | Bar and Rod, Rolled or Cold Finished | 3.7.6   |
| AMS 4125         | 6151       | Die Forging                          | 3.6.3   |
| AMS 4126         | 7075       | Forging                              | 3.7.6   |
| AMS 4127         | 6061       | Forging                              | 3.6.2   |
| AMS 4130         | 2025       | Die Forging                          | 3.2.4   |
| AMS 4132         | 2618       | Die and Hand Forgings                | 3.2.11  |

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| <b>Specification</b> | <b>Alloy Name</b>                 | <b>Form/Application</b>              | <b>Section</b> |
|----------------------|-----------------------------------|--------------------------------------|----------------|
| AMS 4133             | 2014                              | Forging                              | 3.2.1          |
| AMS 4141             | 7075                              | Die Forging                          | 3.7.6          |
| AMS 4144             | 2219                              | Hand Forging                         | 3.2.7          |
| AMS 4147             | 7075                              | Forging                              | 3.7.6          |
| AMS 4148 (T66)       | 7175                              | Die Forging                          | 3.7.8          |
| AMS 4149 (T74)       | 7175                              | Die and Hand Forging                 | 3.7.8          |
| AMS 4152             | 2024                              | Extrusion                            | 3.2.3          |
| AMS 4153             | 2014                              | Extrusion                            | 3.2.1          |
| AMS 4157             | 7049/7149                         | Extrusion                            | 3.7.3          |
| AMS 4160             | 6061                              | Extrusion                            | 3.6.2          |
| AMS 4161             | 6061                              | Extrusion                            | 3.6.2          |
| AMS 4162             | 2219                              | Extrusion                            | 3.2.7          |
| AMS 4163             | 2219                              | Extrusion                            | 3.2.7          |
| AMS 4164             | 2024                              | Extrusion                            | 3.2.3          |
| AMS 4165             | 2024                              | Extrusion                            | 3.2.3          |
| AMS 4172             | 6061                              | Extrusion                            | 3.6.2          |
| AMS 4179 (T7452)     | 7175                              | Hand Forging                         | 3.7.8          |
| AMS 4186             | 7075                              | Bar and Rod, Rolled or Cold Finished | 3.7.6          |
| AMS 4187             | 7075                              | Bar and Rod, Rolled or Cold Finished | 3.7.6          |
| AMS 4200             | 7049/7149                         | Plate                                | 3.7.3          |
| AMS 4201             | 7050                              | Bare Plate                           | 3.7.4          |
| AMS 4202 (T7351)     | 7475                              | Bare Plate                           | 3.7.10         |
| AMS 4204             | 7010                              | Plate                                | 3.7.1          |
| AMS 4205             | 7010                              | Plate                                | 3.7.1          |
| AMS 4206             | 7055                              | Plate                                | 3.7.5          |
| AMS 4207 (T61)       | 7475                              | Clad Sheet                           | 3.7.10         |
| AMS 4211             | 7040                              | Plate                                | 3.7.2          |
| AMS 4216             | 6013 (T4)                         | Sheet                                | 3.6.1          |
| AMS 4217             | 356.0                             | Sand Casting                         | 3.9.4          |
| AMS 4218             | A356.0                            | Casting                              | 3.9.5          |
| AMS 4241             | D357.0                            | Sand Composite Casting               | 3.9.7          |
| AMS 4248             | 6061                              | Hand Forging                         | 3.6.2          |
| AMS 4251             | 2090                              | Sheet                                | 3.2.5          |
| AMS 4252 (T7751)     | 7150                              | Bare Plate                           | 3.7.7          |
| AMS 4254             | 2024-T3 ARAMID Fiber Reinforced   | Sheet Laminate                       | 7.5.1          |
| AMS 4260             | 356.0                             | Investment Casting                   | 3.9.4          |
| AMS 4270             | 2424 (Clad)                       | Sheet                                | 3.2.8          |
| AMS 4273             | 2424 (Bare)                       | Sheet                                | 3.2.8          |
| AMS 4281             | 355.0                             | Permanent Mold Casting               | 3.9.2          |
| AMS 4284             | 356.0                             | Permanent Mold Casting               | 3.9.4          |
| AMS 4296             | 2524-T3                           | Sheet and Plate                      | 3.2.10         |
| AMS 4302             | 7475-T761 ARAMID Fiber Reinforced | Sheet Laminate                       | 7.5.2          |
| AMS 4306 (T6151)     | 7150                              | Bare Plate                           | 3.7.7          |
| AMS 4307 (T61511)    | 7150                              | Extrusion                            | 3.7.7          |
| AMS 4320             | 7049/7149                         | Forging                              | 3.7.3          |
| AMS 4333             | 7050                              | Die Forging                          | 3.7.4          |
| AMS 4334             | 7249                              | Hand Forging                         | 3.7.9          |
| AMS 4337             | 7055                              | Extrusion                            | 3.7.5          |
| AMS 4340             | 7050                              | Extruded Shape                       | 3.7.4          |
| AMS 4341             | 7050                              | Extruded Shape                       | 3.7.4          |
| AMS 4342             | 7050                              | Extruded Shape                       | 3.7.4          |
| AMS 4343             | 7049/7149                         | Extrusion                            | 3.7.3          |

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| <b>Specification</b> | <b>Alloy Name</b>                | <b>Form/Application</b>             | <b>Section</b> |
|----------------------|----------------------------------|-------------------------------------|----------------|
| AMS 4344 (T73511)    | 7175                             | Extrusion                           | 3.7.8          |
| AMS 4345 (T77511)    | 7150                             | Extrusion                           | 3.7.7          |
| AMS 4347             | 6013 (T6)                        | Sheet                               | 3.6.1          |
| AMS 4350             | AZ61A                            | Extrusion                           | 4.2.2          |
| AMS 4352             | ZK60A-T5                         | Extrusion                           | 4.2.3          |
| AMS 4362             | ZK60A-T5                         | Die and Hand Forging                | 4.2.3          |
| AMS 4375             | AZ31B                            | Sheet and Plate                     | 4.2.1          |
| AMS 4376             | AZ31B                            | Plate                               | 4.2.1          |
| AMS 4377             | AZ31B                            | Sheet and Plate                     | 4.2.1          |
| AMS 4418             | QE22A Magnesium                  | Sand Casting                        | 4.3.5          |
| AMS 4434             | AZ92A                            | Sand Casting                        | 4.3.3          |
| AMS 4437             | AZ91C/AZ91E                      | Sand Casting                        | 4.3.2          |
| AMS 4439             | ZE41A Magnesium                  | Sand Casting                        | 4.3.6          |
| AMS 4442             | EZ33A                            | Sand Casting                        | 4.3.4          |
| AMS 4446             | AZ91C/AZ91E                      | Sand Casting                        | 4.3.2          |
| AMS 4452             | AZ91C/AZ91E                      | Investment Casting                  | 4.3.2          |
| AMS 4455             | AM100A                           | Investment Casting                  | 4.3.1          |
| AMS 4483             | AM100A                           | Permanent Mold Casting              | 4.3.1          |
| AMS 4484             | AZ92A                            | Permanent Mold Casting              | 4.3.3          |
| AMS 4530             | Copper Beryllium                 | Strip (TB00)                        | 7.3.2          |
| AMS 4532             | Copper Beryllium                 | Strip (TD02)                        | 7.3.2          |
| AMS 4533             | Copper Beryllium                 | Bar and Rod (TF00)                  | 7.3.2          |
| AMS 4534             | Copper Beryllium                 | Bar and Rod (TH04)                  | 7.3.2          |
| AMS 4535             | Copper Beryllium                 | Mechanical tubing (TF00)            | 7.3.2          |
| AMS 4650             | Copper Beryllium                 | Bar, Rod, Shapes and Forging (TB00) | 7.3.2          |
| AMS 4651             | Copper Beryllium                 | Bar and Rod (TD04)                  | 7.3.2          |
| AMS 4860             | Manganese Bronzes                | Casting                             | 7.3.1          |
