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Strength of Metal Aircraft Elements

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CONTENTS

CHAPTER 1. GENERAL

CHAPTER 2. STEEL

CHAPTER 4. MAGNESIUM ALLOYS

TABLES

CHAPTER 2. STEEL

CHAPTER 3. ALUMINUM ALLOYS

CHAPTER 4. MAGNESIUM ALLOYS

CHAPTER 5. TITANIUM AND ITS ALLOYS

CHAPTER 6. MISCELLANEOUS METALS

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FIGURES

CHAPTER 1. GENERAL

CHAPTER 2. STEEL

CHAPTER 3. ALUMINUM ALLOYS

CHAPTER 4. MAGNESIUM ALLOYS

CHAPTER 5. TITANIUM AND ITS ALLOYS

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CHAPTER 1
GENERAL

1.1 Purpose and use of document

1.11 INTRODUCTION. Since many aircraft manufacturers supply airplanes for both commercial and military use, standardization of the requirements of the various Governmental procuring or certificating agencies is of direct benefit to the manufacturer. Although the types and purposes of military aircraft often differ greatly from those of commercial aircraft, necessitating certain differences in the structural requirements, the requirements for strength of materials and elements have for some time been nearly identical. This publication has therefore been prepared to eliminate the necessity for referring to different handbooks and bulletins in calculating the allowable stresses or minimum strength of typical structures. With a few exceptions (which are noted in the appropriate places) the material contained herein is acceptable to the Air Force, Bureau of Aeronautics, and the Civil Aeronautics Administration.

1.12 SCOPE OF DOCUMENT. Only the most commonly used materials and elements are included in this publication. Until a structural material or element has been used for some time and in considerable quantities, the strength properties will probably vary considerably as manufacturing processes are improved and modified. In such cases special rulings should be obtained by the manufacturer from the procuring or certificating agency. These rulings will be based upon specimen tests and will eventually form a basis for standard accepted strength properties.

In addition to the strength of the materials and elements themselves, there are contained herein some of the more commonly used methods and formulas by which the strength of various structural components are calculated. In some cases the methods presented are empirical and subject to further refinement. Likewise, it is expected that additional material can be added from time to time as the methods of handling new problems become more uniform and reliable.

Engineers making use of the material contained herein are invited to submit comments and suggestions as to the expansion and improvement of the document. Such comments should be submitted to members of the ANC-5 Panel.

1.13 USE OF DESIGN MECHANICAL PROPERTIES. It is customary to assign minimum values to certain mechanical properties of materials for procurement specification purposes. In general, but not necessarily in all cases, the design mechanical properties given herein are based on these minimum values. The manner in which these design mechanical properties are to be used will depend on the type of structure being investigated and will be definitely specified in the detailed structural requirements of the procuring or certificating agencies. The use of the different design mechanical properties such as ultimate tensile strength, yield strength, etc., the factors of safety associated with them, and the arbitrary reductions in allowable stresses which may be considered necessary in particular cases, will not be taken up in detail herein, information of this sort being in the nature of specific requirements which do not affect the material properties as such.

1.2 Standard structural symbols

A—Area of cross section, square inches.

a—Subscript "allowable."

B—Slenderness ratio factor. (See equation 1.392.)

b—Width of sections; subscript "bending."

br—Subscript "bearing."

C—Circumference.

c—Fixity coefficient for columns; distance from neutral axis to extreme fiber; subscript "compression."

cr—Subscript "critical."

D—Diameter.

d—Depth or height; mathematical operator denoting differential.

E—Modulus of elasticity in tension; average ratio of stress to strain for stress below proportional limit.

e—Elongation in percent, this factor being a measure of the ductility of the material and being based on a tension test; unit deformation or strain; eccentricity; subscript for Euler's formula; subscript "endurance."

—The minimum distance from a hole centerline to the edge of the sheet.

E'—Effective modulus of elasticity.

E_c—Modulus of elasticity in compression; average ratio of stress to strain below proportional limit.

E_s—Secant modulus.

E_t—Tangent modulus.

F—Allowable stress.

f—Internal (or calculated) stress.

F_b—Allowable bending stress, modulus of rupture in bending.

f_b—Internal (or calculated) primary bending stress.

f_b'—Internal (or calculated) precise bending stress.

F_{be}—Endurance limit in bending.

f_{br}—Internal (or calculated) bearing stress.

F_{bru}—Ultimate bearing stress.

F_{bry}—Yield bearing stress.

F_c—Allowable compressive stress.

f_c—Internal (or calculated) compressive stress.

F_{cc}—Allowable crushing or crippling stress (upper limit of column stress for local failure).

F_{co}—Column yield stress (upper limit of column stress for primary failure).

F_{cp}—Proportional limit in compression.

F_{cu}—Ultimate compressive stress.

F_{cy}—Compressive yield stress.

F_n—Allowable normal stress.

f_n—Internal (or calculated) normal stress.

F_s—Allowable shearing stress.

f_s—Internal (or calculated) shearing stress.

$F_{s_{cr}}$—Critical shear stress for buckling of rectangular panels.

F_{se}—Endurance limit in torsion.

F_{sp}—Proportional limit in shear.

F_{st}—Modulus of rupture in torsion.

F_{su}—Ultimate stress in pure shear. This value represents the average shearing stress over the cross section.

F_t—Allowable tensile stress.

f_t—Internal (or calculated) tensile stress.

F_{tp}—Proportional limit in tension.

F_{tu}—Ultimate tensile stress (from tests of standard specimens).

F_{ty}—Tensile yield stress at which permanent strain equals 0.002 (from tests of standard specimens).

G—Modulus of rigidity.

g—

H—

h—Height or depth; especially the distance between centroids of chords of beams and trusses.

I—Moment of inertia.

i—Slope (due to bending) of neutral plane of a beam, in radians (1 radian$=57.3°$).

I_p—Polar moment of inertia.

J—Torsion constant ($=I_p$ for round tubes).

j—Stiffness factor$=\sqrt{EI/P}$.

K—A constant generally empirical.

ksi—Kips (1,000 pounds) per square inch.

L—Length; subscript "lateral"; longitudinal (grain direction).

l—(Not used, to avoid confusion with numeral 1).

M—Applied moment or couple, usually a bending moment.

m—

M_a—Allowable bending moment.

N—

n—Subscript "normal."

O—

o—

P—Applied load (total ,not unit load).

p—Subscript "polar"; subscript "proportional limit."

P_a—Allowable load.

psi—Pounds per square inch.

Q—Static moment of a cross section.

q—

R—Stress ratio$=f/F$.

r—Radius.

S—Shear force.

s—Subscript "shear."

ST—Short transverse grain direction.

T—Applied torsional moment torque; transverse grain direction.

t—Thickness.

T_a—Allowable torsional moment.
U—Factor of utilization.
u—Subscript "ultimate."
V—
v—
W—
w—Specific weight, lb/cu. in.
X—
x—Distance along elastic curve of a beam.
Y—
y—Deflection (due to bending) of elastic curve of a beam; distance from neutral axis to given fiber; subscript "yield."
Z—Section modulus, I/y.
z—
Z_p—Polar section modulus $=I_p/y$ (for round tubes).
δ (delta)—Deflection.
ϕ (phi)—Angular deflection.
ρ (rho)—Radius of gyration.
μ (mu)—Poisson's ratio.
$'$ (prime)—In general denotes an "effective" or "precise" value.

1.3 Commonly used formulas

1.31 GENERAL. The formulas of the following sections are listed for reference purposes. The sign conventions generally accepted in their use are that quantities associated with tensile action (load, stress, strain, etc.) are considered as positive, and quantities associated with compressive action are considered as negative. When compressive action is of primary interest, however, it is sometimes convenient to consider the associated quantities to be positive.

1.32 SIMPLE UNIT STRESSES

1.321 $f_t=P/A$ (tension).

1.322 $f_c=P/A$ (compression).

1.323 $f_b=My/I=M/Z$.

1.324 $f_s=S/A$ (average direct shear stress).

1.325 $f_s=SQ/Ib$ (longitudinal or transverse shear stress).

1.326 $f_s=Ty/I_p$ (shear stress in round tubes due to torsion).

1.327 $f_s=T/2At$ (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).

1.33 COMBINED STRESSES (see sec. 1.535)

1.331 $f_n=f_c+f_b$ (compression and bending).

1.332 $f_{s_{max}}=\sqrt{f_s^2+(f_n/2)^2}$ (compression bending, and torsion).

1.333 $f_{n_{max}}=(f_n/2)+f_{s_{max}}$.

1.34 DEFLECTIONS (Axial)

1.341 $e=\delta/L$ (unit deformation or strain).

1.342 $E=f/e$ (this equation applies when E is to be found from tests in which f and e are measured).

1.343 $\delta=eL=(f/E)L$
$=PL/AE$ (this equation applies when the deflection is to be calculated using a known value of E).

1.35 DEFLECTIONS (Bending)

1.351 $di/dx=M/EI$ (change of slope per unit length of beam, radians per unit length).

1.352

$$i_2=i_1+\int_{x_1}^{x_2}(M/EI)dx=\text{slope at point 2.}$$

(The integral denotes the area under the curve of M/EI plotted against x, between the limits x_1 and x_2.)

1.353

$$y_2=y_1+i_1(x_2-x_1)+\int_{x_1}^{x_2}(M/EI)(x_2-x)dx$$

=deflection at point 2. (The integral denotes the area under a curve having ordinates equal to M/EI multiplied by the corresponding distances to point 2, plotted against x, between the limits x_1 and x_2.)

1.353a

$$y_2=y_1+\int_{x_1}^{x_2}i\,dx=\text{deflection at point 2.}$$

(The integral denotes the area under the curve of (i) plotted against x, between the limits x_1 and x_2.)

1.36 DEFLECTIONS (Torsion)

1.361 $d\phi/dx=T/GJ$ (change of angular deflection or twist per unit length of member, radians per unit length).

1.362 $\phi=\int_{x_1}^{x_2}(T/GJ)dx=$ total twist over a length from x_1 to x_2. (The integral denotes the area under the curve of T/GJ plotted against x, between the limits x_1 and x_2.)

1.362a $\phi = TL/GJ$ (used when torque T is constant over length L).

1.37 Transverse Deformations

1.371 $\mu = e_L/e = \frac{\text{unit lateral deformation}}{\text{unit axial deformation}}$ (Poisson's ratio).

1.372 $Ee_x = f_x - \mu f_y$.

1.373 $Ee_y = f_y - \mu f_x$.

1.38 Basic Column Formulas

1.381 $F_{c_o} = c\pi^2 E/(L/\rho)^2$ (Euler formula for long columns).
$= \pi^2 E/(L'/\rho)^2$ where $L' = L/\sqrt{c}$.

1.381a $F_c = c\pi^2 E'/(L/\rho)^2$ (modified Euler formula for short columns).

1.382 $F_c = F_{co}\{1 - K[(L'/\rho)/\pi\sqrt{E/F_{co}}]^n\}$ (general parabolic formula).

1.383 $F_c = F_{co}\ [1 - F_{co}(L'/\rho)^2/4\pi^2 E]$ (2.0 parabola—Johnson formula).

1.384 $F_c = F_{co}\{1 - 0.3027[(L'/\rho)/\pi\sqrt{E/F_{co}}]^{1.5}\}$ (1.5 parabola).

1.385 $F_c = F_{co}[1 - 0.385(L'/\rho)/\pi\sqrt{E/F_{co}}]$ (1.0 parabola—straight line formula).

1.39 Basic Column Formulas (Nondimensional)

1.391 $R_a = F_c/F_{co}$ (allowable stress ratio).

1.392 $B = (L'/\rho)/\pi\sqrt{E/F_{co}}$ (slenderness ratio factor).

1.393 $R_a = (1/B)^2$ (Euler formula).

1.394 $R_a = 1 - KB^n$ (general parabolic formula).

1.395 $R_a = 1 - 0.25B^2$ (2.0 parabola—Johnson formula).

1.396 $R_a = 1 - 0.3027B^{1.5}$ (1.5 parabola).

1.397 $R_a = 1 - 0.385B$ (1.0 parabola—straight line formula).

1.4 Basic principles and definitions

1.41 General. It is assumed that engineers using this document are thoroughly familiar with the basic principles of strength of materials, such as can be found in any standard text book on this subject. A brief summary of such material is presented here for the sake of uniformity and to emphasize certain principles of special importance. The design mechanical properties of various metals and elements are given in the tables in each chapter. In these tables, plate refers to material greater than 0.249 inch thick.

1.42 Stress

1.421 *General.* The term stress as used herein always 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 1.321 and 1.322.) The stress distribution may or may not be uniform, depending on the nature of the loading condition. For example, tensile stresses as found from equation 1.321 are considered to be uniform, while the bending stress determined from equation 1.323 refers to the stress at a point located at a distance y from the neutral axis. Obviously the stress over the cross section of a member subjected to bending is not uniform. (Equation 1.324 gives the average shear stress.)

1.422 *Normal and shear stresses.* The stresses acting at a point in any stressed member can be resolved into components acting on planes through the point.

The normal and shear stresses acting on any particular plane are the stress components perpendicular and parallel, respectively, to the plane. A simple conception of these stresses is that normal stresses tend to pull apart (or press together) adjacent particles of the material, while shear stresses tend to cause such particles to slide on each other.

1.43 Strain

1.431 *Axial strain.* This term refers to the elongation, per unit length, in a member or portion of a member in the axial direction. (See equation 1.341.) There are usually strains present in other directions also, since aircraft elements are usually subjected to more complicated stress conditions than the uniaxial stress present in a simple tension test. To determine the stress state of a member, therefore, strains in three directions must be considered and the principle stresses can then be calculated.

1.432 *Poisson's ratio.* Uniaxial strain in a metal is always accompanied by lateral strains of opposite sign in the two directions mutually perpendicular to the uniaxial strain. Under uniaxial conditions the absolute value of the ratio of either of the lateral strains to the uniaxial strains is called Poisson's ratio. This ratio is usually between 0.25 and 0.33 for steel and aluminum alloys. In multiaxially stressed members the lateral strain will affect strain readings and must be considered in strain measurements under these conditions. The formulae for principle stresses and principle strains in terms of the other principle stresses are given in standard texts on the theory of elasticity. For materials stressed beyond the elastic limit, Poisson's ratio is not a constant but is a function of the axial strain. Information on the variation of Poisson's ratio with strain and with testing direction is available in references 1.432.

1.433 *Shearing strain*. If a square element of uniform thickness is subjected to pure shear there will be a displacement of each side of the element relative to the opposite side. The shearing strain is obtained by dividing this displacement by the distance between the sides of the element. It should be noted that shearing strain is obtained by dividing a displacement by a distance at right angles to the displacement whereas axial strain is obtained by dividing the deformation by a length measured in the same direction as the deformation.

1.44 TENSILE PROPERTIES

1.441 *General*. When a specimen of a certain material is tested in tension using the standard testing procedures of reference 1.441, it is customary to plot the results of such a test as a "stress-strain diagram." This diagram forms the basis for most strength specifications and should be thoroughly understood and frequently applied by all engineers. Typical tensile diagrams, not to scale, are shown in figure 1.441. Typical stress-strain diagrams drawn to scale appear in appropriate chapters for the general information of the users of this document. It should be noted that the strain scale is nondimensional, while the stress scale is in pounds per square inch. The important physical properties which can be shown on the stress-strain diagram are discussed in the following sections.

1.442 *Modulus of elasticity* (E). Referring to figure 1.441, it will be noted that the first part of the diagram is substantially a straight line. This indicates a constant ratio between stress and strain over that range. The numerical value of the ratio is called the Modulus of Elasticity, denoted by E. It will be noted that E is the slope of the straight portion of the stress-strain diagram and is determined by dividing the stress (in pounds per square inch) by the strain (which is nondimensional). (See equation 1.342.) Therefore, E has the same dimensions as a stress; in this case pounds per square inch. A useful conception of E is "the stress at which the member would have elongated a distance equal to its original length (assuming no departure from the straight portion of the stress-strain diagram)." This can be easily understood from equation 1.342 by considering that $\delta = L$ in equation 1.341, making the strain e equal to 1.0.

