APPENDIX F

MIL-HDBK-5J, Department of Defense Handbook: Metallic Materials and Elements for Aerospace Vehicle Structures

F.1 Introduction

One of the great challenges in machine design is the identification of appropriate mechanical properties to use in the analysis process. Beginning in the late 1930s, several U.S. governmental entities formed the Army–Navy–Commerce Committee on Aircraft Requirements. This group fostered the development of a materials property database entitled ANC-5 for aircraft design; it focused on materials such as steel, aluminum, and magnesium alloys. In 1959, ANC-5 was modified and issued as a military handbook entitled *MIL-HDBK-5*; titanium properties were also added in this first version [1]. *MIL-HDBK-5* has undergone several updates since that time; the most recent was revision J issued in 2003, with a total length of 1733 pages [2].

MIL-HDBK-5J was withdrawn in 2004 and replaced by a fee-based document, "Metallic Materials Properties Development and Standardization (MMPDS)." Even so, *MIL-HDBK-5J* remains available for free download from the ASSIST database, the official source for specifications and standards used by the Department of Defense. Earlier versions as well as notes describing the cancellation of *MIL-HDBK-5J* can also be downloaded.

F.2 Overview of Data in *MIL-HDBK-5J*

The purpose of *MIL-HDBK-5J* is perhaps best summarized in its introductory paragraph:

> 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 materials properties presented in *MIL-HDBK-5J* (see Table F.1) represent a collection of data obtained through extensive testing by government agencies and research labs, aerospace companies, material manufacturers, trade groups, and academic publications. The data contained in *MIL-HDBK-5J* have been thoroughly scrutinized over many years and accepted, prior to its cancellation, by government and military entities as a source of statistically reliable material properties [3].

The data presented for each material follows a similar layout. For example, consider 2024 aluminum alloy (*MIL-HDBK-5J*, Section 3.2.3), that begins with an overview of the alloy, its various temper configurations, and basic properties (thermal conductivity, specific heat, thermal expansion coefficient) versus temperature. It continues with tables of "Design Mechanical and Physical Properties" that are organized by temper, form, thickness and statistical basis; these provide strength properties (yield strength, ultimate strength, elongation), elastic properties (modulus of elasticity, shear modulus, Poisson's ratio), and other physical properties such as density, all at room temperature. Subsequent figures provide for temperature adjustment of strength and elastic properties, typical stress-strain curves through yielding, fatigue data and associated *S–N* curve fits, fatigue crack growth rates, and the effect of temperature exposure duration on strength properties. Note that 2024 aluminum alloy is an important aircraft material; most materials are not described at this level of detail.

Table F.1 *Topics Covered in MIL-HDBK-5J*

MIL-HDBK-5J	**Topic Covered**
Chapter 1	Provides background, nomenclature, useful formulas, basic mechanics of materials principles and formulae, and material property definitions
Chapters 2–7	Contains data for steel, aluminum, magnesium, titanium, heat-resistant alloys, and miscellaneous alloys, respectively
Chapter 8	Presents information on structural joints using rivets, threaded fasteners, and welded and brazed joints
Chapter 9	Presents the methods used to incorporate data into *MIL-HDBK-5J*, including test and data requirements and statistical analysis methods
Appendixes	Provides a glossary and conversion factors to SI units along with various indices

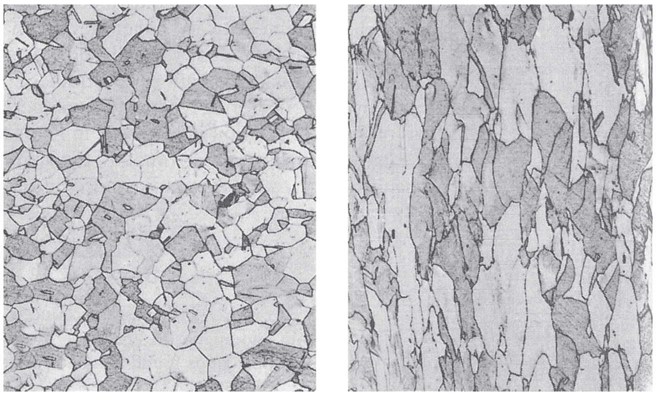
F.3 Advanced Formulas and Concepts Used in *MIL-HDBK-5J*

This section introduces several important formulae and concepts presented in *MIL-HDBK-5J*; additional explanation and usage can be found in the handbook.

F.3.1 Directionality of Material Properties

Typically metals for machine components are assumed to be isotropic; this means that material properties are identical in all directions. This is often a good assumption for properties such as modulus of elasticity. However, there is often directional dependence to strength properties due to material processing. One reason for this is the presence of grains within metals and metal alloys. Operations that involve mechanical work such as rolling, extruding, forging, etc. distort the grains in certain directions (see Figure F.1). This has the effect of introducing anisotropy into the strength properties. It can also play a critical role in failure induced by a combination of stress and corrosion (stress corrosion cracking).