| AMS 4862             | Manganese Bronzes                | Casting                             | 7.3.1          |
| AMS 4899             | Ti-4.5Al-3V-2Fe-2Mo              | Sheet                               | 5.4.3          |
| AMS 4900             | CP Titanium                      | Sheet, Strip and Plate              | 5.2.1          |
| AMS 4901             | CP Titanium                      | Sheet, Strip and Plate              | 5.2.1          |
| AMS 4902             | CP Titanium                      | Sheet, Strip and Plate              | 5.2.1          |
| AMS 4910             | Ti-5Al-2.5Sn                     | Sheet, Strip and Plate              | 5.3.1          |
| AMS 4911             | Ti-6Al-4V                        | Sheet, Strip and Plate              | 5.4.1          |
| AMS 4914             | Ti-15V-3Cr-3Sn-3Al (Ti-15-3)-3-3 | Sheet and Strip                     | 5.5.2          |
| AMS 4915             | Ti-8Al-1Mo-1V                    | Sheet, Strip and Plate              | 5.3.2          |
| AMS 4916             | Ti-8Al-1Mo-1V                    | Sheet, Strip and Plate              | 5.3.2          |
| AMS 4918             | Ti6Al-6V-2Sn                     | Sheet, Strip and Plate              | 5.4.2          |
| AMS 4919             | Ti-6Al-2Sn-4Zr-2Mo               | Sheet, Strip and Plate              | 5.3.3          |
| AMS 4920             | Ti-6Al-4V                        | Die Forging                         | 5.4.1          |
| AMS 4921             | CP Titanium                      | Bar                                 | 5.2.1          |
| AMS 4926             | Ti-5Al-2.5Sn                     | Bar                                 | 5.3.1          |
| AMS 4928             | Ti-6Al-4V                        | Bar and Die Forging                 | 5.4.1          |
| AMS 4934             | Ti-6Al-4V                        | Extrusion                           | 5.4.1          |
| AMS 4935             | Ti-6Al-4V                        | Extrusion                           | 5.4.1          |
| AMS 4962             | Ti-6Al-4V                        | Casting                             | 5.4.1          |
| AMS 4966             | Ti-5Al-2.5Sn                     | Forging                             | 5.3.1          |
| AMS 4967             | Ti-6Al-4V                        | Bar                                 | 5.4.1          |
| AMS 4971             | Ti6Al-6V-2Sn                     | Bar and Forging                     | 5.4.2          |
| AMS 4973             | Ti-8Al-1Mo-1V                    | Forging                             | 5.3.2          |
| AMS 4975             | Ti-6Al-2Sn-4Zr-2Mo               | Bar                                 | 5.3.3          |
| AMS 4976             | Ti-6Al-2Sn-4Zr-2Mo               | Forging                             | 5.3.3          |
| AMS 4978             | Ti6Al-6V-2Sn                     | Bar and Forging                     | 5.4.2          |

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| <b>Specification</b> | <b>Alloy Name</b>          | <b>Form/Application</b>                    | <b>Section</b> |
|----------------------|----------------------------|--------------------------------------------|----------------|
| AMS 4979             | Ti6Al-6V-2Sn               | Bar and Forging                            | 5.4.2          |
| AMS 4983             | Ti-10V-2Fe-3Al (Ti-10-2-3) | Forging                                    | 5.5.3          |
| AMS 4984             | Ti-10V-2Fe-3Al (Ti-10-2-3) | Forging                                    | 5.5.3          |
| AMS 4986             | Ti-10V-2Fe-3Al (Ti-10-2-3) | Forging                                    | 5.5.3          |
| AMS 5046             | AISI 1025                  | Sheet, Strip, and Plate                    | 2.2.1          |
| AMS 5075             | AISI 1025 - N              | Seamless Tubing                            | 2.2.1          |
| AMS 5077             | AISI 1025 - N              | Tubing                                     | 2.2.1          |
| AMS 5342             | 17-4PH                     | Investment Casting (H1100)                 | 2.6.8          |
| AMS 5343             | 17-4PH                     | Investment Casting (H1000)                 | 2.6.8          |
| AMS 5344             | 17-4PH                     | Investment Casting (H900)                  | 2.6.8          |
| AMS 5383             | Inconel 718                | Investment Casting                         | 6.3.5          |
| AMS 5400             | 15-5PH                     | Investment Casting                         | 2.6.6          |
| AMS 5513             | AISI 301                   | Sheet, Strip and Plate                     | 2.7.1          |
| AMS 5516             | AISI 302                   | Sheet, Strip and Plate                     | 2.7.1          |
| AMS 5517             | AISI 301                   | Sheet and Strip (125 ksi)                  | 2.7.1          |
| AMS 5518             | AISI 301                   | Sheet and Strip (150 ksi)                  | 2.7.1          |
| AMS 5519             | AISI 301                   | Sheet and Strip (185 ksi)                  | 2.7.1          |
| AMS 5520             | PH15-7Mo                   | Plate, Sheet and Strip                     | 2.6.7          |
| AMS 5524             | AISI 316                   | Sheet, Strip and Plate                     | 2.7.1          |
| AMS 5525             | A-286                      | Sheet, Strip and Plate                     | 6.2.1          |
| AMS 5528             | 17-7PH                     | Plate, Sheet and Strip                     | 2.6.9          |
| AMS 5532             | N-155                      | Sheet                                      | 6.2.2          |
| AMS 5536             | Hastelloy X                | Sheet and Plate                            | 6.3.1          |
| AMS 5537             | L-605                      | Sheet                                      | 6.4.1          |
| AMS 5540             | Inconel Alloy 600          | Plate, Sheet and Strip                     | 6.3.2          |
| AMS 5542             | Inconel Alloy X-750        | Sheet, Strip and Plate; Annealed           | 6.3.6          |
| AMS 5544             | Waspaloy                   | Plate, Sheet and Strip                     | 6.3.8          |
| AMS 5545             | René 41                    | Plate, Sheet and Strip                     | 6.3.7          |
| AMS 5547             | AM-355                     | Sheet and Strip                            | 2.6.2          |
| AMS 5548             | AM-350                     | Sheet and Strip                            | 2.6.1          |
| AMS 5549             | AM-355                     | Plate                                      | 2.6.2          |
| AMS 5578             | Custom 455                 | Tubing (welded)                            | 2.6.4          |
| AMS 5580             | Inconel Alloy 600          | Tubing, Seamless                           | 6.3.2          |
| AMS 5585             | N-155                      | Tubing (welded)                            | 6.2.2          |
| AMS 5589             | Inconel 718                | Tubing; Creep Rupture                      | 6.3.5          |
| AMS 5590             | Inconel 718                | Tubing; Short-Time                         | 6.3.5          |
| AMS 5596             | Inconel 718                | Sheet, Strip and Plate; Creep Rupture      | 6.3.5          |
| AMS 5597             | Inconel 718                | Sheet, Strip and Plate; Short-Time         | 6.3.5          |
| AMS 5599             | Inconel Alloy 625          | Sheet, Strip and Plate                     | 6.3.3          |
| AMS 5604             | 17-4PH                     | Sheet, Strip and Plate                     | 2.6.8          |
| AMS 5605             | Inconel Alloy 706          | Sheet, Strip and Plate                     | 6.3.4          |
| AMS 5606             | Inconel Alloy 706          | Sheet, Strip and Plate                     | 6.3.4          |
| AMS 5608             | Alloy 188                  | Sheet and Plate                            | 6.4.2          |
| AMS 5617             | Custom 455                 | Bar and Forging                            | 2.6.4          |
| AMS 5629             | PH13-8Mo                   | Bar, Forging Ring and Extrusion (VIM+CEVM) | 2.6.5          |
| AMS 5643             | 17-4PH                     | Bar, Forging and Ring                      | 2.6.8          |
| AMS 5659             | 15-5PH                     | Bar, Forging, Ring and Extrusion (CEVM)    | 2.6.6          |
| AMS 5662             | Inconel 718                | Bar and Forging; Creep Rupture             | 6.3.5          |
| AMS 5663             | Inconel 718                | Bar and Forging; Creep Rupture             | 6.3.5          |
| AMS 5664             | Inconel 718                | Bar and Forging; Short-Time                | 6.3.5          |
| AMS 5666             | Inconel Alloy 625          | Bar, Forging and Ring                      | 6.3.3          |
| AMS 5667             | Inconel Alloy X-750        | Bar and Forging; Equalized                 | 6.3.6          |
| AMS 5701             | Inconel Alloy 706          | Bar, Forging and Ring                      | 6.3.4          |

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|----------------------|-------------------|--------------------------------------------------|----------------|
| AMS 5702             | Inconel Alloy 706 | Bar, Forging and Ring                            | 6.3.4          |
| AMS 5703             | Inconel Alloy 706 | Bar, Forging and Ring                            | 6.3.4          |
| AMS 5704             | Waspaloy          | Forging                                          | 6.3.8          |
| AMS 5706             | Waspaloy          | Bar, Forgings and Ring                           | 6.3.8          |
| AMS 5707             | Waspaloy          | Bar, Forgings and Ring                           | 6.3.8          |
| AMS 5708             | Waspaloy          | Bar, Forgings and Ring                           | 6.3.8          |