Other moduli that are often of interest are the tangent modulus E_t, and the secant modulus E_s. The tangent modulus is the slope of the stress-strain diagram at a point corresponding to a given stress while the secant modulus is the slope of a line drawn through the same point and the origin.

Clad aluminum alloys may have two separate modulus values, as indicated in the typical curve presented in figure 1.441. The initial, or primary, modulus is substantially the same as for the core material; it holds only up to the proportional limit of the covering. Immediately above this point there is a short transition range and the material then exhibits a secondary modulus up to the proportional limit of the core material. This secondary modulus is the slope of the second straight-line portion of the diagram. In some cases the covering is so little different from the core that a single modulus value is used. Both values of the modulus are based on the gross area of the piece, core plus covering.

1.443 *Tensile proportional limit* (F_{tp}). Since it is practically impossible to determine the stress at which the stress-strain diagram begins to depart from a straight line, it is customary to assign a small value of permanent strain for this purpose. In this document the limit of proportionality will be taken as the stress at which the stress-strain diagram departs from a straight line by a strain of 0.0001. This property or characteristic of a material gives an indication of the type of stress-strain diagram which applies in the working range. It also indicates the stress beyond which the standard value of E cannot be accurately applied. This is of special interest in the analysis of redundant structures.

1.444 *Tensile yield stress* (F_{ty}). The stress-strain diagrams for some steels show a sharp break at a stress below the ultimate tensile stress. At this critical stress the material elongates considerably with little or no increase in stress. (See fig. 1.441.) The stress at which this takes place is referred to as the yield point. Nonferrous metals, and some steels do not show this sharp break but yield more gradually so that there is no definite yield point. This condition is illustrated in figure 1.441. Since permanent deformations of any appreciable amount are undesirable in most structures, it is customary to adopt an arbitrary amount of permanent strain that is considered admissible for general purposes. The value of this strain has been established by material testing engineers as 0.002, and the corresponding stress is called the *yield stress*. For practical purposes this may be determined from the stress-strain diagram by drawing a line parallel to the straight or elastic portion of the curve through a point representing zero stress and 0.002 strain. (See fig. 1.441.) The yield stress is taken as the stress at the intersection of this straight line with the stress-strain curve.

1.445 *Ultimate tensile stress* (F_{tu}). Figure 1.441 shows how the ultimate tensile stress is determined from the stress-strain diagram. It is simply the stress at the maximum load reached in the test. It should be noted that all stresses are based on the original cross-sectional area of the test specimen, without regard to the lateral contraction of the specimen which actually occurs during the test. The ultimate tensile stress is commonly used as a criterion of the strength of the material, but it should be borne in mind that most modern aircraft structures have relatively few members which are critical in tension; consequently, other strength properties may often be more important.

1.45 Compressive Properties

1.451 *General.* The results of compression tests can be plotted as stress-strain diagrams similar to those shown in figure 1.441 for tension. The preceding remarks (with the exception of those pertaining to ultimate stress) concerning the specific tensile properties of the material apply in a similar manner to the compressive properties. It should be noted that the moduli of elasticity in tension and compression are approximately equal for most of the commonly used structural materials. Special considerations concerning the ultimate compressive stress are taken up in the following section. An example of a method of obtaining compressive strength properties of thin sheet material is outlined in reference 1.451.

1.452 *Ultimate compressive stress* (F_{cu}). It is difficult to discuss this property without reference to column action. Almost any piece of material, unless very short, tends to buckle laterally as a column under compressive loadings, and the load at failure usually depends on the relation of the length of the piece to its cross-sectional dimensions. Column failure cannot occur, however, when a piece is very short in comparison with its cross-sectional dimensions, or when it is restrained laterally by external means. Under these conditions some materials such as stone, wood, and a few metals will fail by fracture, thus giving a definite value for the ultimate compressive stress. Most metals, however, are so ductile that no fracture is encountered in compression. Instead of fracturing, the material yields and swells out, so that the increasing area continues to support the increasing load. It is almost impossible to select a value for the ultimate compressive stress of such materials without having some arbitrary criterion. For wrought metals it is common practice to assume that the ultimate compressive stress is equal to the ultimate tensile stress. For some cast metals which are relatively weak in tension, an ultimate compressive stress higher than the ultimate tensile stress may be obtained from tests on short compact specimens. When tests are made on such specimens having an L/p approximately equal to 12, the ultimate stress so obtained is called the block compressive stress.

1.46 Shear Properties

1.461 *General.* The results of torsion tests on round tubes or round solid sections are sometimes plotted as torsion stress-strain diagrams. The modulus of elasticity in shear as determined from such a diagram is a basic shear property. Other properties, such as the proportional limit and ultimate shearing stress, cannot be treated as basic properties because of the "form factor" effects.

1.462 *Modulus of rigidity* (G). This property is the ratio of the shearing stress to the shearing strain at low loads, or simply the initial slope of the stress-strain diagram for shear. It is also called the modulus of elasticity in shear. The relation between this property, Poisson's ratio, and the modulus of elasticity in tension,

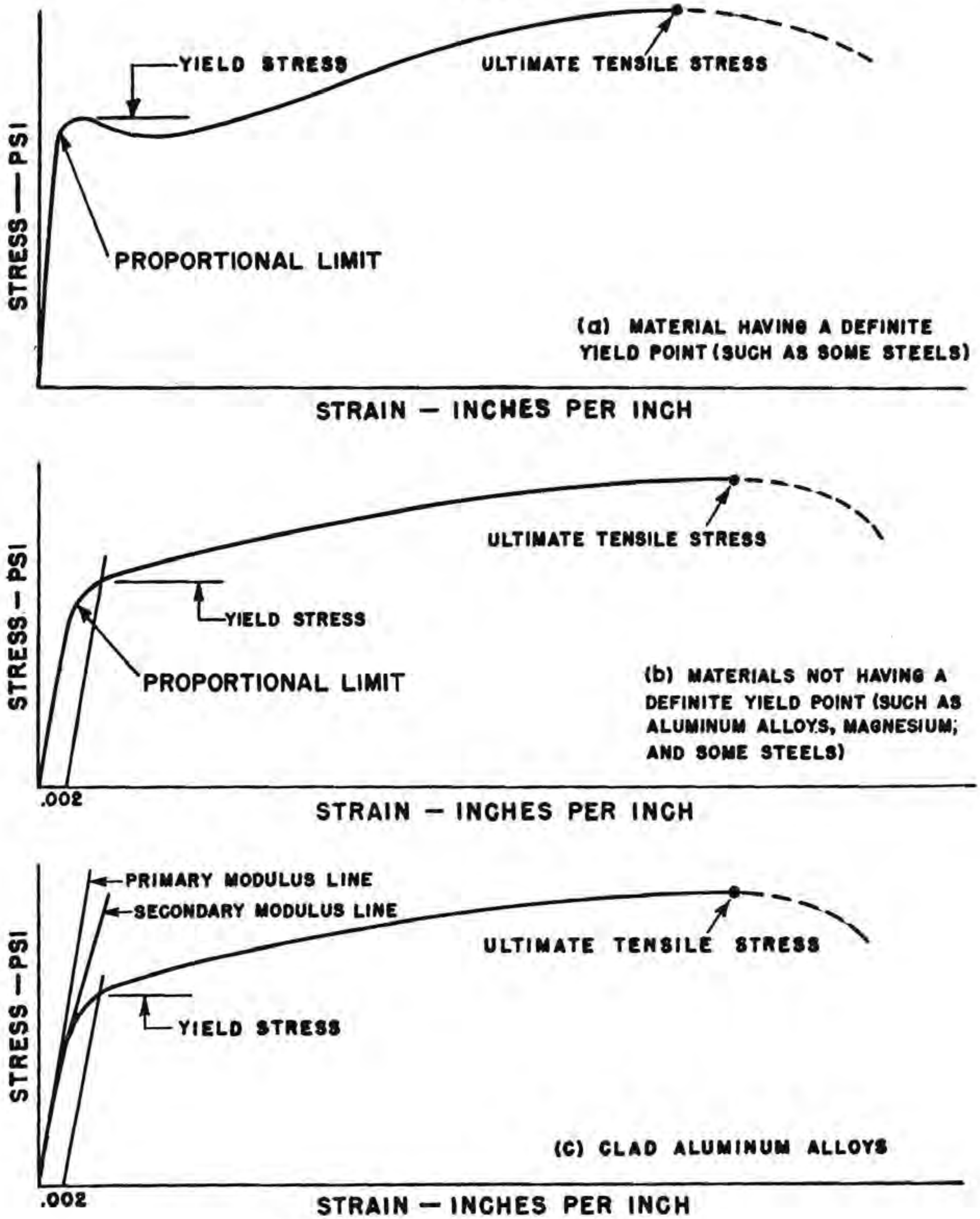


Figure 1.441. Typical tensile stress-strain diagrams.

is expressed for homogeneous materials by the following equation:

$$G=\frac{E}{2\ (1+\mu)} \text{--------} (1.4621)$$

This corresponds to the value E and will apply in calculating the shear deflection of webs, provided that no wrinkling occurs.

1.463 *Proportional limit in shear* (F_{sp}). This property is of particular interest in connection with formulas which are based on considerations of perfect elasticity, as it represents the limiting value of shearing stress to which these formulas can be accurately applied. As previously noted, this property cannot be determined directly from torsion tests. The results of research at the National Bureau of Standards show that the ratio of the proportional limit in shear to the proportional limit in tension can be assumed to be approximately 0.55 for the commonly used materials.

1.464 *Yield and ultimate stresses in shear.* These properties, as usually obtained from torsion 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 be used only with specimens which are geometrically similar to those from which the test results were obtained.

1.47 CREEP AND STRESS-RUPTURE PROPERTIES

1.471 *General.* The results of tests of materials under a constant load at elevated temperatures are usually initially plotted as strain versus time (creep) up to the time of rupture. However, many combinations of the data obtained in these tests are possible and have resulted in many different types of plots. Data included in this publication are as described in the sections below. A typical plot of creep-rupture data is shown in figure 1.471. The strain indicated in this curve includes the initial instantaneous deformation due to loading. From this curve are obtained the stress-rupture curve, the minimum creep curve, the total deformation curve, and the other parameters shown in figures 3.122 (*e*) through 3.122 (*n*).

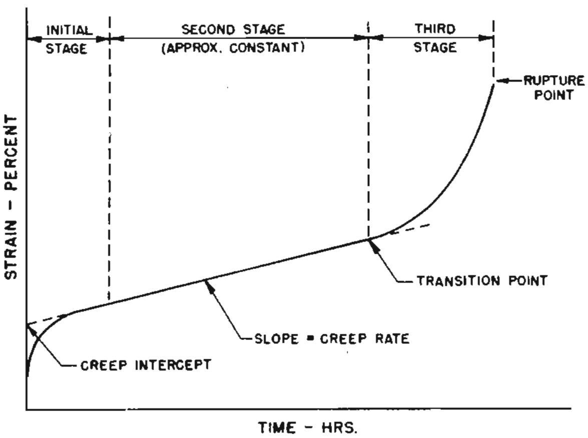


Figure 1.471. Typical creep-rupture curve.

1.472 *Total creep.* This value is defined as the total strain at any given time including initial strain. It is given in percent and may be used to estimate the deformation or deflection of structural parts for given loads and temperatures.

1.473 *Minimum creep rate.* After an initial large strain due to loading, the rate of strain in a creep specimen usually gradually decreases to a constant value (except for high stress), for a time dependent on the test conditions. This strain rate is the minimum encountered in the test and is defined as the creep rate.

1.474 *Transition point.* Subsequent to the constant creep rate described in the previous section an increase in creep rate occurs, in general, which continues up to the rupture point of the material. The inflection point between the constant creep and increasing creep rate is defined as the transition point. Failure generally occurs in a relatively short time after the transition point. Transition points may not occur at very low stresses or may not be definable at very high stresses.

1.475 *Rupture stress.* The stress at which rupture will occur under constant load conditions is defined as the rupture stress. This stress varies inversely with time for constant temperature conditions. Rupture stress data are generally used in design if the amount of deformation allowable is not the critical factor.

1.48 FATIGUE PROPERTIES

1.481 *General.* The results of fatigue tests are usually plotted as stress versus the number of cycles needed to cause failure. This stress is usually the maximum stress in a single cycle. Many variations of the common completely reversed stressing are used; however, in such cases the stress description is not complete if the maximum stress only is recorded. Figure 1.481 indicates the type of stressing which might occur and indicates some of the parameters which affect the fatigue life of a material under fluctuating stresses.

1.482 *Stress.* The stress cycle through which a material is subjected may be of several types even in the commonly accepted sinusoidal variations shown in figure 1.481. To completely describe the stress history the following definitions of stress conditions are used, all of which may affect the fatigue life, either independently or in conjunction with one or more of the other conditions:

1.4821 *Maximum stress* is the highest algebraic stress reached in a single cycle.

1.4822 *Minimum stress.* The lowest algebraic stress reached in a single cycle.

1.4823 *Mean stress.* The stress midway between the maximum and minimum stress. In the completely reversed test, this stress is zero.

1.4824 *Stress range.* Stress range is the stress variation between maximum and minimum.

1.4825 *Stress amplitude.* Stress amplitude is the stress variation between mean and maximum or between mean and minimum and is one-half the stress range.

1.49 TIME EFFECTS. The preceding definitions, with the exception of creep and stress-rupture, have made no mention of time. For normal temperatures, i. e., between −65° F. and +160° F., and for most materials included in this document, the effect of time can safely be neglected. However, as the temperature increases, time becomes an increasingly important factor in defining the behavior of a structural material. Stress and strain no longer uniquely describe its state. It will therefore be noted that rate of straining, short-time creep-rupture, etc., are included as factors affecting properties in several places in the text describing specific properties.

1.5 Types of failures

1.51 GENERAL. In the following discussion the term "failure" will usually denote actual rupture of the member, or the condition of the member when it has just attained its maximum load.

1.52 MATERIAL FAILURES

1.521 *General.* Fracture of a material may occur by either a *separation* of adjacent particles across a section perpendicular to the direction of loading, or by a *sliding* of adjacent particles along other sections. In some cases the mechanism of failure includes both of these actions. For instance, in a simple tension test sliding action along inclined sections may occur first

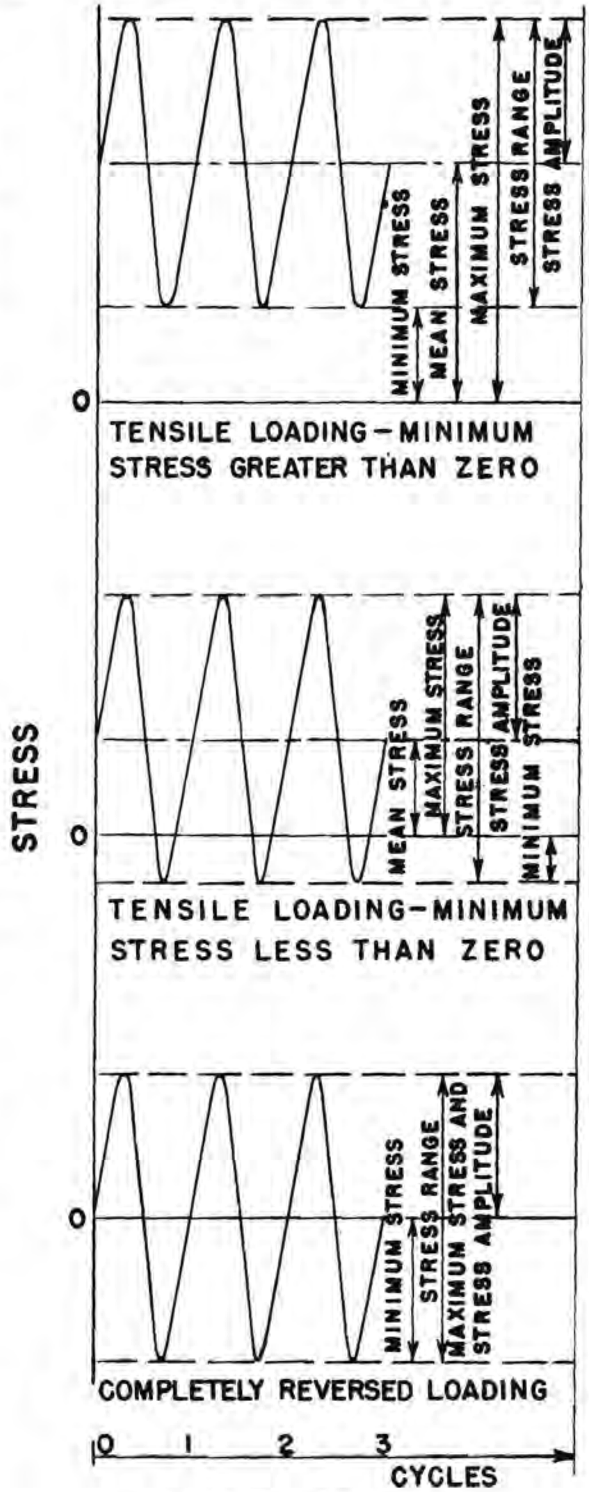


Figure 1.481. Typical fatigue loadings.

with a consequent reduction in the cross-sectional area of the specimen. This may result in strain hardening of the material so that the resistance to sliding is increased, and the final failure may occur by separation of the material across a section perpendicular to the direction of the loading.