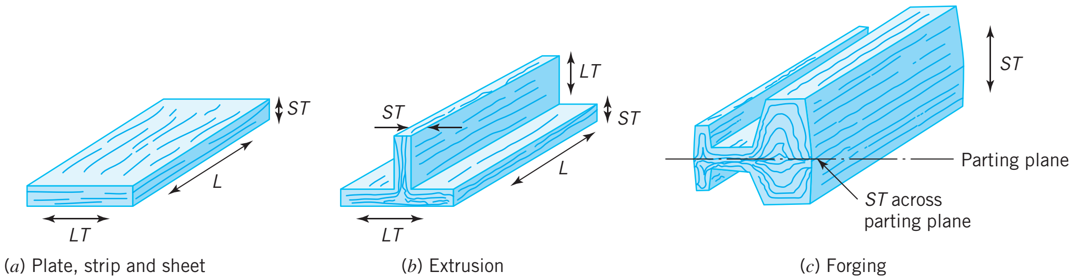
The directions for strength and elastic properties usually refer to letters *L*, *ST*, and *LT* for longitudinal, short transverse (usually in the thickness direction), and long transverse (usually in the plane of the part), respectively. Examples indicating typical directions for several types of parts are shown in Figure F.2. Fracture toughness properties typically refer to two directions, indicating the direction in which the crack opens as well as the direction in which the crack tip advances (see *MIL-HDBK-5J*, Figure 1.4.12.3).



(*a*) (*b*)

FIGURE F.1

Alteration of the grain structure of a polycrystalline metal as a result of plastic deformation. (*a*) Before deformation, the grains are equiaxed. (*b*) The deformation has produced elongated grains. 170×. From W.G. Moffatt, G.W. Pearsall, and J. Wulff, *The Structure and Properties of Metals, Vol. 1, Structure*, p. 140. Copyright 1964 by John Wiley & Sons, New York. Reprinted by permission of the estate of W.G. Moffatt.



(*a*) Plate, strip and sheet (*b*) Extrusion (*c*) Forging

FIGURE F.2

Material grain directions for several types of parts. (Adapted from [4] with permission.)

One other assumption that is commonly made for engineering metals is that modulus of elasticity is identical for tension and compression. In reality, material response is slightly stiffer in compression than tension. As a result, both tensile (E) and compressive (E_c) modulus of elasticity is provided for most tables; similarly, some figures also provide both tensile and compressive stress-strain response.

F.3.2 Elastic-Plastic Stress-Strain Curve and Modulus Definitions

Consider a material under an applied uniaxial normal stress σ with a resulting uniaxial normal strain ϵ; for simplicity, assume there are no thermal strain effects, as these could be easily added later. If the material remains in the linear elastic range, the relationship between stress and strain is simply $\sigma = E\,\epsilon$ (or E_c if in compression). However, if the stress exceeds the proportional limit, plastic strain (ϵ_p) occurs and leads to permanent deformation upon removal of the stress. In this case, the stress-strain response is no longer linear and the single elastic modulus value is not sufficient to describe material response.

MIL-HDBK-5J introduces two new values, called the tangent modulus (E_t) and the secant modulus (E_s) as illustrated in Figure F.3, to characterize stress-strain response beyond the linear range. The tangent modulus at a given stress level is the derivative of the stress-strain curve at that point. It provides a measure of stiffness as a function of stress level; as a result, it can be used for column buckling analysis as a conservative approximation [see *MIL-HDBK-5J*, Eq. 1.3.8(a)]. The secant modulus at a given stress level is the slope of the line connecting the origin to the stress-strain pair in question. It provides a ratio of the stress to the total strain (the sum of the elastic and plastic strains).

Another approach is the Ramberg-Osgood model, which provides an equation relating stress and strain that is appropriate for both the linear and nonlinear (plastic) regions. It is given by:

$$\epsilon = \left(\frac{\sigma}{E}\right) + 0.002\left(\frac{\sigma}{S_y}\right)^n \qquad \textbf{(F.1)}$$

where S_y is the yield strength identified by the 0.2% offset method and n is known as the Ramberg-Osgood parameter. The value of n is provided in many of the stress-strain

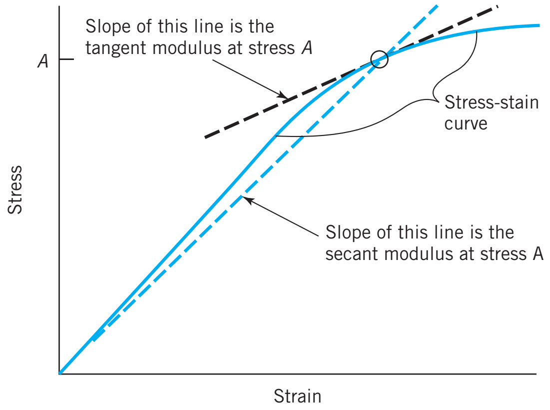


FIGURE F.3

Stress-strain response and associated secant and tangent moduli definitions at point ***A*****.** Adapted from ***MIL-HDBK-5J*****, Figure 9.8.4.2(a).**

figures of *MIL-HDBK-5J*. This approach is not well suited for materials with a definite yield point in that the stress remains constant (or decreases) for a period of strain, which is the case for many steel alloys.

F.3.3 Basis Definitions, Coefficient of Variation

Room temperature mechanical properties such as strength are presented while also indicating their statistical significance. This is done by categorizing the "basis" of the data in one of four categories (A, B, S, typical). Material properties with an "A" basis value indicate that at least 95% of the samples will have an actual property value greater than the given number with a confidence level of 99%. Similarly, the less conservative "B" basis value indicates that 90% of the samples will have an actual property value greater than the given number at a 90% confidence level. "A" and "B" basis values can be thought of as statistical minimum properties. Properties with an "S" basis represent the minimum value according to applicable specification; however, the statistical significance of the data is unknown. "Typical" basis values represent an average with no statistical significance. Additional details regarding the definition of these statistical terms can be found in Chapter 9 of *MIL-HDBK-5J* or any introductory probability and statistics textbook.