| AMS 5709             | Waspaloy          | Bar, Forgings and Ring                           | 6.3.8          |
| AMS 5712             | René 41 - STA     | Bar and Forging                                  | 6.3.7          |
| AMS 5713             | René 41           | Bar and Forging                                  | 6.3.7          |
| AMS 5731             | A-286             | Bar, Forging, Tubing and Ring                    | 6.2.1          |
| AMS 5732             | A-286             | Bar, Forging, Tubing and Ring                    | 6.2.1          |
| AMS 5734             | A-286             | Bar, Forging and Tubing                          | 6.2.1          |
| AMS 5737             | A-286             | Bar, Forging and Tubing                          | 6.2.1          |
| AMS 5743             | AM-355            | Bar, Forging and Forging Stock                   | 2.6.2          |
| AMS 5754             | Hastelloy X       | Bar and Forging                                  | 6.3.1          |
| AMS 5759             | L-605             | Bar and Forging                                  | 6.4.1          |
| AMS 5763             | Custom 450        | Bar, Forging, Tubing, Wire and Ring (air melted) | 2.6.3          |
| AMS 5768             | N-155             | Bar and Forging                                  | 6.2.2          |
| AMS 5769             | N-155             | Bar and Forging                                  | 6.2.2          |
| AMS 5772             | Alloy 188         | Bar and Forging                                  | 6.4.2          |
| AMS 5773             | Custom 450        | Bar, Forging, Tubing, Wire and Ring (CEM)        | 2.6.3          |
| AMS 5842             | MP159 Alloy       | Bar (solution treated and cold drawn)            | 7.4.2          |
| AMS 5843             | MP159 Alloy       | Bar (solution treated, cold drawn and aged)      | 7.4.2          |
| AMS 5844             | MP35N Alloy       | Bar (solution treated and cold drawn)            | 7.4.1          |
| AMS 5845             | MP35N Alloy       | Bar (solution treated, cold drawn and aged)      | 7.4.1          |
| AMS 5862             | 15-5PH            | Sheet, Strip and Plate (CEVM)                    | 2.6.6          |
| AMS 5878             | Haynes®230®       | Plate, Sheet and Strip                           | 6.3.9          |
| AMS 5891             | Haynes®230®       | Bar and Forging                                  | 6.3.9          |
| AMS 5901             | AISI 301          | Plate, Sheet and Strip                           | 2.7.1          |
| AMS 5902             | AISI 301          | Sheet and Strip (175 ksi)                        | 2.7.1          |
| AMS 5903             | AISI 302          | Sheet and Strip (125 ksi)                        | 2.7.1          |
| AMS 5904             | AISI 302          | Sheet and Strip (150 ksi)                        | 2.7.1          |
| AMS 5905             | AISI 302          | Sheet and Strip (175 ksi)                        | 2.7.1          |
| AMS 5906             | AISI 302          | Sheet and Strip (185 ksi)                        | 2.7.1          |
| AMS 5907             | AISI 316          | Sheet, Strip and Plate (125 ksi)                 | 2.7.1          |
| AMS 5910             | AISI 304          | Sheet, Strip and Plate (125 ksi)                 | 2.7.1          |
| AMS 5911             | AISI 304          | Sheet and Strip (150 ksi)                        | 2.7.1          |
| AMS 5912             | AISI 304          | Sheet and Strip (175 ksi)                        | 2.7.1          |
| AMS 5913             | AISI 304          | Sheet and Strip (185 ksi)                        | 2.7.1          |
| AMS 6257             | 300M (0.42C)      | Bar and Forging                                  | 2.3.1          |
| AMS 6257             | 300M (0.42C)      | Tubing                                           | 2.3.1          |
| AMS 6280             | 8630              | Bar and Forging                                  | 2.3.1          |
| AMS 6281             | 8630              | Tubing                                           | 2.3.1          |
| AMS 6282             | 8735              | Tubing                                           | 2.3.1          |
| AMS 6320             | 8735              | Bar and Forging                                  | 2.3.1          |
| AMS 6322             | 8740              | Bar and Forging                                  | 2.3.1          |
| AMS 6323             | 8740              | Tubing                                           | 2.3.1          |
| AMS 6327             | 8740              | Bar and Forging                                  | 2.3.1          |
| AMS 6348             | 4130              | Bar and Forging                                  | 2.3.1          |
| AMS 6349             | 4140              | Bar and Forging                                  | 2.3.1          |
| AMS 6350             | 4130              | Sheet, Strip and Plate                           | 2.3.1          |
| AMS 6351             | 4130              | Sheet, Strip and Plate                           | 2.3.1          |
| AMS 6352             | 4135              | Sheet, Strip and Plate                           | 2.3.1          |

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|----------------------|-------------------|-------------------------|----------------|
| AMS 6355             | 8630              | Tubing                  | 2.3.1          |
| AMS 6357             | 8735              | Sheet, Strip and Plate  | 2.3.1          |
| AMS 6358             | 8740              | Sheet, Strip and Plate  | 2.3.1          |
| AMS 6359             | 4340              | Sheet, Strip and Plate  | 2.3.1          |
| AMS 6360             | 4130              | Tubing (normalized)     | 2.3.1          |
| AMS 6361             | 4130              | Tubing                  | 2.3.1          |
| AMS 6362             | 4130              | Tubing                  | 2.3.1          |
| AMS 6365             | 4135              | Tubing                  | 2.3.1          |
| AMS 6370             | 4130              | Bar and Forging         | 2.3.1          |
| AMS 6371             | 4130              | Tubing                  | 2.3.1          |
| AMS 6372             | 4135              | Tubing                  | 2.3.1          |
| AMS 6373             | 4130              | Tubing                  | 2.3.1          |
| AMS 6374             | 4130              | Tubing                  | 2.3.1          |
| AMS 6381             | 4140              | Tubing                  | 2.3.1          |
| AMS 6382             | 4140              | Bar and Forging         | 2.3.1          |
| AMS 6395             | 4140              | Sheet, Strip and Plate  | 2.3.1          |
| AMS 6411             | 4330V             | Bar and Forging         | 2.3.1          |
| AMS 6411             | 4330V             | Tubing                  | 2.3.1          |
| AMS 6414             | 4340              | Bar and Forging         | 2.3.1          |
| AMS 6414             | 4340              | Tubing                  | 2.3.1          |
| AMS 6415             | 4340              | Bar and Forging         | 2.3.1          |
| AMS 6415             | 4340              | Tubing                  | 2.3.1          |
| AMS 6417             | 300M (0.4C)       | Bar and Forging         | 2.3.1          |
| AMS 6417             | 300M (0.4C)       | Tubing                  | 2.3.1          |
| AMS 6419             | 300M (0.42C)      | Bar and Forging         | 2.3.1          |
| AMS 6419             | 300M (0.42C)      | Tubing                  | 2.3.1          |
| AMS 6425             | Hy-Tuf            | Bar and Forging         | 2.3.1          |
| AMS 6425             | Hy-Tuf            | Tubing                  | 2.3.1          |
| AMS 6427             | 4330V             | Bar and Forging         | 2.3.1          |
| AMS 6427             | 4330V             | Tubing                  | 2.3.1          |
| AMS 6429             | 4335V             | Bar and Forging         | 2.3.1          |
| AMS 6429             | 4335V             | Tubing                  | 2.3.1          |
| AMS 6430             | 4335V             | Bar and Forging         | 2.3.1          |
| AMS 6430             | 4335V             | Tubing                  | 2.3.1          |
| AMS 6431             | D6AC              | Bar and Forging         | 2.3.1          |
| AMS 6431             | D6AC              | Tubing                  | 2.3.1          |
| AMS 6433             | 4335V             | Sheet, Strip and Plate  | 2.3.1          |
| AMS 6435             | 4335V             | Sheet, Strip and Plate  | 2.3.1          |
| AMS 6437             | 5Cr-Mo-V          | Sheet, Strip and Plate  | 2.4.1          |
| AMS 6439             | D6AC              | Sheet, Strip and Plate  | 2.3.1          |
| AMS 6439             | D6AC              | Bar and Forging         | 2.3.1          |
| AMS 6454             | 4340              | Sheet, Strip and Plate  | 2.3.1          |
| AMS 6478             | AerMet 100        | Bar and Forging         | 2.5.3          |
| AMS 6487             | 5Cr-Mo-V          | Bar and Forging (CEVM)  | 2.4.1          |
| AMS 6488             | 5Cr-Mo-V          | Bar and Forging         | 2.4.1          |
| AMS 6512             | 250               | Bar                     | 2.5.1          |
| AMS 6514             | 280 (300)         | Bar                     | 2.5.1          |
| AMS 6520             | 250               | Sheet and Plate         | 2.5.1          |
| AMS 6521             | 280 (300)         | Sheet and Plate         | 2.5.1          |
| AMS 6523             | 9Ni-4Co-0.20C     | Sheet, Strip and Plate  | 2.4.2          |
| AMS 6524             | 9Ni-4Co-0.20C     | Sheet, Strip and Plate  | 2.4.3          |
| AMS 6526             | 9Ni-4Co-0.20C     | Bar and Forging, Tubing | 2.4.3          |
| AMS 6527             | AF1410            | Bar and Forging         | 2.5.2          |

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|----------------------|--------------------------|--------------------------------------|----------------|