1.522 *Direct tension or compression.* This type of failure is associated with the ultimate tensile or compressive stress of the material. For compression it can apply only to members having large cross-sectional dimensions as compared to the length in the direction of the load. (See also sec. 1.452.)

1.523 *Shear.* Pure shear failures are usually obtained only when the shear load is transmitted over a very short length of the member. This condition is approached in the case of rivets and bolts. In cases where the ultimate shear stress is relatively low a pure shear failure may result, but in general a member subjected to a shear load fails under the action of the resulting normal stresses (equation 1.333), usually the compressive stresses. The failure of a tube in torsion, for instance, is not usually caused by exceeding the allowable shear stress, but by exceeding a certain allowable normal compressive stress which causes the tube to buckle. It is customary, for convenience, to determine the allowable stresses for members subjected to shear in the form of shear stresses. Such allowable shear stresses are therefore an indirect measure of the stresses actually causing failure.

1.524 *Bearing.* The failure of a material in bearing may consist of crushing, splitting, or progressive rapid yielding in the region where the load is applied. Failure of this type will depend, to a large extent, on the relative size and shape of the two connecting parts. The allowable bearing stress will not always be applicable to cases in which one of the contacting members is relatively thin. It is also necessary, for practical reasons, to limit the working bearing stress to low values in such cases as joints subjected to reversals of load or in bearings between movable surfaces. These special cases are covered by specific rulings of the procuring or certificating agencies, involving the use of higher factors of safety in most cases.

1.525 *Bending.* For compact sections not subject to instability, a bending failure can be classed as a tensile or compressive failure caused by exceeding a certain allowable stress in some portion of the specimen. It is customary to determine, experimentally, the "modulus of rupture in bending," which is a stress derived from test results through the use of equation 1.323 in which case M is the value of bending moment which caused failure. If not determined experimentally, the value of the modulus of rupture in bending may be assumed equal to the ultimate tensile stress when instability is not critical. Since equation 1.323 is based on assumptions which are not always fulfilled at failure, the modulus at failure cannot be considered as the actual stress at the point of rupture. This should be borne in mind in dealing with combined stresses, such as bending and compression, or bending and torsion.

1.526 *Failure due to stress concentrations.* The static strength properties listed for various materials were determined on machined specimens containing no notches, holes, or other avoidable stress raisers. In the design of aircraft structures such simplicity is unattainable, and stress distributions are not of the uniform quality obtained in the specimen tests. Consideration must be given to this condition since maximum stresses in a material, and not average stresses, are the critical factor in design. The effects of stress raisers vary, and references to available specific data are given in the sections pertaining to each material.

1.527 *Failure due to fatigue.* Although the component parts of airplane structures are usually designed for static load conditions, they are subjected in service to repeated loads. It is well known that the strength of a material under repeated loads is less than that which would be obtained under static loading. This phenomenon of the decreased strength of a material under repeated loading is commonly called fatigue. Stress raisers, such as abrupt changes in cross section, holes, notches and reentrant corners, cause a much greater effect on the fatigue strength than they do on static strength. The local high stress concentrations caused by such stress raisers are often greatly in excess of the nominal calculated stress on the part and consequently it is at such locations that fatigue fractures usually begin. Other factors of major importance in fatigue are the range of a repeated stress cycle, from maximum to minimum stress, and the mean stress in the stress cycle. In the following chapters of this document, fatigue data are presented for various materials. These data were obtained in various types of repeated-load tests and are included for general information. They are not to be used as allowable stress values unless their applicability to the case at hand has been established.

1.528 *Failure from combined stresses.* In 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 has received wide acceptance as a simple working basis in the case of ductile materials. It should be noted that this theory interprets failure as the first yielding of the material, so that any extension of the theory to cover conditions of final rupture must be based on the experience of the designer. The failure of brittle materials under combined stresses can generally be treated by the "maximum stress" theory.

1.53 INSTABILITY FAILURES

1.531 *General.* Practically all structural members such as beams and columns, particularly those made from thin material, are subject to failure through instability. In general, instability can be classed as: (1) Primary, or (2) local. For example, the failure of a tube under compression may occur either through lateral deflection of the tube as a column (primary instability), or by collapse of the tube wall at a stress lower than that required to produce a general column failure. Similarly, an I-beam may fail by a general sidewise deflection of the compression flange, or by local wrinkling of thin outstanding flanges. It is obviously necessary to consider both types of failures unless it is apparent that the critical load for one type is definitely less than that for the other type.

Instability failures may occur in either the elastic range (below the proportional limit) or in the plastic range (above the proportional limit). To distinguish between these two types of action it is not uncommon to refer to them as elastic instability failures and plastic instability failures, respectively. It is important to note that instability failures are not usually associated with the ultimate stresses of the material. This should be borne in mind when correcting test results for material variations. It also has a bearing on the choice of a material for a given type of construction as the "strength-weight ratio" will be determined from different physical characteristics when this type of failure can be expected. For materials which have a very small spread between the proportional limit and the yield stress, the plastic instability type of failure occurs in such a narrow range that it is not of much importance, but in materials which have a considerable spread between these two properties, the plastic instability type of failure may be equally as important as the elastic type.

In studying any structural member it is important to avoid confusion between the different types of failure, particularly where instability is expected to be important. In general, most members should be investigated first from the standpoint of failures of material. They should then be checked separately for their resistance to primary instability failure. Members which are suspected of being weak in resisting local instability should also be checked for this third possible type of failure. Whichever type of failure gives the lowest strength should be used as the criterion in design.

1.532 *Instability failures under compressive loadings.* Failures of this type are discussed in section 1.6 (Columns).

1.533 *Bending instability failures.* Failures of round tubes of usual size when subjected to bending are usually of the plastic instability type. In such cases the criterion of strength is the modulus of rupture as derived from test results through the use of equation 1.323. Elastic instability failures of thin-walled tubes having high D/t ratios are treated in later sections.

1.534 *Torsional instability failures.* The remarks of 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 1.326.

1.535 *Failure under combined loadings.* For combined loading conditions in which failure is caused by buckling or instability, no general theory exists which will apply in all cases. It is convenient, however, to represent such conditions by the use of "stress ratios," which can be considered as nondimensional coefficients denoting the fraction of the allowable stress or strength which is utilized or which can be developed under special conditions. For simple stresses the stress ratio can be expressed as:

$$R=f/F \qquad (1.5351)$$

where

f=applied stress.
F=allowable stress.

Note that the "margin of safety" as usually expressed is given by the equation:

$$\text{M. S.}=1/R-1.0 \qquad (1.5352)$$

Considering the case of combined loadings, the general conditions for failure can be expressed by equations of the following type:

$$R_1^x+R_2^y+R_3^z+ \ . \ . \ . \ =1.0 \qquad (1.5353)$$

In this equation R_1, R_2, and R_3 may denote, for instance, the stress ratios for compression, bending, and shear, and the exponents x, y, and z define the general relationship of the quantities. This equation may be interpreted as indicating that failure will occur only when the sum of the stress ratios is equal to or greater than one. An advantage of this method is that the formula yields correct results when only one loading condition is present. Consequently it tends to give good results when any one loading condition predominates. It also permits test data to be plotted in nondimensional form, which is a decided advantage.

In many cases it is convenient to deal directly with "load ratios" rather than stress ratios. The load ratio is simply the ratio of the applied load to the allowable load and is equal to the corresponding stress ratio.

Considering only two loading conditions, such as bending and torsion, equation 1.5353 can be plotted as a single interaction curve of R_b against R_s. Likewise, in the case of combined bending and compression, R_c can be plotted against R_b. When all three conditions exist, the equation represents an interaction surface, which can be plotted as a family of curves. Typical curves corresponding to various exponents are shown in figure 1.535. The general significance of equation 1.5353 and figure 1.535 is that the addition of a second loading condition will lower the percentage of the allowable stress which may be utilized in the original loading condition. If the exponents approach infinity, the curve of figure 1.535 will approach the lines $R_1=1.0$ and $R_2=1.0$, indicating that the two loading conditions have no effect on each other.

When only two stress-ratios are involved and when the two different applied stresses remain in constant proportion, the margin of safety of the member may be determined from figure 1.535 by the following method:

(1) Locate the point on the chart representing the applied values of R_1 and R_2 computed from the applied stresses (illustrated as point (1) on fig. 1.535).

(2) Draw a straight line through this point and the origin (shown as a diagonal dotted line on fig. 1.535).

(3) Extend this line to intersect the proper stress-ratio curve (corresponding to the condition under consideration) at point (2).

(4) Read the allowable values R_{1a} and R_{2a} as the ordinate and abscissa, respectively, of point (2).

(5) The *factor of utilization* or *strength ratio* is obtained as the ratio of the applied to the allowable value of either stress ratio as follows:

$$U=R_1/R_{1a}=R_2/R_{2a} \qquad (1.5354)$$

(6) The true margin of safety then can be computed from the following equation

$$\text{M. S.}=\frac{1}{U}-1 \qquad (1.5355)$$

Note that when the following stress ratio expressions are used, the margins of safety can be computed as indicated

For $R_1+R_2=1$,

$$\text{M. S.}=\frac{1}{(R_1+R_2)}-1$$

For $R_1^2+R_2^2=1$

$$\text{M. S.}=\frac{1}{\sqrt{R_1^2+R_2^2}}-1$$

Other M. S. formulas can, of course, be determined for the more complicated stress ratio expressions.

The general formula for the margin of safety stated analytically for interaction equations where any or all of x, y, and z are 1 or 2 but no other figure (except one term may be missing) is as follows:

$$\text{M. S.}=\frac{2}{[R'+\sqrt{(R')^2+4(R'')^2}]}-1$$

Here the R' designates the sum of all first power ratios; $(R')^2$ is the square of the same sum; and $(R'')^2$ the sum of the squares of all second-power ratios. The table gives all combinations:

Interaction formula	Margin of safety
$R_1+R_2^2=1.0$	$\dfrac{2}{R_1+\sqrt{R_1^2+4R_2^2}}-1$
$R_1+R_2+R_3=1.0$	$\dfrac{1}{R_1+R_2+R_3}-1$
$R_1+R_2+R_3^2=1.0$	$\dfrac{2}{R_1+R_2+\sqrt{(R_1+R_2)^2+4R_3^2}}-1$
$R_1+R_2^2+R_3^2=1.0$	$\dfrac{2}{R_1+\sqrt{R_1^2+4(R_2^2+R_3^2)}}-1$
$R_1^2+R_2^2+R_3^2=1.0$	$\dfrac{1}{\sqrt{R_1^2+R_2^2+R_3^2}}-1$

The practical application of equation 1.5353 will be taken up in the following chapters.

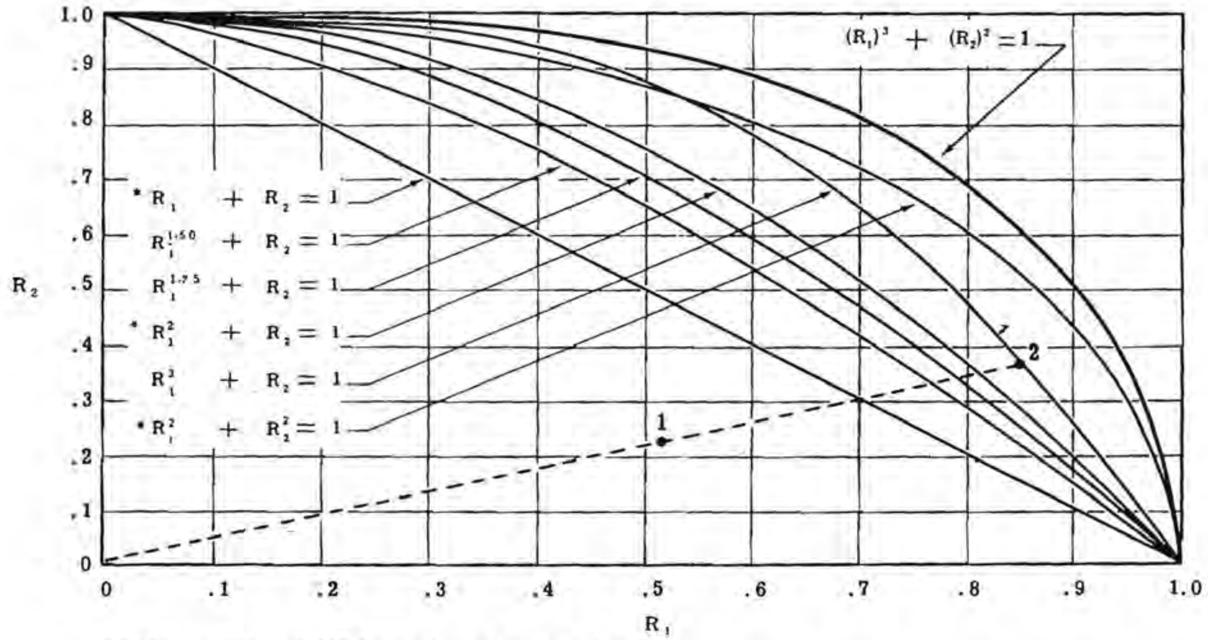
1.6 Columns

1.61 GENERAL. A theoretical treatment of columns can be found in standard textbooks on the strength of materials. The problems confronting the designer include, however, many points which are not well defined by theory and which frequently cause some confusion. These will be taken up in this section. Actual strengths of columns of various types are given in subsequent chapters.

1.62 PRIMARY INSTABILITY FAILURE

1.621 *General.* A column may 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 available information on twisting instability is somewhat limited it may be advisable to conduct tests on all columns subject to this type of failure.

1.622 *Long columns* (Stable sections). The Euler formula for long columns which fail by lateral bending is given by equation 1.381. No explanation of this classical formula need be offered, as its derivation can be found in many standard textbooks on the strength of materials. The value to be used for the restraint coefficient, c, depends on the degree of end fixation. The true significance of the restraint coefficient is best understood by considering the end restraint as modifying the effective column length, as indicated in equation 1.381. For a pin-ended column having zero end restraint $c=1.0$ and $L'=L$. A fixity coefficient of 2 corresponds to



* Refer to section 1.535 for analytical margin of safety.

Figure 1.535. Typical interaction curves for combined loading conditions.

a reduction of the effective length to $1/\sqrt{2}$ or 0.707 times the total length.