In terms of aircraft structure, "A" basis values are used to design structures in which there is not an alternate load path in the event of part failure. Most aircraft parts are designed with an alternate load path in the event of failure (redundant structure); in this case, "B" basis values, that are typically higher than "A" basis values, are commonly used [4]. Design calculations should not use either "S" basis or "typical" basis values, as their statistical significance is not known. However, since 1975 "S" basis values have incorporated statistical characteristics that result from quality assurance requirements in the underlying material specifications; in this case, "S" basis values can be considered as estimated "A" basis values (see Sections 9.1.6 and 9.4 of *MIL-HDBK-5J* for a detailed discussion).

In *MIL-HDBK-5J*, certain properties such as plane strain fracture toughness are provided for a given set of test data. In this case, the average, minimum, and maximum test values are presented, as is an item called the coefficient of variation. This is simply the standard deviation for the data set divided by the average data set value and then multiplied by 100. As such, it expresses the standard deviation as a percentage of the average value (a unitless quantity).

F.3.4 Bearing Strength and Edge Margin

In order to demonstrate bearing strength, consider a pin of diameter D passing through a plate of thickness t. Suppose that a load P is applied to the pin in the plane of the plate, causing it to bear on the hole in the plate. The bearing stress on the plate (calculated using bearing projected area) is $\sigma_b = P/Dt$. The plate bearing strength depends on the *edge margin*, that is defined as the ratio of the edge distance e (distance from the center of the hole to edge of the plate in the load direction) to the hole diameter D (see Figure F.4). For a very large value of edge margin (e/D), the bearing failure mode will be crushing of the plate material. As e/D is reduced, the failure mode will eventually change to tearing out the plate material between the pin and the plate edge. A common value of e/D for design is 2.0, with $e/D = 1.5$ often seen as a minimum acceptable value.

F.3.5 Equivalent Stress Fatigue Model

MIL-HDBK-5J presents fatigue data as S–N plots for stress cycles in that there is either no mean stress (fully reversed) or there is a non-zero mean stress. Rather than reporting the mean (σ_m) and alternating (σ_a) stress values, *MIL-HDBK-5J* presents the maximum value of the stress cycle ($\sigma_{\max}$) and the stress ratio R:

$$R = \frac{\sigma_{\min}}{\sigma_{\max}} \tag{F.2}$$

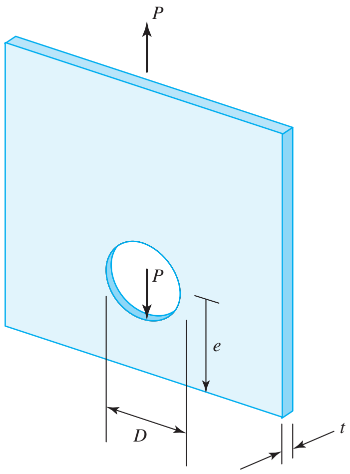


FIGURE F.4
Definition of edge distance e for a joint loaded by pin of diameter D with applied load P.

where $\sigma_{\min}$ is the minimum value of the stress cycle. For fully reversed fatigue tests, R is -1. The value of R remains finite if $\sigma_{\max} > 0$ (typical for fatigue testing).

Rather than using a modified Goodman diagram to predict fatigue with non-zero mean stress, an "equivalent stress model" is identified that best fits the entire set of test data for a given alloy and specimen configuration. This data consists of points ($\sigma_{\max}$, N), obtained at a variety of R ratios, where N is the number of cycles until failure under the applied stress cycle (ranges from $\sigma_{\max}$ to $\sigma_{\min} = R\ \sigma_{\max}$). The model can then be used to predict cycles to failure under a variety of maximum stress and stress ratio combinations. It uses $\sigma_{\max}$ and R to estimate an equivalent stress (σ_{eq}). It then refers to a second equation to determine the number of cycles to failure. Most data in *MIL-HDBK-5J* present this model using 4 constants (A, B, C, D; one or more may be 0) as:

$$\log(N) = A - B \log(\sigma_{eq} - C) \tag{F.3}$$

$$\sigma_{eq} = \sigma_{\max}(1 - R)^{D} \tag{F.4}$$

This indicates that fatigue data ($\sigma_{\max}$, N) at various R ratios collapses to a single line when plotted as $\log(\sigma_{eq} - C) - \log N$ [5]. This model can be rearranged to provide the maximum stress for a given number of cycles to failure and R ratio as:

$$\sigma_{\max} = \left[\left(\frac{10^{A}}{N}\right)^{1/B} + C\right](1-R)^{-D} \tag{F.5}$$

The degree of fit between the model and the data used to generate it is reported in each figure via statistical measures. Each figure also notes that the model can lead to unrealistic results for R ratios outside of those used to generate the model. Similarly, the predicted stress for a given number of cycles may be unrealistic if the number of cycles of interest is not represented in the data set. For example, using the equivalent stress model to predict strength at 10 cycles would likely lead to a stress far in excess of the ultimate tensile stress (obviously incorrect). Hence, caution and judgment must be employed to ensure that model predictions are both realistic and within the bounds of the underlying data set.