| AMS 6528             | 4130                     | Bar and Forging                      | 2.3.1          |
| AMS 6529             | 4140                     | Bar and Forging                      | 2.3.1          |
| AMS 6532             | AerMet 100               | Bar and Forging                      | 2.5.3          |
| AMS 7902             | Standard Grade Beryllium | Sheet and Plate                      | 7.2.1          |
| AMS 7906             | Standard Grade Beryllium | Bar, Rod, Tubing and Machined Shapes | 7.2.1          |
| AMS-A-21180          | A201.0                   | Casting (T7 Temper)                  | 3.8.1          |
| AMS-A-21180          | 354.0                    | Casting                              | 3.9.1          |
| AMS-A-21180          | C355.0                   | Casting                              | 3.9.3          |
| AMS-A-21180          | A356.0                   | Casting                              | 3.9.5          |
| AMS-A-21180          | A357.0                   | Casting                              | 3.9.6          |
| AMS-A-21180          | 359.0                    | Casting                              | 3.9.8          |
| AMS-A-22771          | 2014                     | Forging                              | 3.2.1          |
| AMS-A-22771          | 2618                     | Die Forging                          | 3.2.11         |
| AMS-A-22771          | 6061                     | Forging                              | 3.6.2          |
| AMS-A-22771          | 6151                     | Forging                              | 3.6.3          |
| AMS-A-22771          | 7049/7149                | Forging                              | 3.7.3          |
| AMS-A-22771          | 7050                     | Forging                              | 3.7.4          |
| AMS-A-22771          | 7075                     | Forging                              | 3.7.6          |
| AMS-A-22771          | 7175                     | Forging                              | 3.7.8          |
| AMS-QQ-A-367         | 2014                     | Forging                              | 3.2.1          |
| AMS-QQ-A-367         | 2618                     | Forging                              | 3.2.11         |
| AMS-QQ-A-367         | 6061                     | Forging                              | 3.6.2          |
| AMS-QQ-A-367         | 7049/7149                | Forging                              | 3.7.3          |
| AMS-QQ-A-367         | 7075                     | Forging                              | 3.7.6          |
| AMS-QQ-A-200/2       | 2014                     | Extruded Bar, Rod and Shapes         | 3.2.1          |
| AMS-QQ-A-200/3       | 2024                     | Extruded Bar, Rod and Shapes         | 3.2.3          |
| AMS-QQ-A-200/4       | 5083                     | Extruded Bar, Rod and Shapes         | 3.5.2          |
| AMS-QQ-A-200/5       | 5086                     | Extruded Bar, Rod and Shapes         | 3.5.3          |
| AMS-QQ-A-200/6       | 5454                     | Extruded Bar, Rod and Shapes         | 3.5.4          |
| AMS-QQ-A-200/7       | 5456                     | Extruded Bar, Rod and Shapes         | 3.5.5          |
| AMS-QQ-A-200/8       | 6061                     | Extruded Rod, Bar Shapes and Tubing  | 3.6.2          |
| AMS-QQ-A-200/11, 15  | 7075                     | Extruded Bar, Rod and Shapes         | 3.7.6          |
| AMS-QQ-A-225/4       | 2014                     | Rolled or Drawn Bar, Rod and Shapes  | 3.2.1          |
| AMS-QQ-A-225/5       | 2017                     | Rolled Bar and Rod                   | 3.2.2          |
| AMS-QQ-A-225/6       | 2024                     | Rolled or Drawn Bar, Rod and Wire    | 3.2.3          |
| AMS-QQ-A-225/8       | 6061                     | Rolled Bar, Rod and Shapes           | 3.6.2          |
| AMS-QQ-A-225/9       | 7075                     | Rolled or Drawn Bar and Rod          | 3.7.6          |
| AMS-QQ-A-250/3       | 2014                     | Clad Sheet and Plate                 | 3.2.1          |
| AMS-QQ-A-250/4       | 2024                     | Bare Sheet and Plate                 | 3.2.3          |
| AMS-QQ-A-250/5       | 2024                     | Clad Sheet and Plate                 | 3.2.3          |
| AMS-QQ-A-250/6       | 5083                     | Bare Sheet and Plate                 | 3.5.2          |
| AMS-QQ-A-250/7       | 5086                     | Sheet and Plate                      | 3.5.3          |
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| 3.2.3.1.6(p)             | Vector Graphic             | 3.2.3.4.6(f)             | Vector Graphic             |
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| <b><u>Figure No.</u></b> | <b><u>Current Form</u></b> | <b><u>Figure No.</u></b> | <b><u>Current Form</u></b> |
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| 3.2.3.5.10(b)            | Scanned                    | 3.2.11.1.3               | Vector Graphic             |
| 3.2.4.0                  | Vector Graphic             | 3.2.11.1.4               | Vector Graphic             |
| 3.2.5.1.6(a)             | Vector Graphic             | 3.2.11.1.5               | Vector Graphic             |
| 3.2.5.1.6(b)             | Vector Graphic             | 3.2.11.1.6(a)            | Vector Graphic             |
| 3.2.6.1.1(a)             | Vector Graphic             | 3.2.11.1.6(b)            | Vector Graphic             |
| 3.2.6.1.1(b)             | Vector Graphic             | 3.5.1.0                  | Vector Graphic             |
| 3.2.6.1.6(a)             | Scanned                    | 3.5.1.1.1                | Vector Graphic             |
| 3.2.6.1.6(b)             | Scanned                    | 3.5.1.1.4                | Vector Graphic             |
| 3.2.6.1.9(a)             | Scanned                    | 3.5.1.1.5                | Vector Graphic             |
| 3.2.6.1.9(b)             | Scanned                    | 3.5.1.3.1(a)             | Vector Graphic             |
| 3.2.6.1.9(c)             | Scanned                    | 3.5.1.3.1(b)             | Vector Graphic             |
| 3.2.6.1.9(d)             | Scanned                    | 3.5.1.3.1(c)             | Vector Graphic             |
| 3.2.6.1.9(e)             | Scanned                    | 3.5.1.3.1(d)             | Vector Graphic             |
| 3.2.7.0                  | Vector Graphic             | 3.5.1.3.5(a)             | Vector Graphic             |
| 3.2.7.1.1(a)             | Vector Graphic             | 3.5.1.3.5(b)             | Vector Graphic             |
| 3.2.7.1.1(b)             | Vector Graphic             | 3.5.1.5.1(a)             | Vector Graphic             |
| 3.2.7.1.6(a)             | Vector Graphic             | 3.5.1.5.1(b)             | Vector Graphic             |
| 3.2.7.1.6(b)             | Vector Graphic             | 3.5.1.5.1(c)             | Vector Graphic             |
| 3.2.7.2.1(a)             | Vector Graphic             | 3.5.1.5.1(d)             | Vector Graphic             |
| 3.2.7.2.1(b)             | Vector Graphic             | 3.5.1.5.5(a)             | Vector Graphic             |
| 3.2.7.2.6(a)             | Vector Graphic             | 3.5.1.5.5(b)             | Vector Graphic             |
| 3.2.7.2.6(b)             | Vector Graphic             | 3.5.2.0                  | Vector Graphic             |
| 3.2.7.2.8(a)             | Scanned                    | 3.5.2.1.6(a)             | Vector Graphic             |
| 3.2.7.2.8(b)             | Scanned                    | 3.5.2.1.6(b)             | Vector Graphic             |
| 3.2.7.2.8(c)             | Scanned                    | 3.5.2.1.6(c)             | Vector Graphic             |
| 3.2.7.2.8(d)             | Scanned                    | 3.5.3.1.6(a)             | Vector Graphic             |
| 3.2.7.3.6(a)             | Vector Graphic             | 3.5.3.1.6(b)             | Vector Graphic             |
| 3.2.7.3.6(b)             | Vector Graphic             | 3.5.3.1.6(c)             | Vector Graphic             |
| 3.2.7.3.6(c)             | Vector Graphic             | 3.5.3.2.6(a)             | Vector Graphic             |
| 3.2.7.3.6(d)             | Vector Graphic             | 3.5.3.2.6(b)             | Vector Graphic             |
| 3.2.7.3.6(e)             | Vector Graphic             | 3.5.3.2.6(c)             | Vector Graphic             |
| 3.2.7.4.1(a)             | Vector Graphic             | 3.5.3.3.6(a)             | Vector Graphic             |
| 3.2.7.4.1(b)             | Vector Graphic             | 3.5.3.3.6(b)             | Vector Graphic             |
| 3.2.7.4.6(a)             | Vector Graphic             | 3.5.3.3.6(c)             | Vector Graphic             |
| 3.2.7.4.6(b)             | Vector Graphic             | 3.5.3.4.6                | Vector Graphic             |
| 3.2.7.4.6(c)             | Vector Graphic             | 3.5.3.7.6                | Vector Graphic             |
| 3.2.7.4.6(d)             | Vector Graphic             | 3.5.4.1.6                | Vector Graphic             |
| 3.2.7.4.6(e)             | Vector Graphic             | 3.5.4.2.6                | Vector Graphic             |
| 3.2.9.1.6(a)             | Vector Graphic             | 3.5.4.3.6(a)             | Vector Graphic             |
| 3.2.9.1.6(b)             | Vector Graphic             | 3.5.4.3.6(b)             | Vector Graphic             |
| 3.2.10.1.6(a)            | Vector Graphic             | 3.5.5.0                  | Vector Graphic             |
| 3.2.10.1.6(b)            | Vector Graphic             | 3.5.5.1.6(a)             | Vector Graphic             |
| 3.2.10.1.6(c)            | Vector Graphic             | 3.5.5.1.6(b)             | Vector Graphic             |
| 3.2.11.0                 | Vector Graphic             | 3.5.5.2.6                | Vector Graphic             |
| 3.2.11.1.1(a)            | Vector Graphic             | 3.5.5.4.6                | Vector Graphic             |
| 3.2.11.1.1(b)            | Vector Graphic             | 3.6.1.1.6(a)             | Vector Graphic             |



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| <b><u>Figure No.</u></b> | <b><u>Current Form</u></b> | <b><u>Figure No.</u></b> | <b><u>Current Form</u></b> |