1.623 *Short columns (Stable sections)*. If the length of a column is reduced below a certain critical value, failure in lateral bending will occur at loads below those predicted by the Euler formula. This is in a great part due to a reduction in the effective value of E caused primarily by changes in the slope of the stress-strain diagram and secondarily by unavoidable eccentricities. In this region the test results show more scatter than in the Euler range and empirical or semi-empirical formulas for predicting the allowable column stress are often adopted. When a definite eccentricity exists, the critical column loads are reduced due to the combined effects of axial load and bending. Special formulas for such cases can be found in standard textbooks and handbooks.

Although many types of formulas have been devised to cover the short-column range, it has been customary, in aircraft work, to use the Johnson formula for round steel tubes and the straight line formula for round aluminum alloy tubes; these formulas are used in this document.

It will be noted that the above column formulas are of the general form given by equation 1.382. For example, the straight line formula is a special case of equation 1.382 in which the exponent n is equal to 1.0. In a similar manner the Johnson formula can be obtained from equation 1.382 by setting n equal to 2.0. The above equations strictly apply only to round tube sections as they were derived from tests on such sections. In many cases, however, they will be found to be satisfactory for sections of other shapes when local instability is not critical.

Short column failure can also be expressed by the modified Euler formula in which the elastic modulus is replaced by an effective modulus, E', as in the following equation:

$$F_c=\pi^2E'/(L'/\rho)^2 \quad \text{(1.6231)}$$

This equation has come to have much practical importance in recent years in determining the short column curve; it is of particular interest to note that an effective modulus equal to the tangent modulus can usually be used to compute failing stresses. The value of the effective modulus at any given compressive stress, F_c, can be determined from stress-strain curves for the material.

1.624 *Column yield stress* (F_{co}). The upper limit of the allowable column stress for primary failure is called the *column yield stress* and will be designated F_{co}. It can be determined by extending the "short-column" curve to a point corresponding to zero length, ignoring any tendency of the curve to rise rapidly or "pick-up" for very short lengths. The short-column curve used in determining F_{co} should be obtained from tests on specimens having geometrical proportions such that local failure is precluded except for very low values of L'/ρ.

When the column yield stress is reached, the walls of the column will tend to buckle unless restrained by extreme shortness, or by the application of lateral restraining forces. In some cases, however, if the specimen has not been allowed to buckle, the stress may be increased considerably above this value. Due to the danger of buckling when the column yield stress is approached, the latter should be considered as the limiting stress for all columns.

The column yield stress is mainly determined by the nature of the compressive stress-strain diagram of the material. When the material has a definite yield point in compression, this value may be assumed for the column yield stress. Few aircraft materials, however, have a sharply defined yield point. In such cases it is usually possible to determine the column yield stress as a function of either the tensile or compressive yield stress. For example F_{co} for round steel tubes is approximately equal to 1.06 times the tensile yield stress; whereas, by reference 1.624, F_{co} for some aluminum alloys, see table 3.21, is approximately equal to $F_{cy}\ (1+F_{cy}/200{,}000)$.

Column yield stresses for the various materials are given in the appropriate sections.

1.63 Nondimensional Column Curves for Primary Failure

1.631 *General*. On account of the many factors involved it is often difficult to predict the effects of possible material variations on the strength of columns as obtained by tests. When the column failure is definitely of the primary bending type it is advisable to plot the test results with nondimensional coefficients, such as are employed in reference 2.53. The following coefficients will be adopted for this purpose:

R_a=allowable stress ratio=F_c/F_{co}- - - - -(1.6311)

where

F_c =allowable column stress

F_{co}=column yield stress

B=slenderness ratio factor=$\dfrac{L'/\rho}{\pi\sqrt{E/F_{co}}}$- -(1.6312)

where

$L'=L/\sqrt{c}$ (see equation 1.381)

The slenderness ratio factor can be considered as the ratio between the effective slenderness ratio (L'/ρ) and the (L'/ρ) at which the Euler stress for a pin-ended column would equal F_{co}. Thus, when B=2, the Euler stress F_{co} would equal ¼F_{co}, or R_a would be 0.25 (since the Euler stress varies inversely as the square of L'/ρ).

1.632 *Typical column curves.* Typical column curves plotted in terms of these non-dimensional coefficients are illustrated in figure 1.632. It will be noted that the Johnson parabolic curve is tangent to the Euler curve at a value of R_a=0.5; that is, the Euler formula will not apply when it gives stresses higher than half the column yield stress. It is also convenient to know that the stresses given by the 1.5 parabolic formula and the straight line formula are equal to those given by the Euler formula at values of R_a equal to 0.4286 and 0.333, respectively.

1.64 LOCAL INSTABILITY FAILURE

1.641 *General.* Columns may fail by a local collapse of the wall at a stress below the primary failure stress. The general equation for the local failure of round tubes is given in the following section. The local failure of columns having cross sections other than those of round tubes is discussed in section 1.65.

1.642 *Crushing or crippling stress* (F_{cc}). The upper limit of the allowable column stress for local failure is called the crushing or crippling stress and is designated F_{cc}. The crushing

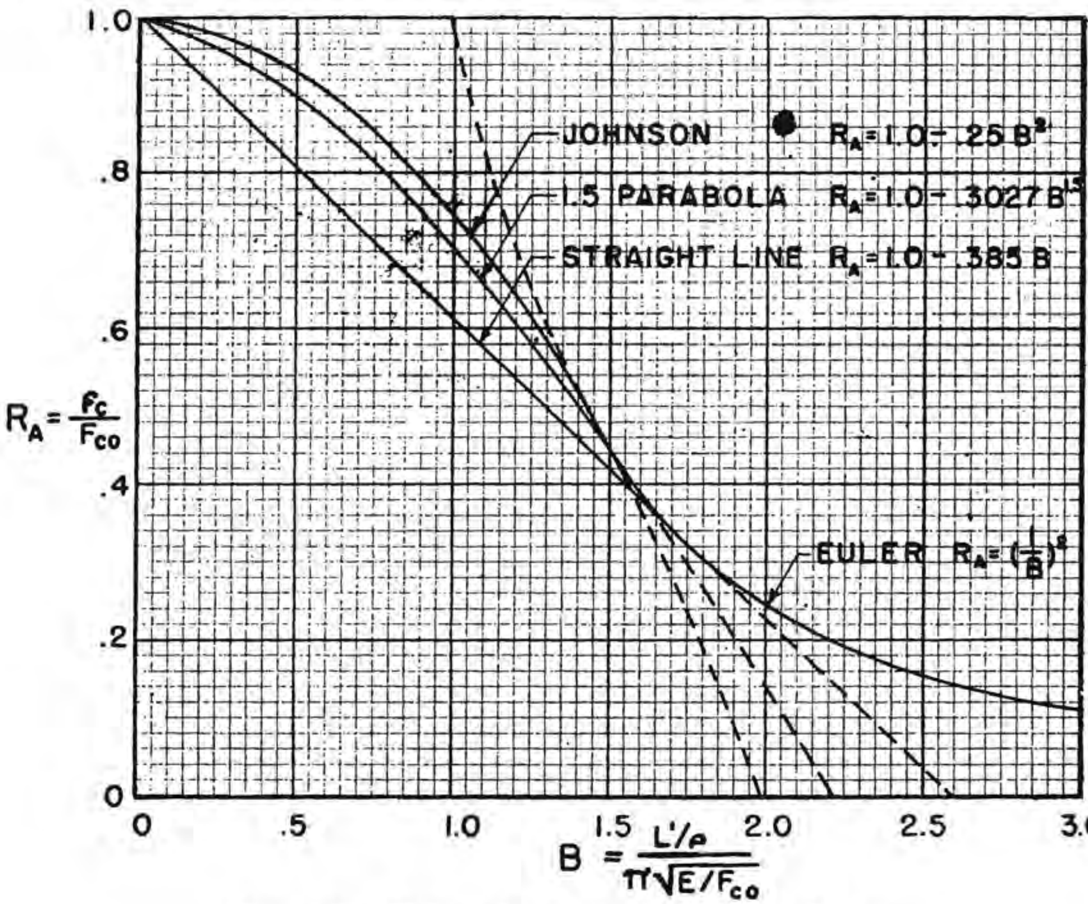


Figure 1.632. Various column curves in nondimensional form.

stresses of round tubes subject to plastic failure generally can be expressed by a modified form of the equation for the buckling of a thin-walled cylinder in compression as given below:

$$F_{cc}=K\frac{\sqrt{EE'}}{D/t} \quad (1.6421)$$

The effective modulus E′ can be determined from the basic column curve for primary failure by the method given in section 1.623. As the value of the effective modulus corresponds to a given value of stress it usually is convenient to: (1) Assume a value of F_{cc}; (2) compute the corresponding value of E'; (3) substitute these values into equation 1.6421 and solve for D/t. This latter value is the D/t at which crushing will occur at the assumed stress. Values of the constant K must be determined empirically. As noted above, equation 1.6421 applies to plastic failure; i. e., for stresses above the proportional limit. In the case of thin-walled tubes which fail locally at stresses below the proportional limit, the initial eccentricities are likely to be larger relatively and the constant should be suitably reduced.

1.65 Columns of Unconventional Cross Section

1.651 *General.* In the case of columns having unconventional cross sections which are particularly subject to local instability, it is necessary to establish the curve of transition from local to primary failure. In determining the strength curves for such columns, sufficient tests should be made to cover the following points:

1.652 *Nature of "short column" curve.* The test specimens should cover a range of $\frac{L'}{\rho}$ which will extend to the Euler range, or at least well beyond the values to be used in construction. When columns are to be attached eccentrically in the structure, some tests should be made to determine the effects of eccentricity. This is important particularly in the case of open sections, as the allowable loads may be affected considerably by the location of the point of application of the column load.

1.653 *Local failure.* When local failure occurs, the crushing or crippling stress F_{cc} can be determined by extending the "short column" curve for the specific cross section under consideration to a point corresponding to zero L'/ρ. When a family of columns of the same general cross section is used, it is often possible to determine a relationship between F_{cc} and some factor depending on the wall thickness, width, diameter, or some combination of these dimensions. Extrapolations of such data should be avoided by covering an adequate range in the tests.

1.654 *Reduction of test results on aluminum and magnesium alloys to standard.* The use of correction factors given in figures 1.654 (*a*) through (*k*) is considered satisfactory and is acceptable to the Air Force, Navy, and the Civil Aeronautics Administration for use in connection with tests on aluminum and magnesium alloys. (Note that an alternate method is given in par. 1.655.) In using figures 1.654 (*a*) through (*k*), the correction of the test result to standard is made by multiplying the stress developed in a test of a column specimen by the factor K. This factor may be considered applicable regardless of the type of failure involved (i. e., column crushing or twisting). In figures 1.654 (*a*) through (*k*), F_c is the ultimate compressive stress of the test specimen, F_{cy} is the compressive yield stress of the test specimen, and F_{cy} (std.) is the standard compressive yield stress as given in Tables 3.111 (*a*) through (*o*).

Acceptable methods for obtaining compressive yield strengths for use in determining values of K from figures 1.654 (*a*) through (*k*) are as follows:

(*a*) Direct compressive stress-strain measurements of the material of which the test column is made in the direction of loading of the test column.

(*b*) If method (*a*) is not feasible, the compressive stress desired may be obtained from the tensile yield stress as follows: Determine the tensile yield stress of the column test specimen material by direct tensile stress-strain measurements in a direction parallel to the test column length. Compute the compressive yield stress along the length of the test column by multiplying the tensile yield strength by the proper ratio of the design allowable compressive yield strength to the design allowable tensile yield strength; the ratio chosen should account for the grain direction of the test column. In case the compression test column is manufactured indiscriminately with respect to material grain, the tensile test specimen should be made with the grain parallel to its length and the with-the-grain ratio of the design allowable compressive yield to design allowable tensile yield strength for the material should be used.

(*c*) In case neither methods (*a*) nor (*b*) are feasible or applicable, it should be assumed that the compressive yield of the column test specimen parallel to its length is 15 percent greater than the minimum established design allowable yield strength for the material in the column test specimen.

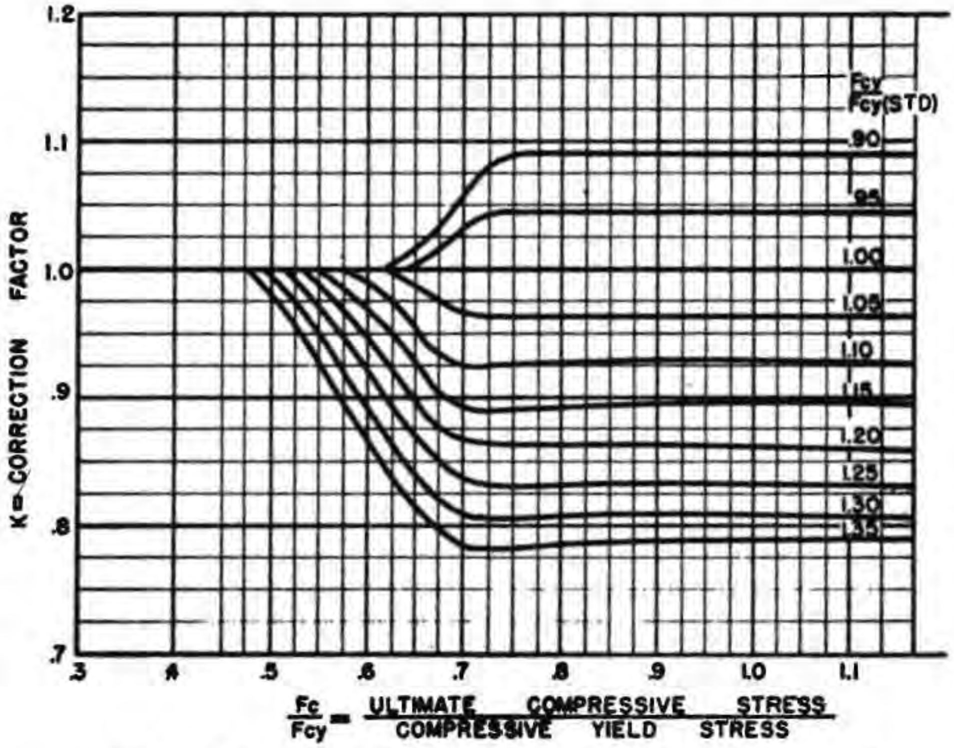


Figure 1.654 (a). Nondimensional material correction chart for 24S–T3 sheet.

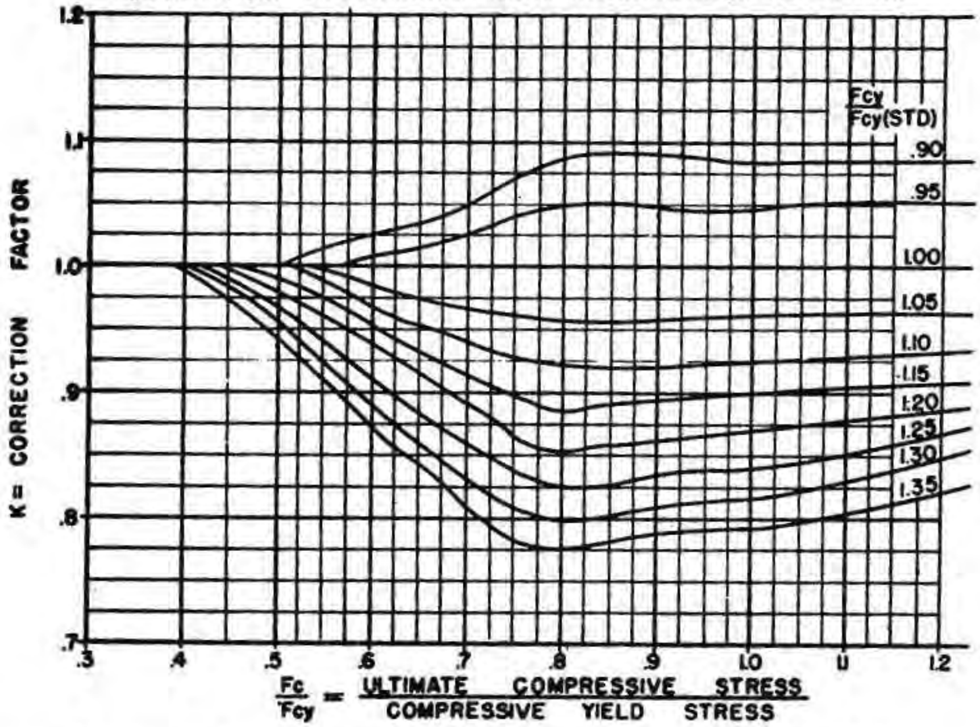


Figure 1.654 (b). Nondimensional material correction chart for 24S–T3 clad sheet.