Fatigue test data in *MIL-HDBK-5J* is presented for a mix of unnotched and notched specimens. In all cases, the theoretical stress concentration factor (K_t) is reported and the notch geometry used is described. From this, the user could identify the notch sensitivity factor (q) and the associated fatigue stress concentration factor (K_f) if desired. However, the stress data reported in *MIL-HDBK-5J* are based upon net section; this means that the stresses are calculated using the minimum cross-sectional area and *are not* adjusted to account for the stress concentration factor. For example, if the net area stress is 10 ksi for a specimen with $K_t = 2.0$, the stress in the *S–N* figure would be reported as 10 ksi, not 20 ksi ($= K_t \cdot 10$ ksi).

F.4 Mechanical and Physical Properties of 2024 Aluminum Alloy

The following sections illustrate the basic features of *MIL-HDBK-5J* and how tables and figures can be used to determine properties for 2024 aluminum alloys. Information in *MIL-HDBK-5J* regarding 2024 aluminum alloy sheet begins on page 3–68.

F.4.1 Mechanical Properties at Room Temperature

For each material in *MIL-HDBK-5J*, design mechanical and physical properties at room temperature (70°F) are presented—see Table F.2 for a specific example of properties for 2024-T351 plate with thicknesses in the range 0.250 in.–1.000 in.

Table F.2 *Design Mechanical and Physical Properties of 2024-T351 Aluminum Alloy Plate*

AMS 4037 and AMS-QQ-A-250/4				
Plate				
T351				
Thickness, in.	**0.250–0.499**		**0.500–1.000**	
Basis	**A**	**B**	**A**	**B**
Mechanical Properties:				
F_{tu}, ksi:				
L	64	66	63	65
LT	64	66	63	65
ST	—	—	—	—
F_{ty}, ksi:				
L	48	50	48	50
LT	42	44	42	44
ST	—	—	—	—
F_{cy}, ksi:				
L	39	41	39	41
LT	45	47	45	47
ST	—	—	—	—
F_{su}, ksi:	38	39	37	38
F_{bru}, ksi:				
($e/D = 1.5$)	97	100	95	98
($e/D = 2.0$)	119	122	117	120

Source: Adapted from MIL-HDBK-5J, Table 3.2.3.0(b_1).

F_{bry}, ksi:				
(e/D = 1.5)	72	76	72	76
(e/D = 2.0)	86	90	86	90
e, percent (S-basis):				
LT	12	…	8	…
E, 10^3 ksi	10.7			
E_c, 10^3 ksi	10.9			
G, 10^3 ksi	4.0			
μ	0.33			
Physical Properties:				
ρ, lb/in^3	0.100			
C, K, and α	See Figure 3.2.3.0			

The table is headed by the governing specification, typically an Aerospace Material Specification (AMS) issued by the SAE Aerospace Materials Division. ASTM or government (military, federal) specifications are also used in some cases. The form of the material (sheet, plate, bar, etc.) and the material condition or temper is stated. The individual properties are then presented for various material thicknesses and the basis of the value (“A,” “B,” “S”). The items in each table and their associated definitions are shown in Table F.3.

As expected, “A” basis values are somewhat below the “B” basis values due to the differing statistical significance requirements (note that they are occasionally

Table F.3 ***Symbols and Definitions for Mechanical and Physical Properties Provided in MIL-HDBK-5J (See Table F.2.)***

Label	**Definition**	**Label**	**Definition**
F_{tu}	Tensile ultimate strength	E	Modulus of elasticity (tension)
F_{ty}	Tensile yield strength	E_c	Modulus of elasticity (compression)
F_{cy}	Compression yield strength	G	Shear modulus
F_{su}	Shear ultimate strength	μ	Poisson’s ratio
F_{bru}	Bearing ultimate strength	ρ	Density
F_{bry}	Bearing yield strength	C	Specific heat
e	Percent elongation at break	K	Thermal conductivity
		α	Coefficient of thermal expansion

equal to one another as well). Such tables in *MIL-HDBK-5J* also generally contain footnotes providing additional information for certain properties. For example, one footnote indicates that the application of stress in the short transverse (*ST*) direction for thick 2024-T351 plate is not ideal if corrosion can occur; in this case, the strength in the *ST* direction is dramatically reduced due to a phenomenon known as stress corrosion cracking (see Section F.5).

F.4.2 Strength and Other Properties versus Temperature

Many strength properties are also provided as functions of temperature. For example, an adjustment factor for tensile ultimate strength at a desired temperature is presented in Figure F.5. This adjustment factor (ranging from 0 to 100) is used as follows:

$$F_{\text{tu desired temperature}} = \frac{\textit{adjustment factor}}{100} \times F_{\text{tu room temperature}} \qquad \textbf{(F.6)}$$

where F_{tu} at room temperature is obtained from Table F.3. For 2024-T3 and 2024-T351, long-term exposure to elevated temperature alters the heat treatment characteristics of the material. Hence, Figure F.5 provides adjustment factors that are dependent on the duration of the exposure time at elevated temperature that the part has experienced. Other physical properties such as thermal expansion, thermal conductivity, and specific heat are also provided as functions of temperature. An example is presented in Figure F.6.