|--------------------------|----------------------------|--------------------------|----------------------------|
| 3.6.1.1.6(b)             | Vector Graphic             | 3.7.3.1.8(f)             | Scanned                    |
| 3.6.2.0                  | Vector Graphic             | 3.7.3.1.8(g)             | Scanned                    |
| 3.6.2.2.1(a)             | Vector Graphic             | 3.7.4.1.6(a)             | Vector Graphic             |
| 3.6.2.2.1(b)             | Vector Graphic             | 3.7.4.1.6(b)             | Vector Graphic             |
| 3.6.2.2.1(c)             | Vector Graphic             | 3.7.4.1.6(c)             | Vector Graphic             |
| 3.6.2.2.1(d)             | Vector Graphic             | 3.7.4.1.6(d)             | Vector Graphic             |
| 3.6.2.2.4                | Vector Graphic             | 3.7.4.1.8(a)             | Scanned                    |
| 3.6.2.2.5(a)             | Vector Graphic             | 3.7.4.1.8(b)             | Scanned                    |
| 3.6.2.2.5(b)             | Vector Graphic             | 3.7.4.2.1                | Vector Graphic             |
| 3.6.2.2.6(a)             | Vector Graphic             | 3.7.4.2.6(a)             | Vector Graphic             |
| 3.6.2.2.6(b)             | Vector Graphic             | 3.7.4.2.6(b)             | Vector Graphic             |
| 3.6.2.2.6(c)             | Vector Graphic             | 3.7.4.2.6(c)             | Vector Graphic             |
| 3.6.2.2.6(d)             | Vector Graphic             | 3.7.4.2.6(d)             | Vector Graphic             |
| 3.6.2.2.6(e)             | Vector Graphic             | 3.7.4.2.6(e)             | Vector Graphic             |
| 3.6.2.2.6(f)             | Vector Graphic             | 3.7.4.2.6(f)             | Vector Graphic             |
| 3.6.2.2.6(g)             | Vector Graphic             | 3.7.4.2.6(g)             | Vector Graphic             |
| 3.6.2.2.6(h)             | Vector Graphic             | 3.7.4.2.6(h)             | Vector Graphic             |
| 3.6.2.2.6(i)             | Vector Graphic             | 3.7.4.2.6(i)             | Vector Graphic             |
| 3.6.2.2.6(j)             | Vector Graphic             | 3.7.4.2.6(j)             | Vector Graphic             |
| 3.6.2.2.6(k)             | Vector Graphic             | 3.7.4.2.8(a)             | Scanned                    |
| 3.6.2.2.6(l)             | Vector Graphic             | 3.7.4.2.8(b)             | Vector Graphic             |
| 3.6.2.2.6(m)             | Vector Graphic             | 3.7.4.2.8(c)             | Vector Graphic             |
| 3.6.2.2.6(n)             | Vector Graphic             | 3.7.4.2.8(d)             | Vector Graphic             |
| 3.6.2.2.6(o)             | Vector Graphic             | 3.7.4.2.8(e)             | Scanned                    |
| 3.6.2.2.8                | Vector Graphic             | 3.7.4.2.8(f)             | Scanned                    |
| 3.6.3.0                  | Vector Graphic             | 3.7.4.2.8(g)             | Scanned                    |
| 3.7.1.1.1                | Vector Graphic             | 3.7.4.2.8(h)             | Scanned                    |
| 3.7.1.1.6(a)             | Vector Graphic             | 3.7.4.2.8(i)             | Scanned                    |
| 3.7.1.1.6(b)             | Vector Graphic             | 3.7.4.2.8(j)             | Scanned                    |
| 3.7.1.1.6(c)             | Vector Graphic             | 3.7.4.2.8(k)             | Scanned                    |
| 3.7.1.1.6(d)             | Vector Graphic             | 3.7.4.2.8(l)             | Scanned                    |
| 3.7.1.2.6(a)             | Vector Graphic             | 3.7.4.2.9(a)             | Scanned                    |
| 3.7.1.2.6(b)             | Vector Graphic             | 3.7.4.2.9(b)             | Scanned                    |
| 3.7.1.2.6(c)             | Vector Graphic             | 3.7.4.2.9(c)             | Scanned                    |
| 3.7.1.2.6(d)             | Vector Graphic             | 3.7.4.3.6(a)             | Vector Graphic             |
| 3.7.2.0                  | Vector Graphic             | 3.7.4.3.6(b)             | Vector Graphic             |
| 3.7.3.1.1                | Vector Graphic             | 3.7.4.3.6(c)             | Vector Graphic             |
| 3.7.3.1.6(a)             | Vector Graphic             | 3.7.4.3.6(d)             | Vector Graphic             |
| 3.7.3.1.6(b)             | Vector Graphic             | 3.7.4.3.6(e)             | Vector Graphic             |
| 3.7.3.1.6(c)             | Vector Graphic             | 3.7.4.3.6(f)             | Vector Graphic             |
| 3.7.3.1.6(d)             | Vector Graphic             | 3.7.4.3.8(a)             | Scanned                    |
| 3.7.3.1.6(e)             | Vector Graphic             | 3.7.4.3.8(b)             | Scanned                    |
| 3.7.3.1.6(f)             | Vector Graphic             | 3.7.6.0                  | Vector Graphic             |
| 3.7.3.1.6(g)             | Vector Graphic             | 3.7.6.1.1(a)             | Scanned                    |
| 3.7.3.1.8(a)             | Scanned                    | 3.7.6.1.1(b)             | Scanned                    |
| 3.7.3.1.8(b)             | Scanned                    | 3.7.6.1.1(c)             | Vector Graphic             |
| 3.7.3.1.8(c)             | Scanned                    | 3.7.6.1.1(d)             | Vector Graphic             |
| 3.7.3.1.8(d)             | Scanned                    | 3.7.6.1.2(a)             | Vector Graphic             |
| 3.7.3.1.8(e)             | Scanned                    | 3.7.6.1.2(b)             | Vector Graphic             |

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| <b><u>Figure No.</u></b> | <b><u>Current Form</u></b> | <b><u>Figure No.</u></b> | <b><u>Current Form</u></b> |
|--------------------------|----------------------------|--------------------------|----------------------------|
| 3.7.6.1.3(a)             | Vector Graphic             | 3.7.6.2.10(b)            | Scanned                    |
| 3.7.6.1.3(b)             | Vector Graphic             | 3.7.7.1.6(a)             | Vector Graphic             |
| 3.7.6.1.4                | Vector Graphic             | 3.7.7.1.6(b)             | Vector Graphic             |
| 3.7.6.1.5(a)             | Vector Graphic             | 3.7.7.1.6(c)             | Vector Graphic             |
| 3.7.6.1.5(b)             | Vector Graphic             | 3.7.7.1.6(d)             | Vector Graphic             |
| 3.7.6.1.6(a)             | Vector Graphic             | 3.7.7.2.6(a)             | Vector Graphic             |
| 3.7.6.1.6(b)             | Vector Graphic             | 3.7.7.2.6(b)             | Vector Graphic             |
| 3.7.6.1.6(c)             | Vector Graphic             | 3.7.7.2.6(c)             | Vector Graphic             |
| 3.7.6.1.6(d)             | Vector Graphic             | 3.7.7.2.6(d)             | Vector Graphic             |
| 3.7.6.1.6(e)             | Vector Graphic             | 3.7.7.2.8(a)             | Vector Graphic             |
| 3.7.6.1.6(f)             | Vector Graphic             | 3.7.7.2.8(b)             | Vector Graphic             |
| 3.7.6.1.6(g)             | Vector Graphic             | 3.7.7.2.8(c)             | Vector Graphic             |
| 3.7.6.1.6(h)             | Vector Graphic             | 3.7.8.1.6(a)             | Vector Graphic             |
| 3.7.6.1.6(i)             | Vector Graphic             | 3.7.8.1.6(b)             | Vector Graphic             |
| 3.7.6.1.6(j)             | Vector Graphic             | 3.7.8.1.8(a)             | Vector Graphic             |
| 3.7.6.1.6(k)             | Vector Graphic             | 3.7.8.1.8(b)             | Vector Graphic             |
| 3.7.6.1.6(l)             | Vector Graphic             | 3.7.8.1.8(c)             | Vector Graphic             |
| 3.7.6.1.6(m)             | Vector Graphic             | 3.7.8.1.8(d)             | Vector Graphic             |
| 3.7.6.1.6(n)             | Vector Graphic             | 3.7.8.2.6(a)             | Vector Graphic             |
| 3.7.6.1.6(o)             | Vector Graphic             | 3.7.8.2.6(b)             | Vector Graphic             |
| 3.7.6.1.6(p)             | Vector Graphic             | 3.7.8.2.6(c)             | Vector Graphic             |
| 3.7.6.1.6(q)             | Vector Graphic             | 3.7.8.2.6(d)             | Vector Graphic             |
| 3.7.6.1.8(a)             | Scanned                    | 3.7.8.2.6(e)             | Vector Graphic             |
| 3.7.6.1.8(b)             | Scanned                    | 3.7.8.2.6(f)             | Vector Graphic             |
| 3.7.6.1.8(c)             | Scanned                    | 3.7.8.2.8(a)             | Scanned                    |
| 3.7.6.1.8(d)             | Vector Graphic             | 3.7.8.2.8(b)             | Scanned                    |
| 3.7.6.1.8(e)             | Scanned                    | 3.7.9.1.6(a)             | Vector Graphic             |
| 3.7.6.1.8(f)             | Vector Graphic             | 3.7.9.1.6(b)             | Vector Graphic             |
| 3.7.6.1.8(g)             | Scanned                    | 3.7.9.1.6(c)             | Vector Graphic             |
| 3.7.6.1.8(h)             | Vector Graphic             | 3.7.10.1.6(a)            | Vector Graphic             |
| 3.7.6.1.9                | Scanned                    | 3.7.10.1.6(b)            | Vector Graphic             |
| 3.7.6.1.10(a)            | Scanned                    | 3.7.10.1.6(c)            | Vector Graphic             |
| 3.7.6.1.10(b)            | Scanned                    | 3.7.10.1.6(d)            | Vector Graphic             |
| 3.7.6.1.10(c)            | Scanned                    | 3.7.10.1.6(e)            | Vector Graphic             |
| 3.7.6.1.10(d)            | Scanned                    | 3.7.10.1.6(f)            | Vector Graphic             |
| 3.7.6.1.10(e)            | Scanned                    | 3.7.10.1.6(g)            | Vector Graphic             |
| 3.7.6.1.10(f)            | Scanned                    | 3.7.10.1.8(a)            | Scanned                    |