409440—56——3

1.655 *Reduction of test results to standard-alternate method.* The use of the method of reducing test results to standard illustrated in figure 1.655 is considered satisfactory and is acceptable to the Air Force, Navy, and the Civil Aeronautics Administration. This method is conservative for aluminum alloys and is considered an acceptable method of correcting test results for other materials.

The following procedure should be used to obtain the corrected test results:

(*a*) Determine the compressive yield strength of the material in the column test specimen by one of the methods outlined in paragraphs 1.654 (*a*), (*b*), or (*c*); for materials other than aluminum alloy use a method similar to one of those described in these paragraphs.

(*b*) Construct an Euler curve (see fig. 1.655) for the material in the column test specimen.

(*c*) Plot two straight lines tangent to the Euler curve with intercepts on the compressive stress ordinate at values determined from the appropriate formula:

Aluminum alloys—$F_c=F_{cy}(1+F_{cy}/200{,}000)$
Magnesium alloys—$F_c=1.18\ F_{cy}$
Steel—$F_c=F_{cy}$

One intercept is determined by substituting the compressive yield strength of the material in the appropriate formula and the other by substituting the design allowable compressive yield strength for the material in the test specimen in the formula.

(*d*) When the test specimen has been tested, the test value is marked on the compressive stress ordinate, a horizontal line is drawn to intersect the straight line based on the test material compressive yield stress. A vertical line is erected at this point of intersection to intersect the other straight line based on the standard compressive yield stress, and a horizontal line extended from this point of intersection back to the compressive stress ordinate thus establishing the corrected test stress value.

1.7 Thin-walled and stiffened thin-walled sections

1.71 General. A bibliography of information compiled by the National Advisory Committee for Aeronautics on thin-walled and stiffened thin-walled sections is contained in reference 1.71.

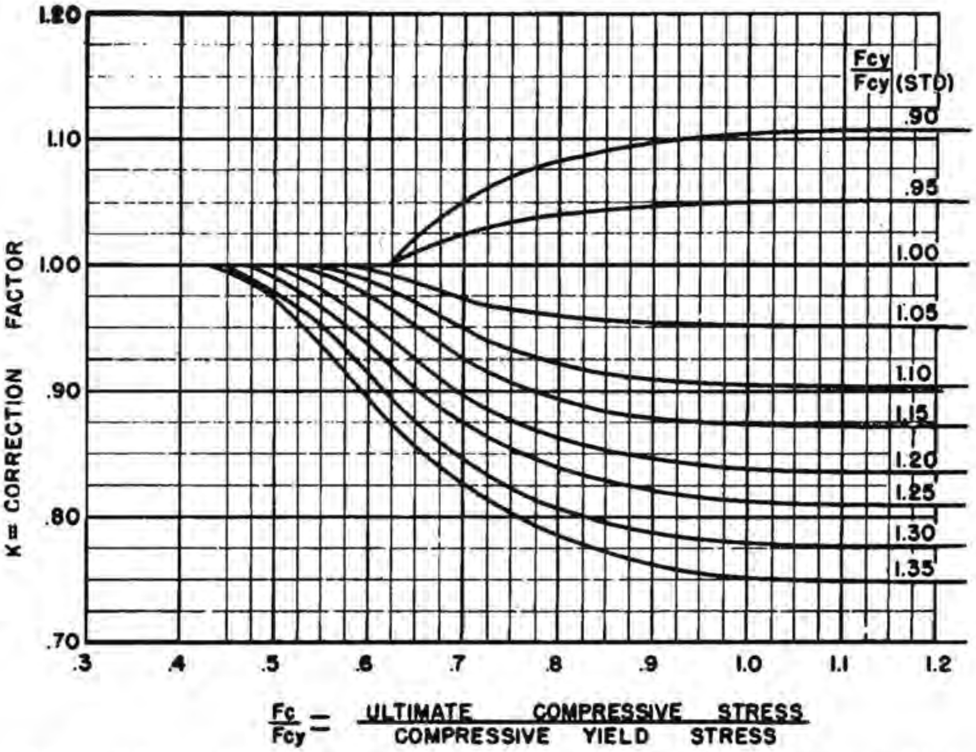


Figure 1.654 (c). Nondimensional material correction chart for 24S–T4 extrusions less than ¼ inch thick.

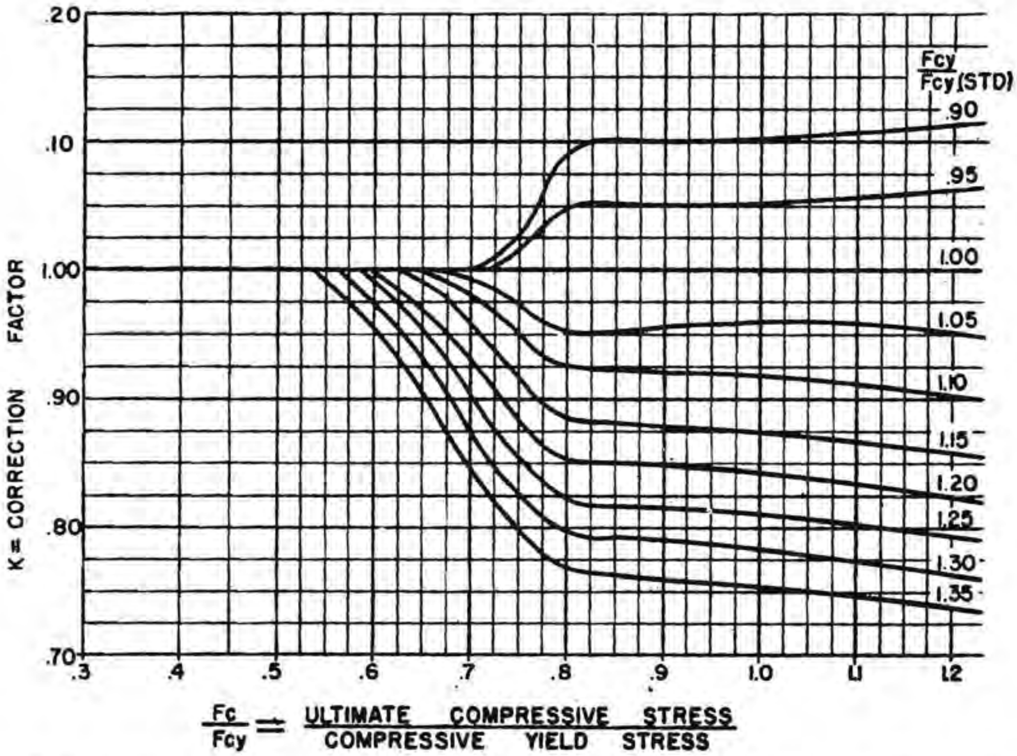


Figure 1.654 (d). Nondimensional material correction chart for 24S–T4 extrusions ¼ to 1½ inches thick.

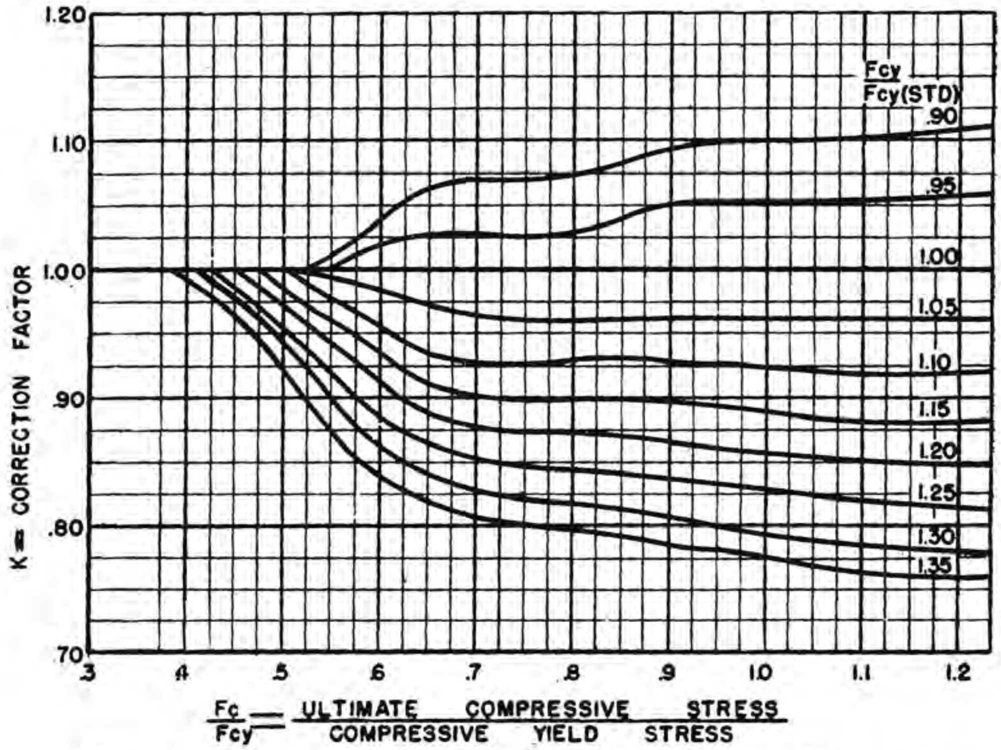


Figure 1.654 (e). Nondimensional material correction chart for 24S–T3 tubing.

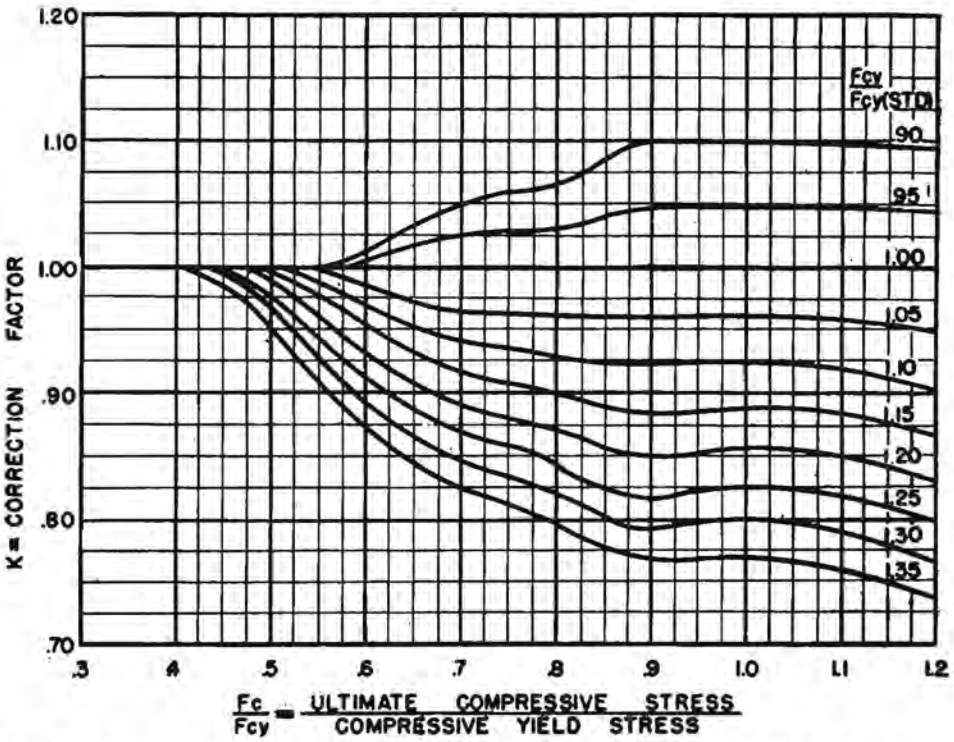


Figure 1.654 (f). Nondimensional material correction chart for 14S–T3 (R301–T3) clad sheet.

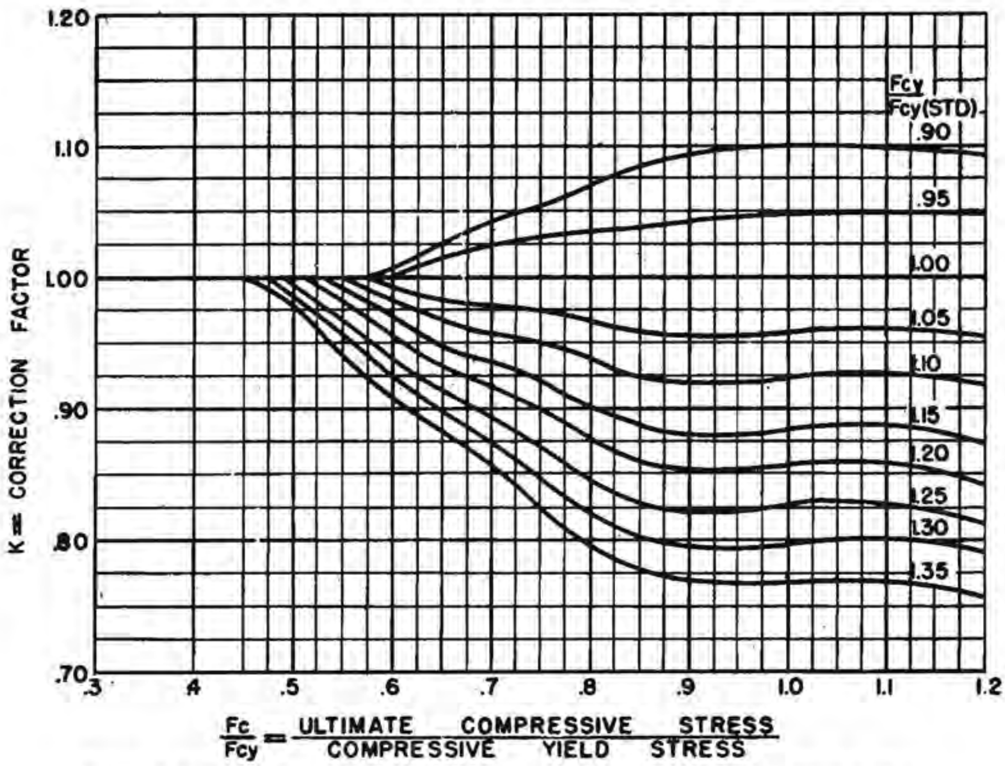


Figure 1.654 (g). Nondimensional material correction chart for 75S–T6 clad sheet.