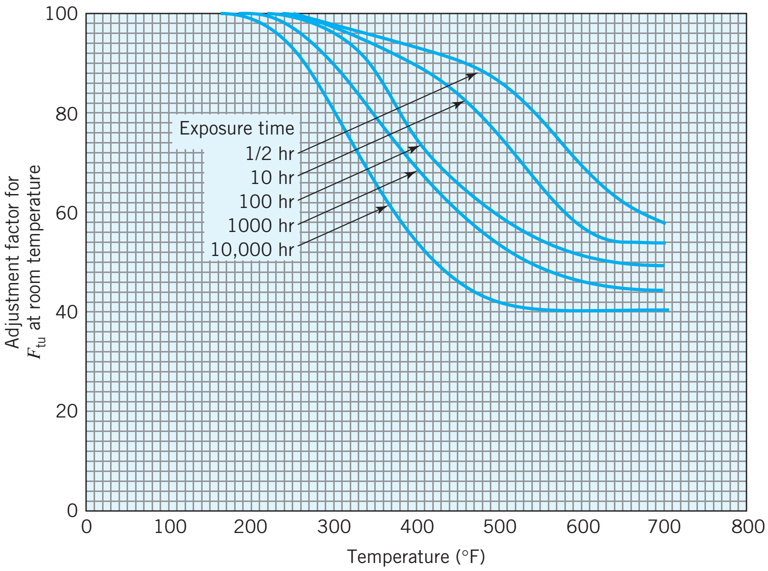


Figure F.5
Effect of temperature and exposure time on tensile ultimate strength for 2024-T3 and 2024-T351 aluminum alloys, excluding thick extrusions. Adapted from MIL-HDBK-5J, Figure 3.2.3.1.1 (e).

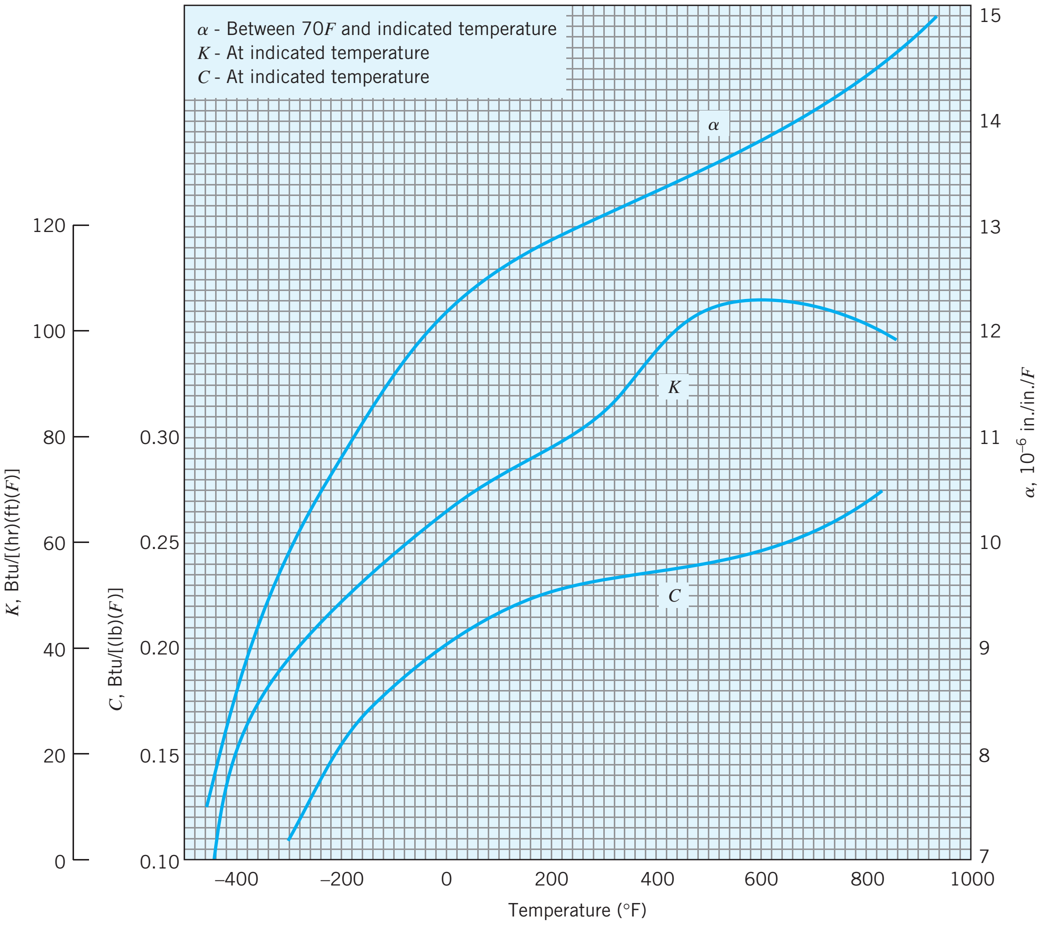


FIGURE F.6
Thermal expansion (α), thermal conductivity (*K*) and specific heat (*C*) for 2024 alloys versus temperature. Adapted from *MIL-HDBK-5J*, Figure 3.2.3.0.