| 3.7.6.1.10(g)            | Scanned                    | 3.7.10.1.8(b)            | Vector Graphic             |
| 3.7.6.1.10(h)            | Scanned                    | 3.7.10.1.8(c)            | Scanned                    |
| 3.7.6.2.6(a)             | Vector Graphic             | 3.7.10.1.10(a)           | Scanned                    |
| 3.7.6.2.6(b)             | Vector Graphic             | 3.7.10.1.10(b)           | Scanned                    |
| 3.7.6.2.6(c)             | Vector Graphic             | 3.7.10.1.10(c)           | Scanned                    |
| 3.7.6.2.6(d)             | Vector Graphic             | 3.7.10.1.10(d)           | Scanned                    |
| 3.7.6.2.6(e)             | Vector Graphic             | 3.7.10.2.6(a)            | Vector Graphic             |
| 3.7.6.2.6(f)             | Vector Graphic             | 3.7.10.2.6(b)            | Vector Graphic             |
| 3.7.6.2.9(a)             | Scanned                    | 3.7.10.2.8(a)            | Scanned                    |
| 3.7.6.2.9(b)             | Scanned                    | 3.7.10.2.8(b)            | Scanned                    |
| 3.7.6.2.9(c)             | Scanned                    | 3.7.10.2.9(a)            | Scanned                    |
| 3.7.6.2.10(a)            | Scanned                    | 3.7.10.2.9(b)            | Scanned                    |

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| <b><u>Figure No.</u></b> | <b><u>Current Form</u></b> | <b><u>Figure No.</u></b> | <b><u>Current Form</u></b> |
|--------------------------|----------------------------|--------------------------|----------------------------|
| 3.7.10.3.6(a)            | Vector Graphic             | 4.2.3.2.8(b)             | Scanned                    |
| 3.7.10.3.6(b)            | Vector Graphic             | 4.2.3.2.8(c)             | Scanned                    |
| 3.7.10.3.6(c)            | Vector Graphic             | 4.3.2.1.4                | Vector Graphic             |
| 3.7.10.3.6(d)            | Vector Graphic             | 4.3.2.1.6                | Vector Graphic             |
| 3.7.10.3.6(e)            | Vector Graphic             | 4.3.3.0                  | Vector Graphic             |
| 3.7.10.3.6(f)            | Vector Graphic             | 4.3.3.1.1(a)             | Vector Graphic             |
| 3.7.10.3.6(g)            | Vector Graphic             | 4.3.3.1.1(b)             | Vector Graphic             |
| 3.7.10.3.6(h)            | Vector Graphic             | 4.3.3.1.1(c)             | Vector Graphic             |
| 3.7.10.3.6(i)            | Vector Graphic             | 4.3.3.1.4                | Vector Graphic             |
| 3.7.10.3.6(j)            | Vector Graphic             | 4.3.3.1.6(a)             | Vector Graphic             |
| 3.7.10.3.6(k)            | Vector Graphic             | 4.3.3.1.6(b)             | Vector Graphic             |
| 3.7.10.3.6(l)            | Vector Graphic             | 4.3.4.0                  | Vector Graphic             |
| 3.7.10.3.10(a)           | Scanned                    | 4.3.4.1.1(a)             | Scanned                    |
| 3.7.10.3.10(b)           | Scanned                    | 4.3.4.1.1(b)             | Scanned                    |
| 3.8.1.0                  | Vector Graphic             | 4.3.4.1.1(c)             | Scanned                    |
| 3.8.1.1.6                | Vector Graphic             | 4.3.4.1.6                | Vector Graphic             |
| 3.8.1.1.8(a)             | Scanned                    | 4.3.5.1.1                | Scanned                    |
| 3.8.1.1.8(b)             | Scanned                    | 4.3.5.1.4                | Scanned                    |
| 3.8.1.1.8(c)             | Scanned                    | 4.3.5.1.6                | Vector Graphic             |
| 3.9.2.0                  | Vector Graphic             | 4.3.6.0                  | Scanned                    |
| 3.9.4.0                  | Vector Graphic             | 4.3.6.1.1                | Scanned                    |
| 3.9.5.1.6(a)             | Vector Graphic             | 4.3.6.1.4                | Scanned                    |
| 3.9.5.1.6(b)             | Vector Graphic             | 4.3.6.1.6(a)             | Scanned                    |
| 3.9.6.1.6                | Vector Graphic             | 4.3.6.1.6(b)             | Vector Graphic             |
| 3.9.7.1.6                | Vector Graphic             | 4.4.2.3(a)               | Scanned                    |
| 3.11.1.1.1               | Vector Graphic             | 4.4.2.3(b)               | Scanned                    |
| 3.11.2.3                 | Scanned                    | 4.4.3.2                  | Scanned                    |
| 3.11.3.2(a)              | Scanned                    | 5.2.1.0                  | Scanned                    |
| 3.11.3.2(b)              | Vector Graphic             | 5.2.1.1.1(a)             | Scanned                    |
| 3.11.3.2(c)              | Scanned                    | 5.2.1.1.1(b)             | Scanned                    |
| 3.11.3.2(d)              | Scanned                    | 5.2.1.1.2(a)             | Scanned                    |
| 3.11.3.2(e)              | Vector Graphic             | 5.2.1.1.2(b)             | Scanned                    |
| 3.11.3.2(f)              | Vector Graphic             | 5.2.1.1.3(a)             | Scanned                    |
| 3.11.3.2(g)              | Vector Graphic             | 5.2.1.1.3(b)             | Scanned                    |
| 4.2.1.0                  | Vector Graphic             | 5.2.1.1.6(a)             | Scanned                    |
| 4.2.1.1.4                | Scanned                    | 5.2.1.1.6(b)             | Scanned                    |
| 4.2.1.1.6                | Vector Graphic             | 5.3.1.0                  | Vector Graphic             |
| 4.2.1.2.1                | Scanned                    | 5.3.1.1.1                | Scanned                    |
| 4.2.1.2.2                | Scanned                    | 5.3.1.1.2                | Scanned                    |
| 4.2.1.2.3                | Scanned                    | 5.3.1.1.3                | Scanned                    |
| 4.2.1.2.4                | Scanned                    | 5.3.1.1.4                | Scanned                    |
| 4.2.1.2.6                | Vector Graphic             | 5.3.1.1.5                | Scanned                    |
| 4.2.1.4.8(a)             | Vector Graphic             | 5.3.1.1.9(a)             | Scanned                    |
| 4.2.1.4.8(b)             | Scanned                    | 5.3.1.1.9(b)             | Scanned                    |
| 4.2.3.0                  | Vector Graphic             | 5.3.1.1.9(c)             | Scanned                    |
| 4.2.3.2.6(a)             | Vector Graphic             | 5.3.2.0                  | Scanned                    |
| 4.2.3.2.6(b)             | Scanned                    | 5.3.2.1.1                | Scanned                    |
| 4.2.3.2.8(a)             | Scanned                    | 5.3.2.1.4                | Scanned                    |
|                          |                            | 5.3.2.1.6(a)             | Vector Graphic             |

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| <b><u>Figure No.</u></b> | <b><u>Current Form</u></b> | <b><u>Figure No.</u></b> | <b><u>Current Form</u></b> |
|--------------------------|----------------------------|--------------------------|----------------------------|
| 5.3.2.1.6(b)             | Vector Graphic             | 5.4.1.2.8(b)             | Scanned                    |
| 5.3.2.2.1                | Scanned                    | 5.4.1.2.8(c)             | Scanned                    |
| 5.3.2.2.6(a)             | Vector Graphic             | 5.4.1.2.8(d)             | Scanned                    |
| 5.3.2.2.6(b)             | Vector Graphic             | 5.4.1.2.8(e)             | Scanned                    |
| 5.3.2.2.8(a)             | Scanned                    | 5.4.1.2.8(f)             | Scanned                    |
| 5.3.2.2.8(b)             | Scanned                    | 5.4.1.2.8(g)             | Scanned                    |
| 5.3.2.2.8(c)             | Scanned                    | 5.4.1.2.8(h)             | Scanned                    |
| 5.3.2.2.8(d)             | Scanned                    | 5.4.1.2.8(i)             | Scanned                    |
| 5.3.2.2.8(e)             | Scanned                    | 5.4.2.0                  | Scanned                    |
| 5.3.2.2.8(f)             | Scanned                    | 5.4.2.1.1(a)             | Scanned                    |
| 5.3.3.0                  | Scanned                    | 5.4.2.1.1(b)             | Scanned                    |
| 5.3.3.1.1                | Scanned                    | 5.4.2.1.2(a)             | Scanned                    |
| 5.3.3.1.2                | Scanned                    | 5.4.2.1.2(b)             | Scanned                    |
| 5.3.3.1.4                | Scanned                    | 5.4.2.1.3(a)             | Scanned                    |
| 5.3.3.1.6(a)             | Vector Graphic             | 5.4.2.1.3(b)             | Scanned                    |
| 5.3.3.1.6(b)             | Vector Graphic             | 5.4.2.1.6(a)             | Vector Graphic             |
| 5.3.3.1.6(c)             | Scanned                    | 5.4.2.1.6(b)             | Vector Graphic             |
| 5.4.1.0                  | Vector Graphic             | 5.4.2.1.6(c)             | Scanned                    |
| 5.4.1.1.1                | Vector Graphic             | 5.4.2.1.8(a)             | Scanned                    |
| 5.4.1.1.2                | Scanned                    | 5.4.2.1.8(b)             | Scanned                    |
| 5.4.1.1.3                | Scanned                    | 5.4.2.2.1                | Scanned                    |
| 5.4.1.1.4                | Scanned                    | 5.4.2.2.2                | Scanned                    |
| 5.4.1.1.5                | Scanned                    | 5.4.3.1.6(a)             | Vector Graphic             |
| 5.4.1.1.6(a)             | Vector Graphic             | 5.4.3.1.6(b)             | Vector Graphic             |