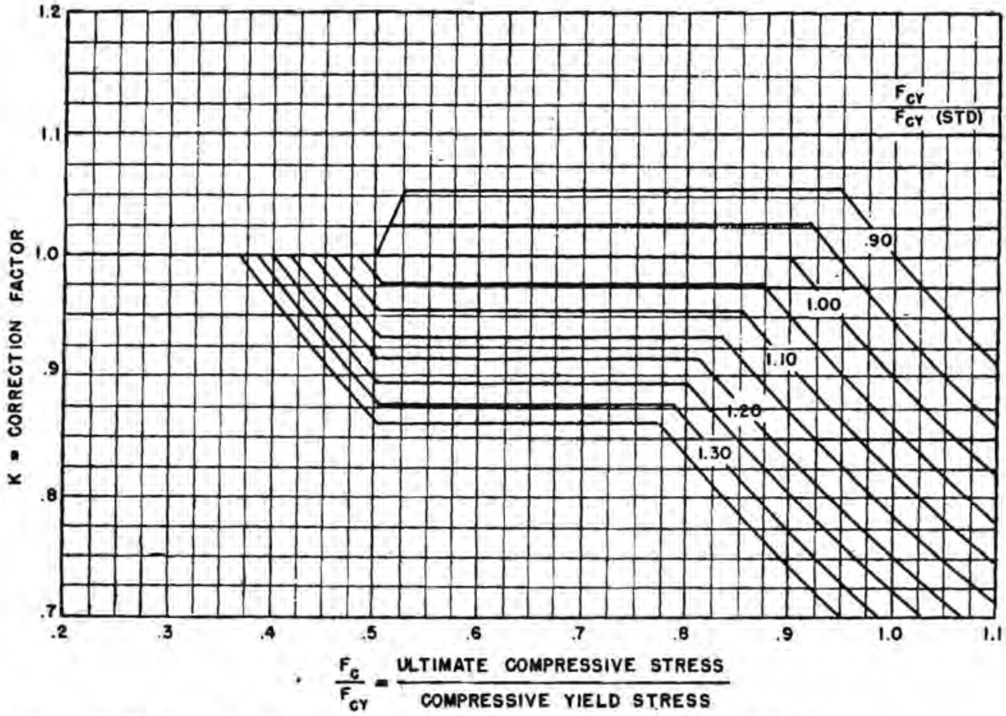


Figure 1.654 (h). Nondimensional material correction chart for M or AM 3S open extrusions.

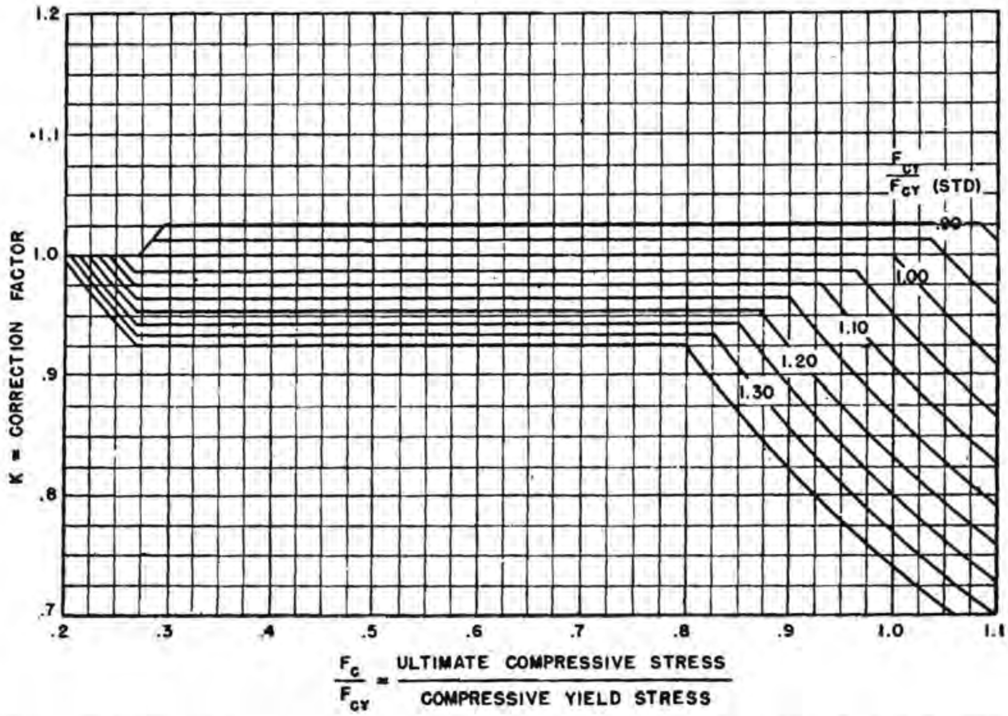


Figure 1.654 (i). Nondimensional material correction chart for FS-1, J-1, O-1, AMC52S, AMC57S, or AMC58S open extrusions.

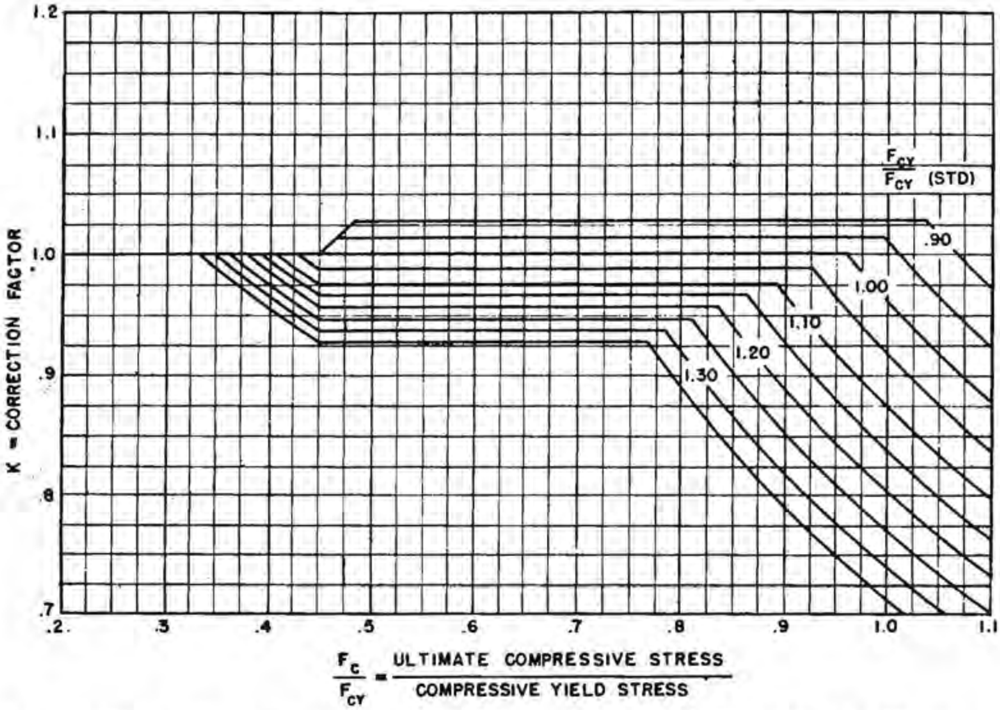


Figure 1.654 (j). *Nondimensional material correction chart for AMC58S–T5 or O–1HTA open extrusions.*

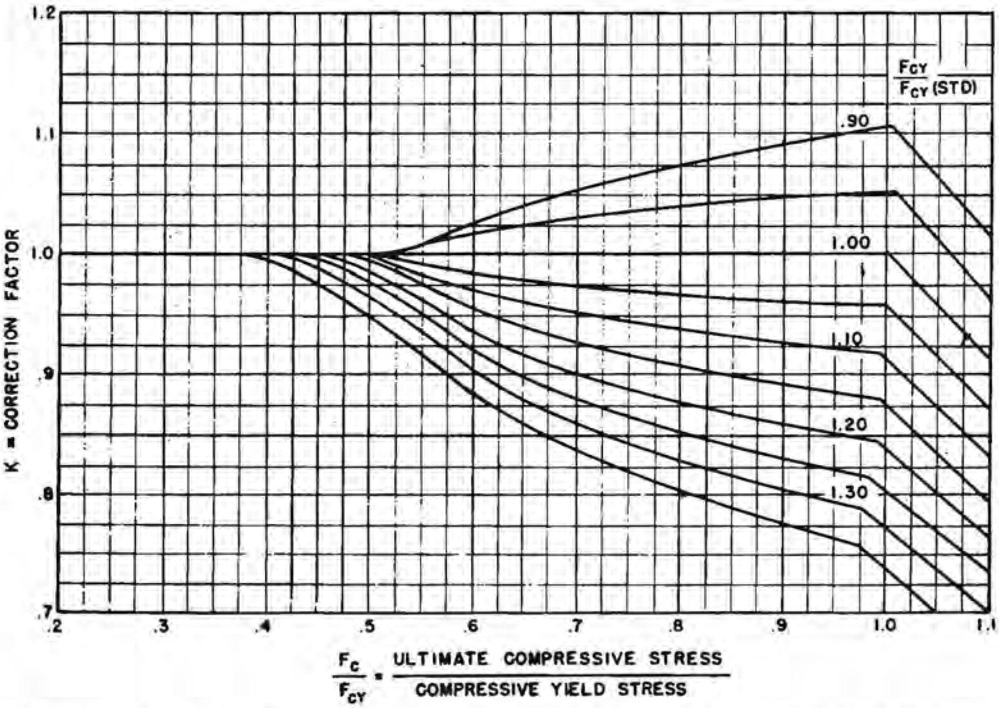


Figure 1.654 (k). *Nondimensional material correction chart for FS–1h or AM C52S–H sheet.*

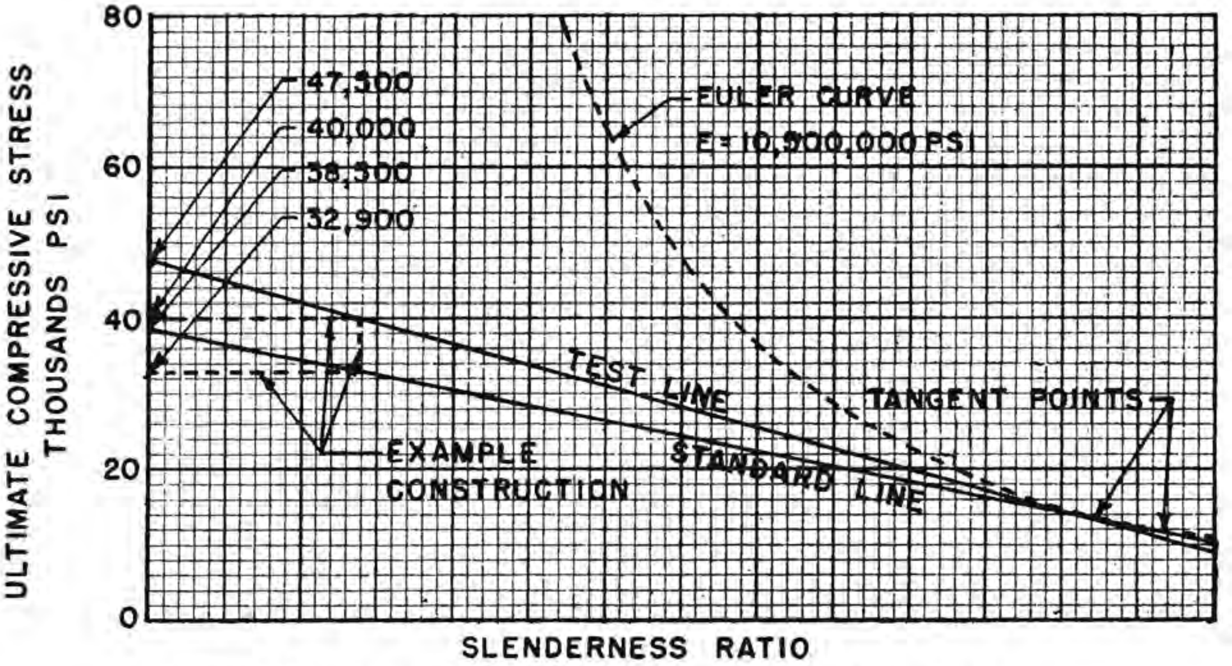


Figure 1.655. Illustrative material correction curves for columns (alternate methods).

CHAPTER 2

STEEL

2.1 General properties

2.11 NORMAL (ROOM) TEMPERATURE PROPERTIES

2.111 *Design mechanical properties.* Design mechanical properties and related characteristics for steels are listed in tables 2.111 (*a*) through (*d*). The values in table 2.111 (*b*) are 95 percent of the average test results, this percentage having been chosen because of the scatter of test data. The tensile and compressive strength properties apply to both longitudinal and transverse directions. Elongation values are typical for bar stock and are measured in the longitudinal direction. Elongation values for the transverse direction may be appreciably less.

The properties of table 2.111 (*b*) are based upon alloys heat treated in a manner which resulted in a quenched structure containing 90 percent or more martensite at the center.

The maximum diameters of round bars of various alloy steels capable of attaining the properties indicated by table 2.111 (*b*) throughout (surface to center) are indicated by table 2.111 (*c*). Limiting dimensions for common shapes other than round, which are capable of attaining the properties indicated by table 2.111 (*b*), are indicated by means of the "equivalent round" concept of figure 2.111. The equivalent round 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 physical properties at the centers of both the respective shape and the equivalent round are substantially the same.

In the definition of bearing values, "D" is equal to the hole diameter and e is equal to the edge distance measured from the hole center to the edge of the material in the direction of applied stress. Values of $e/D=2.0$ shall be used for larger values of edge distance; values of e/D less than 1.5 shall be substantiated by adequate tests subject to the approval of the procuring or certificating agency. For values of edge distance between $e/D=2.0$ and $e/D=1.5$ linear interpolation may be employed.

Table 2.111 (a). Design Mechanical Properties of Plain Carbon and Alloy Steels (Kips per Square Inch)

Type of product	Tube, sheet, bar	Sheet, plate, tube	
Alloy	1023, 1025	4130, 8630	
Specification	QQ-S-633, MIL-S-7952, MIL-T-5066.	MIL-T-6731, -6732, -6734, -6736, AN-S-12, AN-QQ-S-685.	
Condition		[a]N	[a]N
Thickness, inches		>0.188	≤ 0.188
F_{tu}	55	90	95
F_{ty}	36	70	75
F_{cy}	36	70	75
F_{su}	35	55	55
F_{bru} $(e/D=1.5)$			
F_{bru} $(e/D=2.0)$	90	140	140
F_{bry} $(e/D=1.5)$			
F_{bry} $(e/D=2.0)$			
E, E_c	29,000	29,000	29,000
G	11,000	11,000	11,000
w	0.283	0.283	0.283
e	22.0	23.0	

[a] This value is applicable when the material is furnished in condition N of the applicable MIL specification but the yield strength is appreciably reduced when normalized.

Table 2.111 (b).—Design Mechanical Properties of Fully Hardened Alloy Steel (Kips per Square Inch) [a]

Alloy	8630 and 4340				
Type of product	Sheet, tube, and bar				
Condition	Heat treated (quenched and tempered) to obtain the F_{tu} indicated				
Specifications	MIL-S-6050, AN-S-12, MIL-T-6732, MIL-T-6734, MIL-S-5000				
F_{tu}	125	150	180	[b] 200	[c]260
F_{ty}	103	132	163	176	217
F_{cy}	113	145	179	198	242
F_{su}	82	95	109	119	149
F_{bru} $(e/D=1.5)$	194	219	250	272	347
F_{bru} $(e/D=2.0)$	251	287	326	355	440
F_{bry} $(e/D=1.5)$	151	189	230	255	312
F_{bry} $(e/D=2.0)$	180	218	256	280	346
E and E_c	29, 000				
G	11, 000				
w	0. 283				
e	23. 0	18. 5	15. 0	13. 5	10. 5

[a] The design mechanical values listed correspond closely to those for 4130, 4140, 8735, 8740, and 9840.

[b] The use of heat treatments for design ultimate tensile strengths greater than 180,000 p. s. i. are subject to the specific approval of the procuring or certificating agency. The absence of a 220-ksi column does not preclude consideration of approval for design at this strength level. Data are not published herein because of the differences in properties among the various special steels which can be used at this strength level.

[c] Design mechanical properties at the 260-ksi strength level apply to 4340.

Table 2.111 (c). Maximum Round Diameters for Fully Hardened Steel Bars

(Through Hardening to 90 Percent Martensite at Center)

[For use with properties of table 2.111 (b)]

F_{tu}	Diameter of round or equivalent round, inches [a]				
	0.5	0.8	1.0	2.0	3.5
200 k.s.i. and above	------	8740	4140	9840	4340
200 k.s.i.	4130	8735	------	------	------
180 k.s.i.	8630	------	------	------	------

[a] Steels listed in any block may be used in smaller sizes or heat treated to lower strengths than listed. Use of steels in larger diameters of equivalent round than listed will result in incomplete hardening and reduction in tensile and compressive yield properties and is subject to the specific approval of the procuring or certificating agency.