F.4.3 Stress-strain curves and tangent modulus

An example of stress-strain curves and associated tangent modulus curves for 2024-T3 alloy sheet is shown in Figure F.7 for the L direction. The Ramberg-Osgood exponent (n) for each stress-strain curve is noted. The tangent modulus (E_t) curves represent the local slope of the stress-strain curve at the indicated stress level. The tangent modulus begins as a vertical line whose value is E (or E_c in compression) until the proportional limit is reached. For higher stress values, the tangent modulus declines in value, reflecting that the local slope of the stress-strain curve (E_t) is less than E (or E_c). The primary use of the tangent modulus is in the determination of structural buckling loads and therefore is only shown for the compression case.

Recall that the equation for critical load (P_{cr}) and critical stress (σ_{cr}) for Euler column buckling is given by:

$$P_{cr} = \frac{\pi^2 EI}{L_c^2} \rightarrow \sigma_{cr} = \frac{P_{cr}}{A} \tag{F.3}$$

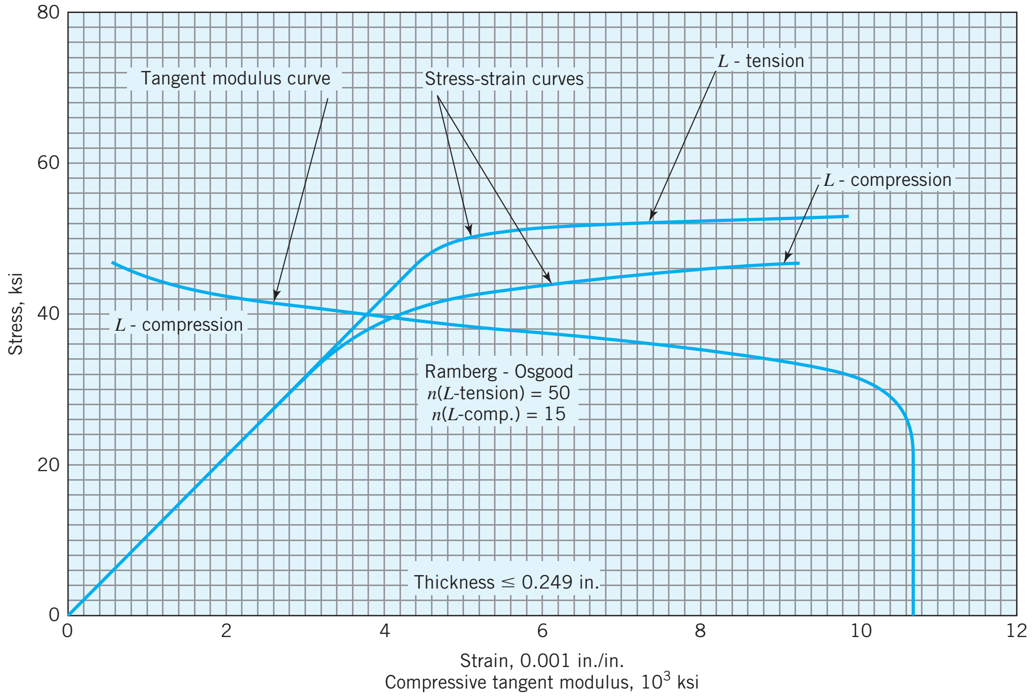


FIGURE F.7

Typical stress-strain curves and tangent modulus curves for 2024-T3 alloy sheet in the *L* direction at room temperature. Adapted from *MIL-HDBK-5J*, Figure 3.2.3.1.6(a).

where I is the moment of inertia, A is the cross-sectional area, and L_e is the effective length of the column. If the critical stress is below the proportional limit, E_c and E_t are identical and lead to the same result. However, when the critical stress is above the proportional limit, it is best to use the tangent modulus for design; it is both conservative (since $E_t < E_c$) and better reflects the local stiffness of the column at the stress level being considered. For further discussion of this topic see *MIL-HDBK-5J*, Section 1.6 ("Columns").

F.4.4 Fatigue *S–N* data and equivalent stress model

An example of fatigue data (indicated symbols) and the associated equivalent stress model fits (solid lines) is shown in Figure F.8 for rolled bar 2024-T4 alloy specimens tested axially in the unnotched condition ($K_t = 1.0$). Runout data points are those that did not fail within a certain number of cycles; these are indicated with symbols at the associated cycle count with arrows pointing to the right.

Details of the tests used to obtain the data in Figure F.8 are shown in Table F.4 along with the parameters describing the equivalent stress model. As discussed previously, the equivalent stress model can be used to predict the number of cycles to failure at a specified maximum fatigue stress level ($S_{\max}$) and stress ratio (R). The model can also be used to predict the maximum stress associated with a certain number of cycles to failure (see Equation F.6). Caution should be used if the model is