| 5.4.1.1.6(b)             | Vector Graphic             | 5.4.3.1.6(c)             | Vector Graphic             |
| 5.4.1.1.6(c)             | Vector Graphic             | 5.4.3.1.8(a)             | Scanned                    |
| 5.4.1.1.6(d)             | Scanned                    | 5.4.3.1.8(b)             | Scanned                    |
| 5.4.1.1.8(a)             | Scanned                    | 5.4.3.1.9                | Scanned                    |
| 5.4.1.1.8(b)             | Scanned                    | 5.5.1.0                  | Scanned                    |
| 5.4.1.1.8(c)             | Scanned                    | 5.5.1.1.1                | Scanned                    |
| 5.4.1.1.8(d)             | Scanned                    | 5.5.1.1.2                | Scanned                    |
| 5.4.1.1.8(e)             | Scanned                    | 5.5.1.1.3(a)             | Scanned                    |
| 5.4.1.1.8(f)             | Scanned                    | 5.5.1.1.3(b)             | Scanned                    |
| 5.4.1.1.8(g)             | Scanned                    | 5.5.1.1.4                | Scanned                    |
| 5.4.1.1.9                | Scanned                    | 5.5.1.1.6                | Vector Graphic             |
| 5.4.1.2.1                | Scanned                    | 5.5.1.1.8(a)             | Scanned                    |
| 5.4.1.2.2                | Scanned                    | 5.5.1.1.8(b)             | Scanned                    |
| 5.4.1.2.3                | Scanned                    | 5.5.1.1.8(c)             | Scanned                    |
| 5.4.1.2.4                | Scanned                    | 5.5.1.1.8(d)             | Scanned                    |
| 5.4.1.2.6(a)             | Vector Graphic             | 5.5.1.2.1                | Scanned                    |
| 5.4.1.2.6(b)             | Vector Graphic             | 5.5.1.2.2                | Scanned                    |
| 5.4.1.2.6(c)             | Vector Graphic             | 5.5.1.2.3                | Scanned                    |
| 5.4.1.2.6(d)             | Vector Graphic             | 5.5.1.2.4                | Scanned                    |
| 5.4.1.2.6(e)             | Vector Graphic             | 5.5.1.2.6                | Vector Graphic             |
| 5.4.1.2.6(f)             | Vector Graphic             | 5.5.1.2.8(a)             | Scanned                    |
| 5.4.1.2.6(g)             | Vector Graphic             | 5.5.1.2.8(b)             | Scanned                    |
| 5.4.1.2.6(h)             | Scanned                    | 5.5.1.2.8(c)             | Scanned                    |
| 5.4.1.2.7                | Scanned                    | 5.5.2.0                  | Scanned                    |
| 5.4.1.2.8(a)             | Scanned                    | 5.5.2.1.6(a)             | Vector Graphic             |

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| <b><u>Figure No.</u></b> | <b><u>Current Form</u></b> | <b><u>Figure No.</u></b> | <b><u>Current Form</u></b> |
|--------------------------|----------------------------|--------------------------|----------------------------|
| 5.5.2.1.6(b)             | Vector Graphic             | 6.3.4.1.6(c)             | Scanned                    |
| 5.5.3.1.6                | Vector Graphic             | 6.3.5.0                  | Vector Graphic             |
| 5.5.3.2.6                | Vector Graphic             | 6.3.5.1.1                | Scanned                    |
| 5.6.1.1.1                | Scanned                    | 6.3.5.1.4(a)             | Scanned                    |
| 6.2.1.0                  | Scanned                    | 6.3.5.1.4(b)             | Scanned                    |
| 6.2.1.1.1                | Scanned                    | 6.3.5.1.4(c)             | Scanned                    |
| 6.2.1.1.3                | Scanned                    | 6.3.5.1.6(a)             | Vector Graphic             |
| 6.2.1.1.4(a)             | Scanned                    | 6.3.5.1.6(b)             | Vector Graphic             |
| 6.2.1.1.4(b)             | Scanned                    | 6.3.5.1.6(c)             | Vector Graphic             |
| 6.2.1.1.4(c)             | Scanned                    | 6.3.5.1.6(d)             | Scanned                    |
| 6.2.1.1.8(a)             | Scanned                    | 6.3.5.1.7(a)             | Scanned                    |
| 6.2.1.1.8(b)             | Scanned                    | 6.3.5.1.7(b)             | Scanned                    |
| 6.2.1.1.8(c)             | Scanned                    | 6.3.5.1.7(c)             | Scanned                    |
| 6.2.1.1.8(d)             | Scanned                    | 6.3.5.1.7(d)             | Vector Graphic             |
| 6.2.1.1.8(e)             | Scanned                    | 6.3.5.1.7(e)             | Vector Graphic             |
| 6.2.2.0                  | Scanned                    | 6.3.5.1.8(a)             | Vector Graphic             |
| 6.2.2.1.1(a)             | Scanned                    | 6.3.5.1.8(b)             | Vector Graphic             |
| 6.2.2.1.1(b)             | Scanned                    | 6.3.5.1.8(c)             | Vector Graphic             |
| 6.2.2.1.4(a)             | Scanned                    | 6.3.5.1.8(d)             | Vector Graphic             |
| 6.2.2.1.4(b)             | Scanned                    | 6.3.5.1.8(e)             | Vector Graphic             |
| 6.3.1.0                  | Scanned                    | 6.3.5.1.8(f)             | Vector Graphic             |
| 6.3.1.1.1                | Scanned                    | 6.3.5.1.8(g)             | Vector Graphic             |
| 6.3.1.1.4                | Scanned                    | 6.3.5.1.9(a)             | Vector Graphic             |
| 6.3.1.1.6(a)             | Vector Graphic             | 6.3.5.1.9(b)             | Scanned                    |
| 6.3.1.1.6(b)             | Vector Graphic             | 6.3.5.1.9(c)             | Scanned                    |
| 6.3.2.0                  | Scanned                    | 6.3.6.0                  | Scanned                    |
| 6.3.2.1.1                | Scanned                    | 6.3.6.1.1                | Scanned                    |
| 6.3.2.1.2                | Scanned                    | 6.3.6.1.2                | Scanned                    |
| 6.3.2.1.3                | Scanned                    | 6.3.6.1.3                | Scanned                    |
| 6.3.2.1.4                | Scanned                    | 6.3.6.2.1(a)             | Scanned                    |
| 6.3.3.0                  | Scanned                    | 6.3.6.2.1(b)             | Scanned                    |
| 6.3.3.1.1(a)             | Scanned                    | 6.3.6.2.4(a)             | Scanned                    |
| 6.3.3.1.1(b)             | Scanned                    | 6.3.6.2.4(b)             | Scanned                    |
| 6.3.3.1.4(a)             | Scanned                    | 6.3.7.0                  | Scanned                    |
| 6.3.3.1.4(b)             | Scanned                    | 6.3.7.1.1                | Vector Graphic             |
| 6.3.3.1.6(a)             | Vector Graphic             | 6.3.7.1.2                | Vector Graphic             |
| 6.3.3.1.6(b)             | Vector Graphic             | 6.3.7.1.3(a)             | Scanned                    |
| 6.3.3.1.6(c)             | Vector Graphic             | 6.3.7.1.3(b)             | Scanned                    |
| 6.3.3.1.6(d)             | Vector Graphic             | 6.3.7.1.4                | Scanned                    |
| 6.3.3.1.8(a)             | Scanned                    | 6.3.7.1.5                | Scanned                    |
| 6.3.3.1.8(b)             | Scanned                    | 6.3.7.1.7                | Scanned                    |
| 6.3.3.1.8(c)             | Scanned                    | 6.3.8.0                  | Scanned                    |
| 6.3.3.1.8(d)             | Scanned                    | 6.3.8.1.1                | Scanned                    |
| 6.3.4.0                  | Vector Graphic             | 6.3.8.1.4                | Scanned                    |
| 6.3.4.1.1                | Vector Graphic             | 6.3.8.1.5(a)             | Scanned                    |
| 6.3.4.1.4                | Vector Graphic             | 6.3.8.1.5(b)             | Scanned                    |
| 6.3.4.1.5                | Vector Graphic             | 6.3.8.1.6(a)             | Scanned                    |
| 6.3.4.1.6(a)             | Vector Graphic             | 6.3.8.1.6(b)             | Scanned                    |
| 6.3.4.1.6(b)             | Vector Graphic             | 6.3.9.0(a)               | Vector Graphic             |

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| <b><u>Figure No.</u></b> | <b><u>Current Form</u></b> | <b><u>Figure No.</u></b> | <b><u>Current Form</u></b> |
|--------------------------|----------------------------|--------------------------|----------------------------|
| 6.3.9.0(b)               | Vector Graphic             | 7.5.1.1.6(h)             | Vector Graphic             |
| 6.3.9.0(c)               | Vector Graphic             | 7.5.1.1.6(i)             | Vector Graphic             |
| 6.3.9.0(d)               | Vector Graphic             | 7.5.1.1.6(j)             | Vector Graphic             |
| 6.3.9.0(e)               | Vector Graphic             | 7.5.1.1.6(k)             | Vector Graphic             |
| 6.4.1.0                  | Scanned                    | 7.5.1.1.6(l)             | Vector Graphic             |
| 6.4.1.1.1                | Vector Graphic             | 7.5.2.1.6(a)             | Vector Graphic             |
| 6.4.1.1.2                | Vector Graphic             | 7.5.2.1.6(b)             | Vector Graphic             |
| 6.4.1.1.3                | Vector Graphic             | 7.5.2.1.6(c)             | Vector Graphic             |
| 6.4.1.1.4(a)             | Vector Graphic             | 7.5.2.1.6(d)             | Vector Graphic             |
| 6.4.1.1.4(b)             | Scanned                    | 7.5.2.1.6(e)             | Vector Graphic             |
| 6.4.1.1.5                | Scanned                    | 7.5.2.1.6(f)             | Vector Graphic             |