409440—56——4

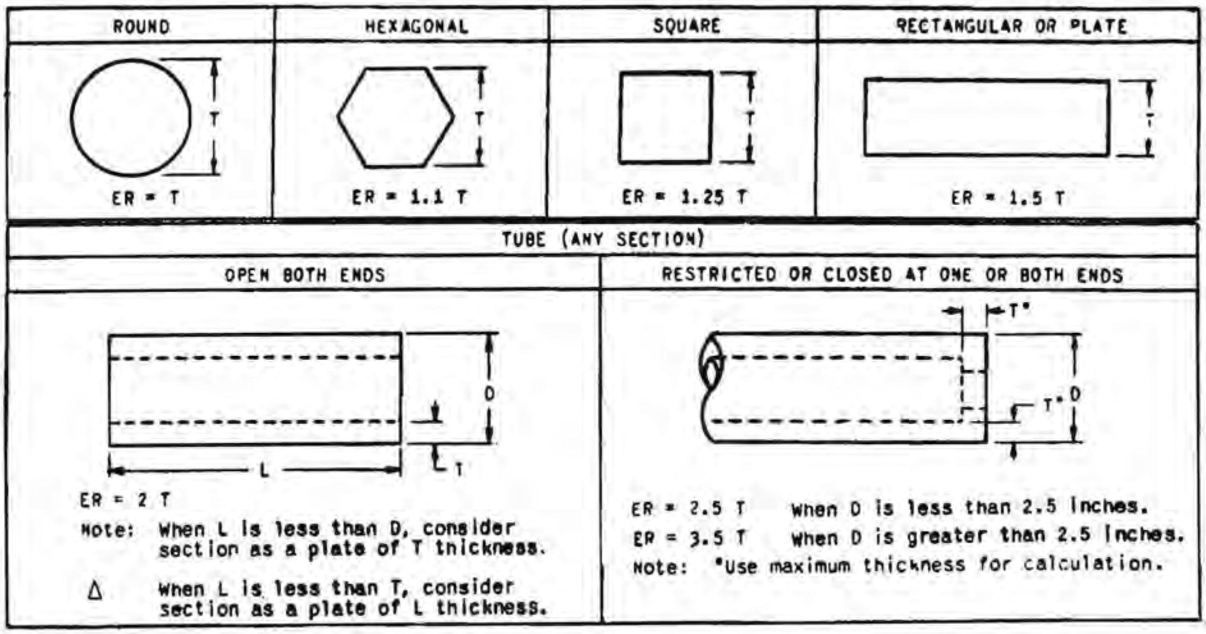
Table 2.111 (d). Design Mechanical Properties of Corrosion Resisting Steels (Kips per Square Inch)

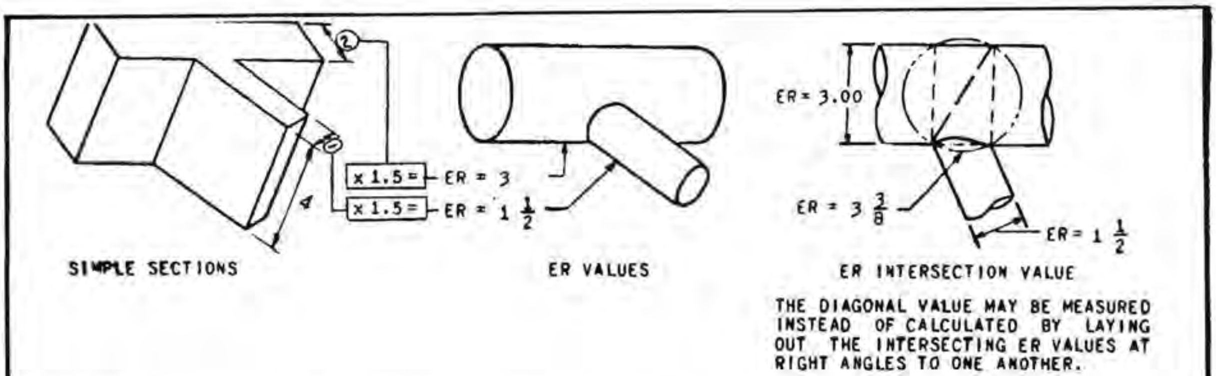
Type		Sheet and strip								
Alloy		18-8								
Specification		MIL-S-5059 Grades C and G								
Condition		Annealed	Cold rolled				Cold rolled and heat-treated [a]			
			¼ hard	½ hard	¾ hard	Full hard	¼ hard	½ hard	¾ hard	Full hard
F_{tu}	L, T	75	125	150	175	185	125	150	175	185
F_{ty} [b]	L, T	30	75	110	135	140	75	120	140	160
F_{cy}	L	35	65	85	95	105	75	105	120	140
	T	35	100	120	140	170	105	125	160	185
F_{su}		40	67.5	80	95	100	[c] 67.5	[c] 80	[c] 95	[c] 100
$F_{bru}(e/D=1.5)$		----	----	----	----	----	----	----	----	----
$F_{bru}(e/D=2.0)$		75	150	180	190	195	[c] 150	[c] 180	[c] 190	[c] 195
$F_{bry}(e/D=1.5)$		----	----	----	----	----	----	----	----	----
$F_{bry}(e/D=2.0)$		----	----	----	----	----	----	----	----	----
E	L	29,000	27,000	26,000	26,000	26,000	27,000	27,000	27,000	27,000
	T	29,000	28,000	28,000	28,000	28,000	29,000	29,000	29,000	29,000
E_c	L	28,000	26,000	26,000	26,000	26,000	27,000	27,000	27,000	27,000
	T	28,000	27,000	27,000	27,000	27,000	28,000	28,000	28,000	28,000
G		12,500	12,000	11,500	11,000	11,000	12,000	11,500	11,000	11,000
w		0.286	0.286	0.286	0.286	0.286	0.286	0.286	0.286	0.286

[a] Heat treatment consists of holding from 16 to 36 hours at 300°–200° C., (570°–392° F.), and cooling in air.

[b] The 0.2 percent offset minimum yield stresses were determined on the basis of the initial moduli of elasticity as shown by the stress-strain data.

[c] These data are safely based on the "as-cold-rolled" material, and should be higher for the "cold-rolled and heat-treated" material.





The following steps should be used in determining the governing equivalent round for complex sections:

1. Reduce the components to simple sections.

2. Convert simple section to ER values. The ER value at an intersection is equivalent to a diagonal through the diameter of a circle which would circumscribe the ER area intersection, normal to the larger ER section, as shown on the upper right-hand sketch.

3. The maximum ER value, whether it is for a single component or an intersection, shall be taken as the ER of the complex section.

ER-e. Equivalent round diameter of round bars.

Figure 2.111. Correlation between significant dimensions of common shapes other than round and the diameters of round bars.

2.112 *Fatigue properties.* Rotating beam and direct-stress tension compression fatigue strengths at room temperature for several alloy steels are given in table 2.112 (*a*) and figures 2.112 (*a*). Reversed bending fatigue strengths for 18 percent chromium, 8 percent nickel sheet material are given in table 2.112 (*b*). These data are average values. Even under carefully controlled conditions there is considerable scatter in fatigue test results. The tabulated and plotted test results, therefore, must be considered as values lying at about the center of a scatter band. The width of this band may be as much as 20 percent above and below the average depending on the material and test procedure used. See reference 2.112 (*a*) for a discussion of scatter of the fatigue strength of steel.

The values given in the tables 2.112 (*a*) and (*b*) and those shown in figure 2.112 (*a*) have been determined on smooth specimens, for which stress concentrations have been purposely minimized. They do not apply directly to the design of structures because they do not take account of 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. They reduce the fatigue life of fabricated parts far below that which would be predicted by comparing the smooth specimen strengths directly with the nominal calculated stresses for the parts in question. Fabricated parts in test have been found to fail at less than 50,000 repetitions of load when the nominal stress was far below that which could be repeated many millions of times on a smooth machined specimen.

The data shown in figure 2.112 (*a*) were obtained in direct stress fatigue tests in a Schenck testing machine using machined specimens with a 0.400-inch diameter. The material was taken from rolled bar stock and the specimens were cut parallel to the direction of rolling.

Figure 2.112 (*b*) shows notched fatigue strength data for SAE 4340 steel. The data in this figure were obtained in the same type of direct test as used for unnotched specimens, only the specimen form being different. By comparing figures 2.112 (*a*) and (*b*) the serious effect of a mildly severe notch on fatigue strength is shown. The notched data are presented to show the effect of one type on moderate stress concentration since effects of the large variety of notches and stress concentrations which may occur in practice cannot, of course, be given. The scatter of fatigue results mentioned previously for the results on smooth specimens occurs also for the notched specimens, although the amount of scatter is less for the notched specimens.

The values for 10 million cycles given in the tables are considered to be endurance limits.

Table 2.112 (a). Rotating Beam Fatigue Data for Ferrous Materials

(All values of stress in p. s. i.)

[Values given were determined by testing 0.30 inch diameter machined specimens in R. R. Moore rotating beam fatigue machines and represent extreme fiber stresses which such specimens will withstand in completely reversed flexure]

Material	Condition	Ultimate tensile strength	Approximate maximum stresses which material will withstand for various numbers of cycles		
			100,000 cycles	1,000,000 cycles	10,000,000 cycles
S. A. E. 4340 steel bar	Heat treated	188, 000	100, 000	82, 000	82, 000
S. A. E. 4340 steel forged bar [a]	do	150, 000	96, 000	80, 000	76, 000
S. A. E. 2330 steel bar	do	116, 000	82, 000	72, 000	66, 000
Do	do	193, 000	98, 000	95, 000	92, 000
S. A. E. 4130 steel bar	do	129, 000	85, 000	75, 000	74, 000
Do	do	152, 000	97, 000	86, 000	84, 000
Do	do	205, 000	105, 000	100, 000	99, 000

[a] With grain flow.

Table 2.112 (b). Reversed Bending Fatigue Data for Chromium 18 Percent, Nickel 8 Percent, Sheet Steel—Longitudinal Direction

(All values of stress in p. s. i.)

[Values given were determined by testing cantilever sheet specimens in Krouse constant deflection type fatigue testing machines and represent extreme fiber stresses which such specimens will withstand in completely reversed flexure]

Temper	Thickness of sheet	Heat treatment	Ultimate tensile strength	Approximate maximum stresses which material will withstand for various numbers of cycles		
				100,000 cycles	1,000,000 cycles	10,000,000 cycles
Full hard	0. 025	As rolled	191, 700	86, 000	75, 000	72, 000
Do	. 025	At 450° F., 24 hours	202, 700	90, 000	80, 000	76, 000
Do	. 050	As rolled	200, 000	94, 000	91, 000	88, 000
Do	. 050	At 450° F., 24 hours	208, 000	----------	98, 000	93, 000
Half hard	. 025	As rolled	154, 000	73, 000	66, 000	62, 000
Do	. 025	At 450° F., 24 hours	150, 000	75, 000	73, 000	64, 000

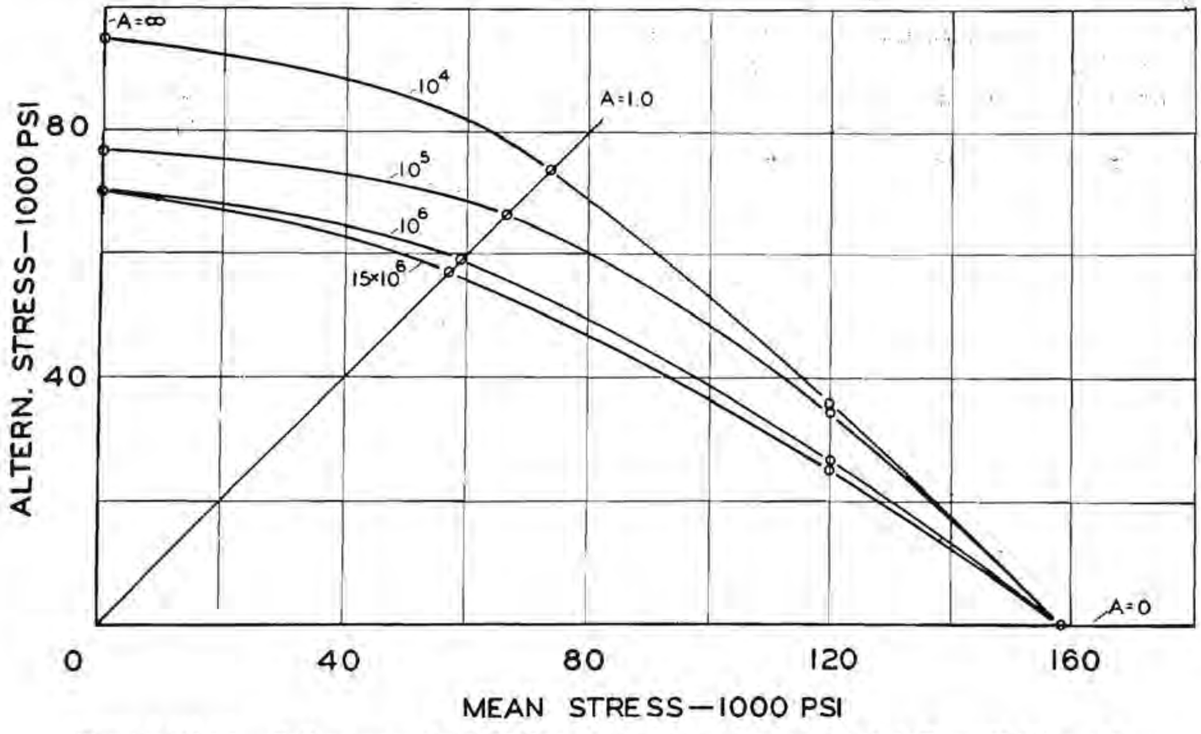


Figure 2.112 (a). Fatigue properties of 4340 steel—room temperature; unnotched, F_{tu}=158,000 p. s. i.

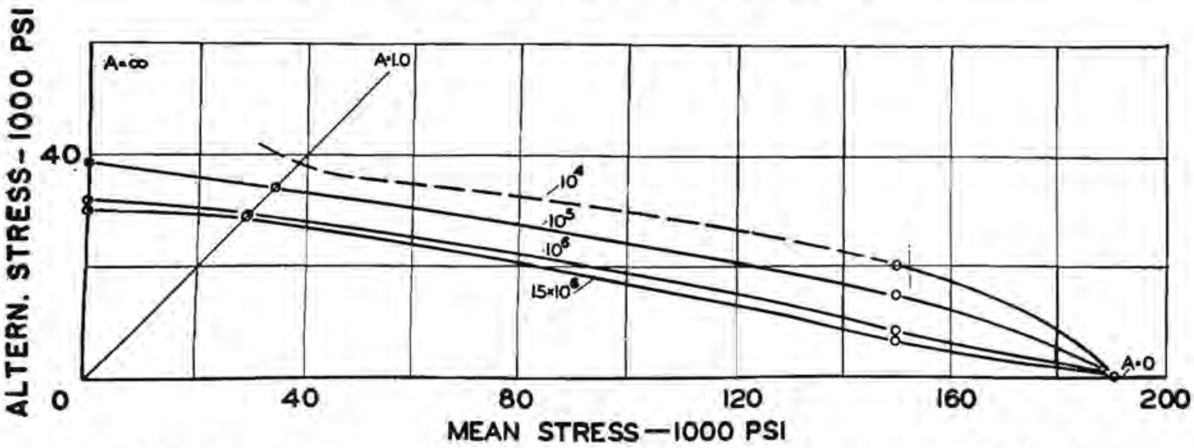


Figure 2.112 (b). Fatigue properties of 4340 steel—room temperature; notched, F_{tu}=158,000 p. s. i.