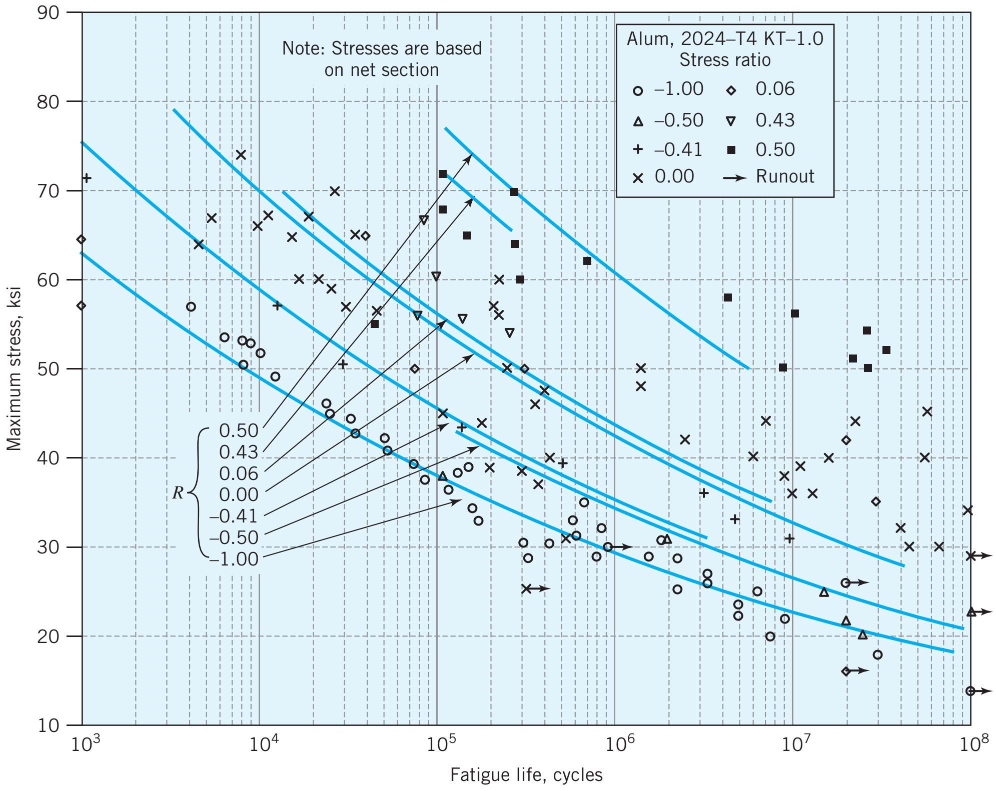


FIGURE F.8

S–N curves for unnotched 2024-T4 aluminum alloy (longitudinal direction) with equivalent stress model parameters shown. Adapted from MIL-HDBK-5J, Figure 3.2.3.1.8(a).

extended beyond the data set used to create it. For example, using Figure F.8 to determine the maximum stress for an R ratio of 0.50 at 10^3 cycles would clearly be invalid, as the prediction would be well above 75 ksi (the highest stress test specimen in the data set).

In addition to *S–N* curves, fatigue crack growth data is also presented for certain alloys and represents the crack length (a) versus the number of fatigue cycles applied (N). This experimentally obtained information can be used to assess the Paris equation for the material. For example, data for 2124-T851 aluminum plate can be found at *MIL-HDBK-5J*, Figures 3.2.7.1.9(a)–(e).

F.5 Fracture Toughness and Other Miscellaneous Properties

A limited set of plane strain fracture toughness (K_{Ic}) values are presented in *MIL-HDBK-5J*. Configurations are presented for steel, aluminum, and titanium alloys, representing different alloys, heat treatments, and crack orientations. These values are labeled “for information only,” as they lack the statistical reliability of the mechanical design properties previously presented (i.e., “A,” “B,” “S” basis). A subset of these

Table F.4 ***Fatigue Test Details and Equivalent Stress Model Parameters Used to Develop the S–N Curves Shown in Figure F.8 Which are for Unnotched 2024-T4 Aluminum Alloy (Longitudinal Direction).***

Product Form	**Specimen Details**
Rolled bar, 0.75 to 1.25 in diameter	Unnotched
Drawn rod, 0.75 in diameter	0.160 to 0.400 in diameter
Extruded rod, 1.25 in diameter	Longitudinally polished surface
Extruded bar, 1.25 in × 4 in	
Mechanical Properties at Room Temp.	**Test Parameters**
F_{tu} = 69 ksi F_{ty} = 45 ksi (rolled)	Loading – axial
F_{tu} = 71 ksi F_{ty} = 44 ksi (drawn)	Frequency – 1800 to 3600 cycles/min
F_{tu} = 85 ksi F_{ty} = 65 ksi (extruded)	Room temperature in air
	Equivalent Stress
	$\log(N_f) = 20.83 - 9.09 \log(S_{eq})$
	$S_{eq} = S_{max}(1 - R)^{0.52}$

Source: Adapted from MIL-HDBK-5J, Figure 3.2.3.1.8(a).

entries is shown in Table F.5. Additional test details, limitations on property usage, and full heat treat condition specifications can be found in *MIL-HDBK-5J*.

A number of other topics regarding material behavior are addressed in Chapters 2–7, and are grouped under common section titles throughout *MIL-HDBK-5J*. These titles can be consulted for each material under consideration. A summary of the headings as well as a brief discussion of each with examples is presented in Table F.6.

One environmental concern for many materials is *stress corrosion cracking*, in which exposure to certain environments (such as salt water) in the presence of stress can lead to crack formation. This can lead to dramatic reductions in properties relative to pristine specimen mechanical properties. A demonstration of the impact of salt water exposure time for high alloy steels is shown in Figure F.9. An extensive list of property reductions for aluminum alloys exposed to corrosive environments under applied stress can be found in *MIL-HDBK-5J* in Tables 3.1.2.3.1(a)–(e). Proper corrosion protection through painting, plating, etc. is critical for materials with stress corrosion cracking issues.