| 6.4.1.1.7                | Scanned                    | 7.5.2.1.6(g)             | Vector Graphic             |
| 6.4.2.0                  | Scanned                    | 7.5.2.1.6(h)             | Vector Graphic             |
| 6.4.2.1.1(a)             | Scanned                    | 7.5.2.1.6(i)             | Vector Graphic             |
| 6.4.2.1.1(b)             | Scanned                    | 7.5.2.1.6(j)             | Vector Graphic             |
| 6.4.2.1.2                | Scanned                    | 8.2.1                    | Scanned                    |
| 6.4.2.1.4(a)             | Scanned                    | 8.2.2.3.1.1(a)           | Scanned                    |
| 6.4.2.1.4(b)             | Scanned                    | 8.2.2.3.1.1(b)           | Scanned                    |
| 6.4.2.1.4(c)             | Scanned                    | 8.2.2.3.1.1(c)           | Scanned                    |
| 6.4.2.1.5                | Scanned                    | 8.2.2.3.2.1              | Scanned                    |
| 6.4.2.1.6(a)             | Vector Graphic             | 8.2.2.3.2.2(a)           | Scanned                    |
| 6.4.2.1.6(b)             | Vector Graphic             | 8.2.2.3.2.2(b)           | Scanned                    |
| 6.4.2.1.8(a)             | Scanned                    | 8.2.2.3.2.2(c)           | Scanned                    |
| 6.4.2.1.8(b)             | Scanned                    | 8.2.2.3.2.2(d)           | Scanned                    |
| 6.4.2.1.8(c)             | Scanned                    | 8.2.2.3.2.2(e)           | Scanned                    |
| 6.4.2.1.8(d)             | Scanned                    | 9.2.3                    | Scanned                    |
| 7.2.1.0                  | Vector Graphic             | 9.2.4                    | Scanned                    |
| 7.2.1.1.1                | Vector Graphic             | 9.2.6.1                  | Vector Graphic             |
| 7.2.1.1.4                | Vector Graphic             | 9.2.6(a)                 | Vector Graphic             |
| 7.3.2.0                  | Vector Graphic             | 9.2.6(b)                 | Vector Graphic             |
| 7.3.2.1.6(a)             | Vector Graphic             | 9.2.11                   | Scanned                    |
| 7.3.2.1.6(b)             | Vector Graphic             | 9.2.12                   | Scanned                    |
| 7.3.2.2.6                | Vector Graphic             | 9.2.15(a)                | Scanned                    |
| 7.4.1.0                  | Scanned                    | 9.2.15(b)                | Scanned                    |
| 7.4.1.1.1                | Scanned                    | 9.3.1.1.2                | Scanned                    |
| 7.4.1.1.4(a)             | Scanned                    | 9.3.1.1.3(a)             | Scanned                    |
| 7.4.1.1.4(b)             | Scanned                    | 9.3.1.1.3(b)             | Scanned                    |
| 7.4.1.1.5                | Scanned                    | 9.3.1.2                  | Scanned                    |
| 7.4.1.1.6                | Vector Graphic             | 9.3.1.3                  | Scanned                    |
| 7.4.2.0                  | Scanned                    | 9.3.1.4(a)               | Scanned                    |
| 7.4.2.1.4                | Scanned                    | 9.3.1.4(b)               | Scanned                    |
| 7.4.2.1.6                | Vector Graphic             | 9.3.1.5                  | Scanned                    |
| 7.5.1.1.6(a)             | Vector Graphic             | 9.3.1.6.1                | Scanned                    |
| 7.5.1.1.6(b)             | Vector Graphic             | 9.3.1.6.2                | Vector Graphic             |
| 7.5.1.1.6(c)             | Vector Graphic             | 9.3.2.3(a)               | Scanned                    |
| 7.5.1.1.6(d)             | Vector Graphic             | 9.3.2.3(b)               | Scanned                    |
| 7.5.1.1.6(e)             | Vector Graphic             | 9.3.2.3(c)               | Vector Graphic             |
| 7.5.1.1.6(f)             | Vector Graphic             | 9.3.2.4                  | Scanned                    |
| 7.5.1.1.6(g)             | Vector Graphic             | 9.3.2.5(a)               | Scanned                    |

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| <b><u>Figure No.</u></b> | <b><u>Current Form</u></b> | <b><u>Figure No.</u></b> | <b><u>Current Form</u></b> |
|--------------------------|----------------------------|--------------------------|----------------------------|
| 9.3.2.5(b)               | Vector Graphic             | 9.4.1.5.2(d)             | Scanned                    |
| 9.3.2.5(c)               | Vector Graphic             | 9.4.1.5.2(e)             | Scanned                    |
| 9.3.2.5(d)               | Vector Graphic             | 9.4.1.5.2(f)             | Scanned                    |
| 9.3.2.6                  | Scanned                    | 9.4.1.5.2(g)             | Scanned                    |
| 9.3.2.8(a)               | Scanned                    | 9.4.1.5.2(h)             | Scanned                    |
| 9.3.2.8(b)               | Scanned                    | 9.4.1.5.3                | Scanned                    |
| 9.3.2.8(c)               | Scanned                    | 9.4.1.6                  | Scanned                    |
| 9.3.4.1(a)               | Scanned                    | 9.4.1.7.2                | Scanned                    |
| 9.3.4.1(b)               | Scanned                    | 9.4.1.7.2, cont.         | Scanned                    |
| 9.3.4.1(c)               | Scanned                    | 9.4.2.2                  | Scanned                    |
| 9.3.4.1(d)               | Scanned                    | 9.4.2.3.2                | Scanned                    |
| 9.3.4.3                  | Scanned                    | 9.4.2.3.5(a)             | Scanned                    |
| 9.3.4.4                  | Scanned                    | 9.4.2.3.5(b)             | Scanned                    |
| 9.3.4.5                  | Scanned                    | 9.4.2.5.2                | Scanned                    |
| 9.3.4.7                  | Scanned                    | 9.4.2.5.3                | Scanned                    |
| 9.3.4.10(a)              | Scanned                    | 9.5.1.3                  | Scanned                    |
| 9.3.4.10(b)              | Scanned                    | 9.5.1.5.1(a)             | Scanned                    |
| 9.3.4.10(c)              | Scanned                    | 9.5.1.5.1(b)             | Scanned                    |
| 9.3.4.12(a)              | Scanned                    | 9.5.1.5.1(c)             | Scanned                    |
| 9.3.4.12(b)              | Scanned                    | 9.5.1.5.3                | Scanned                    |
| 9.3.4.13                 | Scanned                    | 9.6.1.3                  | Vector Graphic             |
| 9.3.4.16(a)              | Scanned                    | 9.6.1.5(a)               | Vector Graphic             |
| 9.3.4.17(a)              | Scanned                    | 9.6.1.5(b)               | Vector Graphic             |
| 9.3.4.17(b)              | Scanned                    | 9.6.1.5(c)               | Vector Graphic             |
| 9.3.4.17(c)              | Scanned                    | 9.6.1.9(a)               | Vector Graphic             |
| 9.3.4.17(d)              | Scanned                    | 9.6.1.9(b)               | Vector Graphic             |
| 9.3.4.17(e)              | Scanned                    | 9.6.3                    | Scanned                    |
| 9.3.4.17(f)              | Scanned                    | A.1                      | Scanned                    |
| 9.3.4.17(g)              | Scanned                    |                          |                            |
| 9.3.4.17(h)              | Scanned                    |                          |                            |
| 9.3.5.1(a)               | Scanned                    |                          |                            |
| 9.3.5.1(b)               | Scanned                    |                          |                            |
| 9.3.5.2                  | Scanned                    |                          |                            |
| 9.3.5.6                  | Scanned                    |                          |                            |
| 9.3.6.2                  | Scanned                    |                          |                            |
| 9.3.6.7                  | Scanned                    |                          |                            |
| 9.3.6.8(a)               | Scanned                    |                          |                            |
| 9.3.6.8(b)               | Scanned                    |                          |                            |
| 9.3.6.8(c)               | Scanned                    |                          |                            |
| 9.3.6.8(d)               | Scanned                    |                          |                            |
| 9.4.1.3                  | Scanned                    |                          |                            |
| 9.4.1.3.4(a)             | Scanned                    |                          |                            |
| 9.4.1.3.4(b)             | Scanned                    |                          |                            |
| 9.4.1.3.4(c)             | Scanned                    |                          |                            |
| 9.4.1.3.4(d)             | Scanned                    |                          |                            |
| 9.4.1.3.4(e)             | Scanned                    |                          |                            |
| 9.4.1.5.2(a)             | Scanned                    |                          |                            |
| 9.4.1.5.2(b)             | Scanned                    |                          |                            |
| 9.4.1.5.2(c)             | Scanned                    |                          |                            |

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