As mentioned in the introduction, Chapter 8 of *MIL-HDBK-5J* also presents data for structural joints. One section focuses on joint strength made with various fasteners (rivets, blind fasteners, swaged collar fasteners, threaded fasteners, etc.) in different configurations (protruding head, flush head, etc.). All joint data assumes an edge margin (*e/D*) of 2.0. Another section focuses on metallurgical joints formed by welding or brazing and presents extensive data on the static and fatigue strength of spot welded joints with limited data for other items such as fusion welding, flash welding, and brazing.

Table F.5 *Plane Strain Fracture Toughness of Selected Steel (Top), Aluminum (Middle), and Titanium (Bottom) Alloys. MIL-HDBK-5J, Subset of Tables 2.1.2.1.3 (Steel), 3.1.2.1.6 (Aluminum), 5.1.2.1.1 (titanium).*

Alloy	Heat Treat Condition/ Temper	Product Form	Orientation	F_{ty} Range (ksi)	Specimen Thickness Range (in.)	K_{Ic} (ksi $\sqrt{\text{in}}$)			Coefficent of Variation
						Max.	Avg.	Min.	
D6AC	Q&T salt	Plate	L–T	217	0.6	88	62	40	22.5
D6AC	Q&T oil	Plate	L–T	217	0.6 – 0.8	101	92	64	8.9
9Ni-4Co-.20C	Q&T oil	Forging	L–T	186 – 192	1.5 – 2.0	147	134	120	8.5
PH13-8Mo	H1000	Forging	L–T	205 – 212	0.7 – 2.0	104	90	49	21.5
2024	T351	Plate	L–T	—	0.8 – 2.0	43	31	27	16.5
2024	T851	Plate	L–S	—	0.5 – 0.8	32	25	20	17.8
2024	T851	Plate	L–T	—	0.4 – 1.4	32	23	15	10.1
2024	T851	Plate	T–L	—	0.4 – 1.4	25	20	18	8.8
Ti-6Al-4V	Mill Ann.	Forged bar	L–T	121 – 143	0.6 – 1.1	77	60	38	10.5
Ti-6A1-4V	Mill Ann.	Forged bar	T–L	124 – 145	0.5 – 1.3	81	57	33	11.7

Table F.6 *Common Sections in MIL-HDBK-5J and Examples of Associated Information.*

Heading	Presented Information
Material properties	Discussion at the beginning of each chapter relating to the material therein. Examples: grain structure (martensitic, austenitic, etc.) for steel; review of tempering for aluminum.
Mechanical properties	Issues related to strength and other mechanical properties. Example: property variation and directional dependence for thick steel parts, especially when heat treated for high strength.
Metallurgical considerations	Issues related to the metallurgy of the material. Examples: heat treatment for carbon steel; the effect of alloys in low, intermediate, and high alloy steels; composition of superalloys.
Manufacturing considerations	Issues related to manufacturing methods. Examples: formability of steels by forging, rolling, extrusion, etc.; machining; suitability of joining by welding, brazing, etc.
Environmental considerations	Issues related to environmental exposure and corrosion. Examples: Oxidation resistance for various materials; ductile-to-brittle transformation for steels; stress-corrosion cracking.

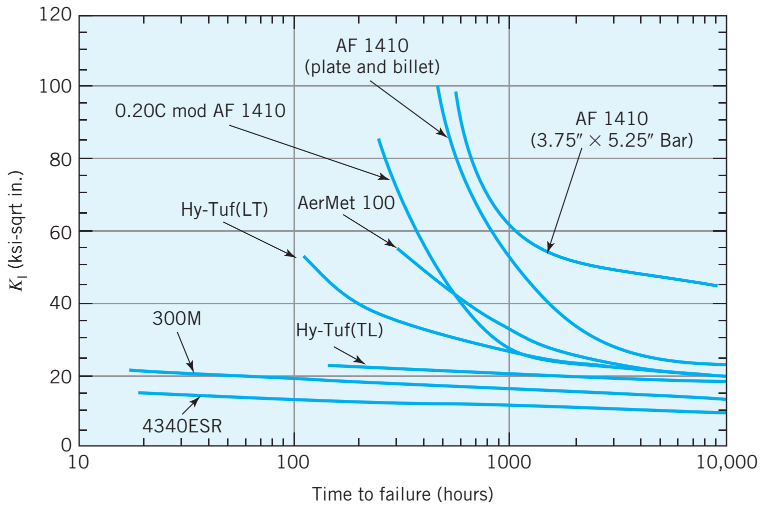


FIGURE F.9

Critical stress intensity factor (K_{Ic}) for high alloy steels after exposure to 3.5% NaCl environment for period indicated. Adapted from *MIL-HDBK-5J*, Figure 2.5.0.2(a).

F.6 Conclusion

MIL-HDBK-5J represents an extensive database of material properties for metals commonly used in machine components. It is available as a free download and can serve as an outstanding resource for students in their academic studies and later engineering practice. *MIL-HDBK-5J* was canceled in May, 2004 and superseded by *MMPDS*, a fee-based document. As such, *MIL-HDBK-5J* is no longer current and users should be aware that the subsequent revisions in *MMPDS* are not reflected. For many general applications, the values in *MIL-HDBK-5J* can still serve as a useful resource. However, regardless of what material properties are used, testing and evaluation should be conducted to establish proper and safe machine component performance.

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