2.113 *Typical stress-strain and tangent modulus data.* Typical stress-strain and tangent modulus curves for normalized and heat-treated, quenched and tempered alloy steels are shown on figures 2.113 (*a*) and 2.113 (*b*), respectively. Typical tangent modulus curves for corrosion resisting steel sheet are shown on figure 2.113 (*c*). These curves are based on relatively few tests and are therefore subject to modification as further data become available. Where the value of initial modulus indicated by the curves differs from that given in the tables, the table values shall be used. The stress-strain curve in the region of low strains can be predicted accurately from the formula 1.342 where an appropriate value of E is selected from table 2.111.

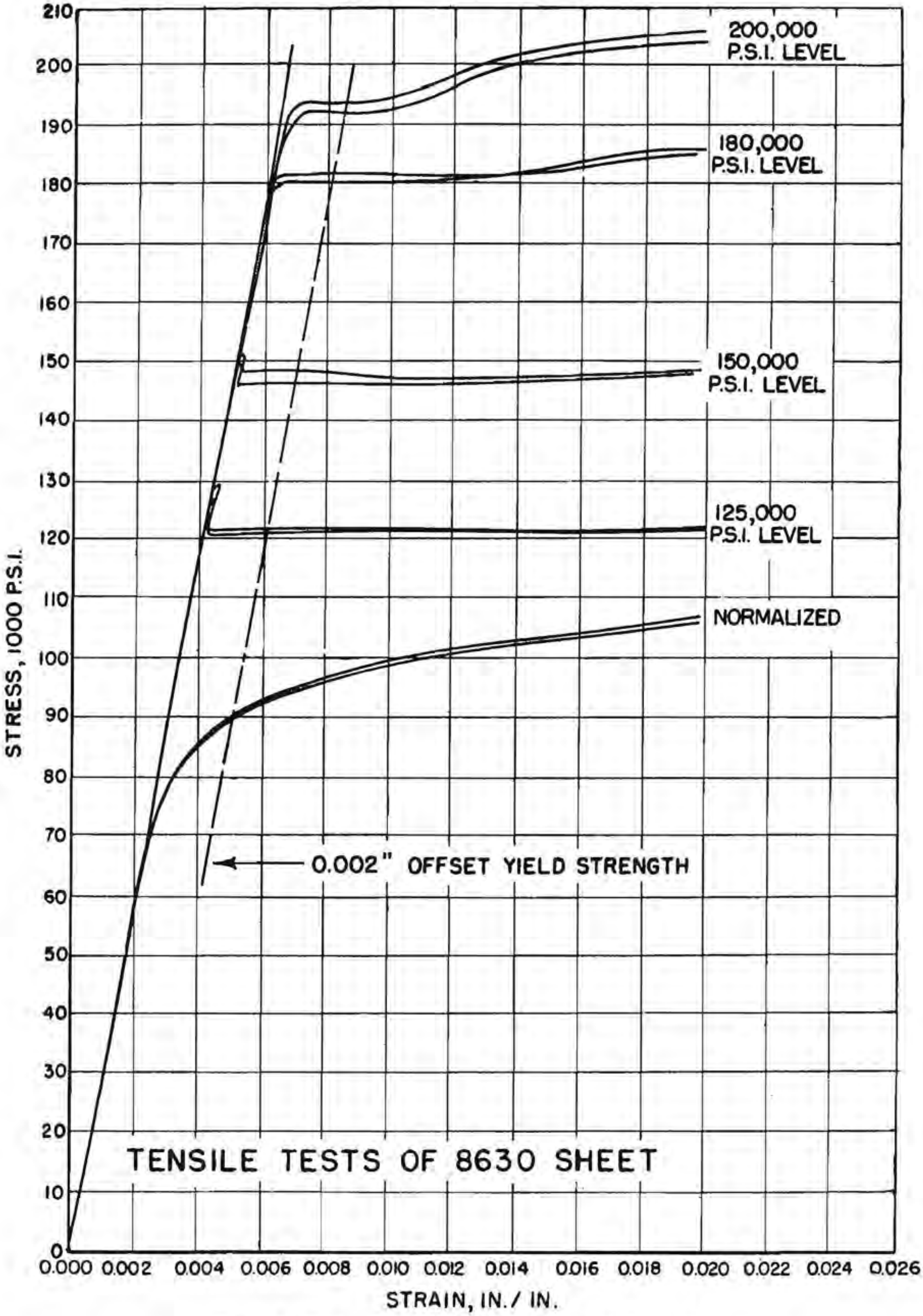


Figure 2.113 (a). Typical stress-strain curves of alloy steels.

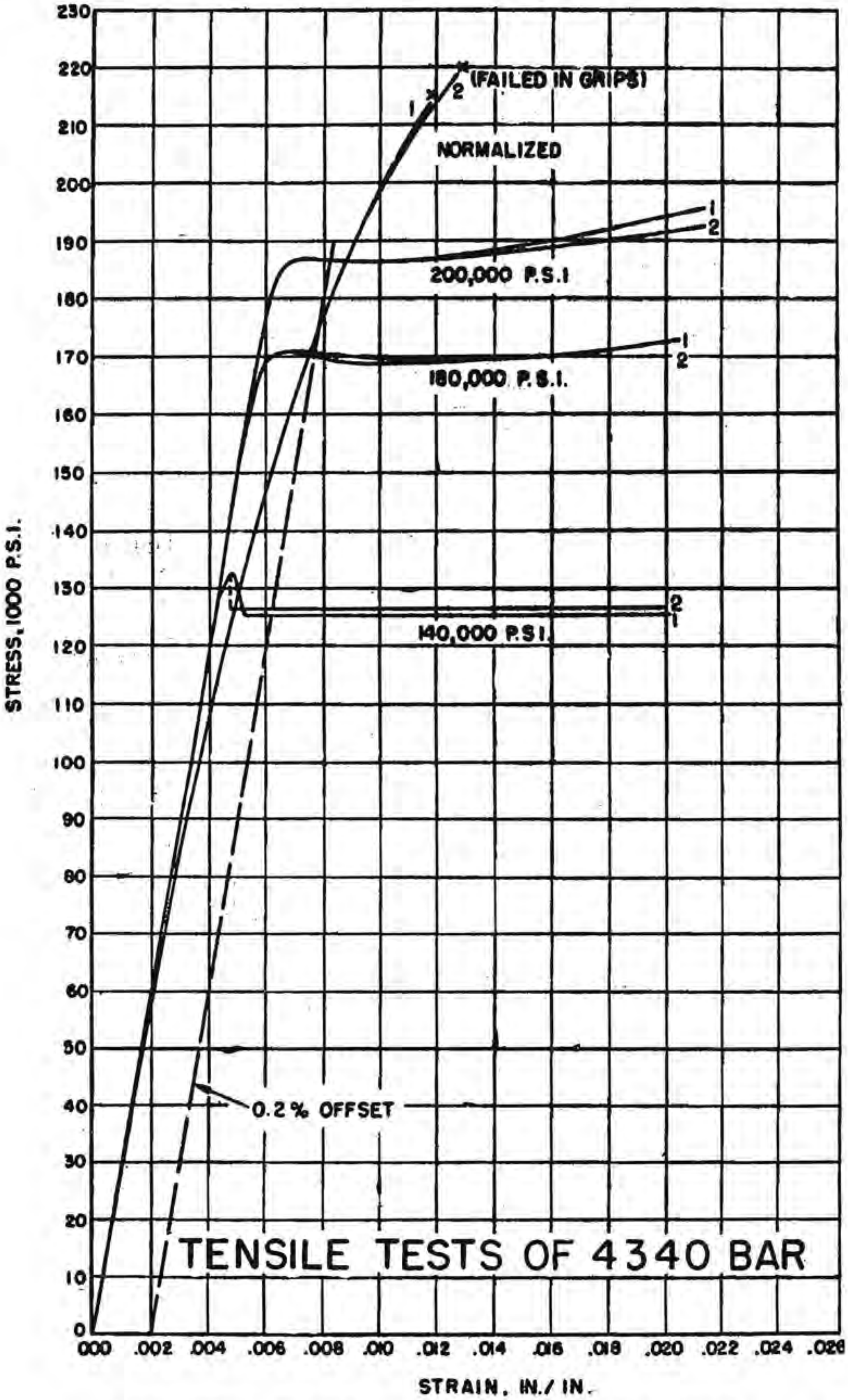


Figure 2.113 (a) Typical stress-strain curves of alloy steels—Continued.

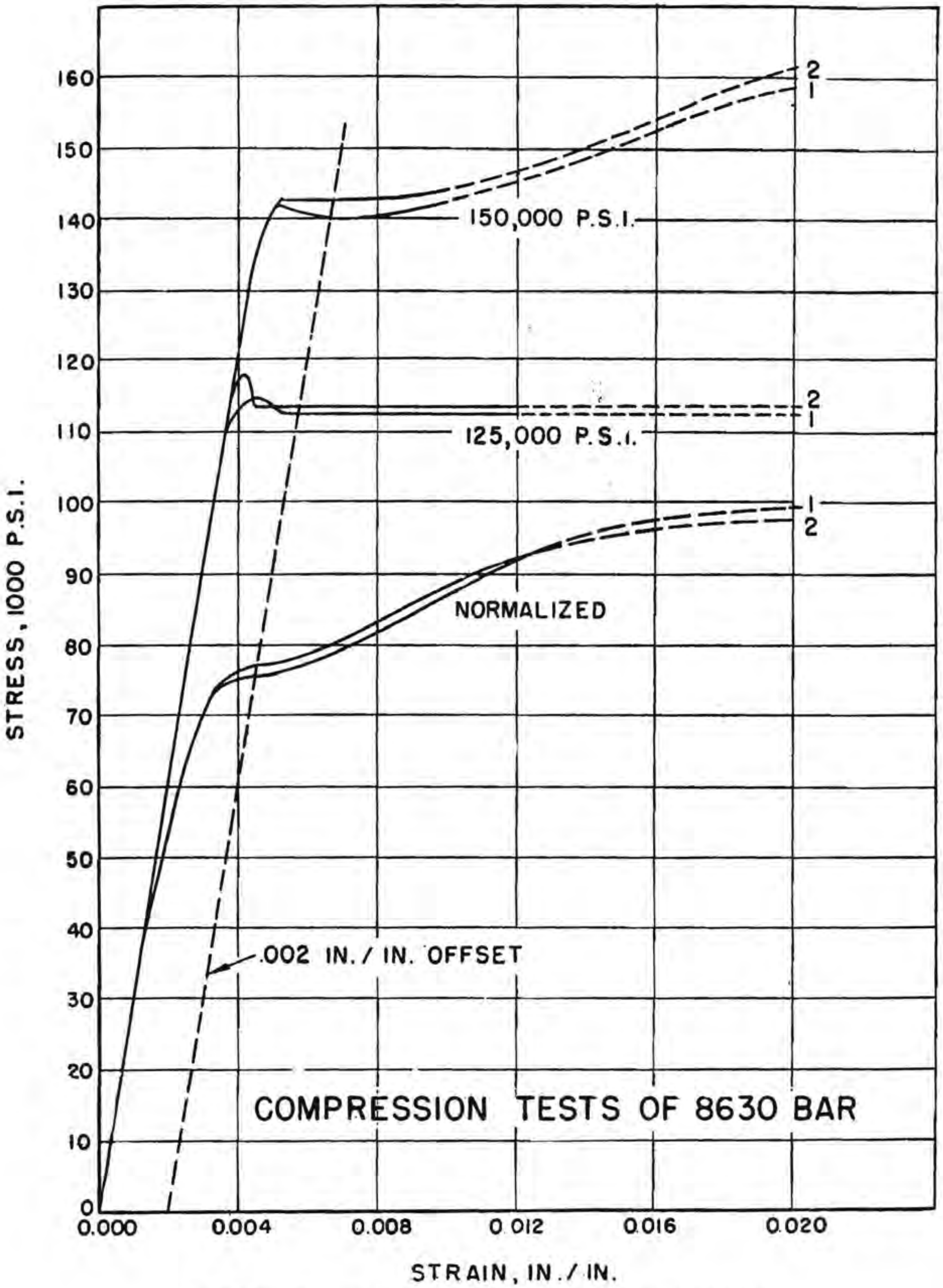


Figure 2.113 (a). Typical stress-strain curves of alloy steels—Continued.

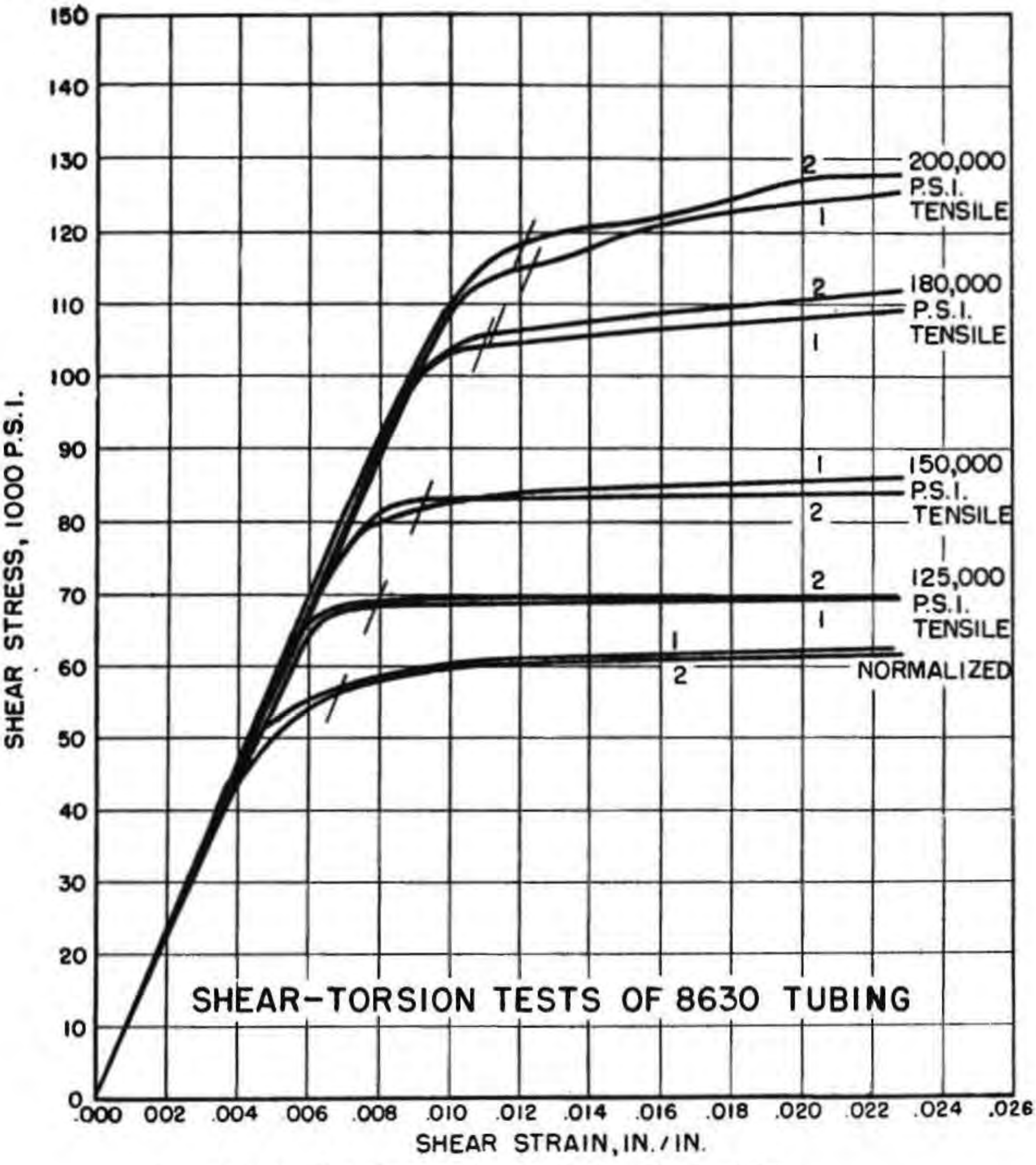


Figure 2.113 (a). Typical stress-strain curves of alloy steels—Concluded.

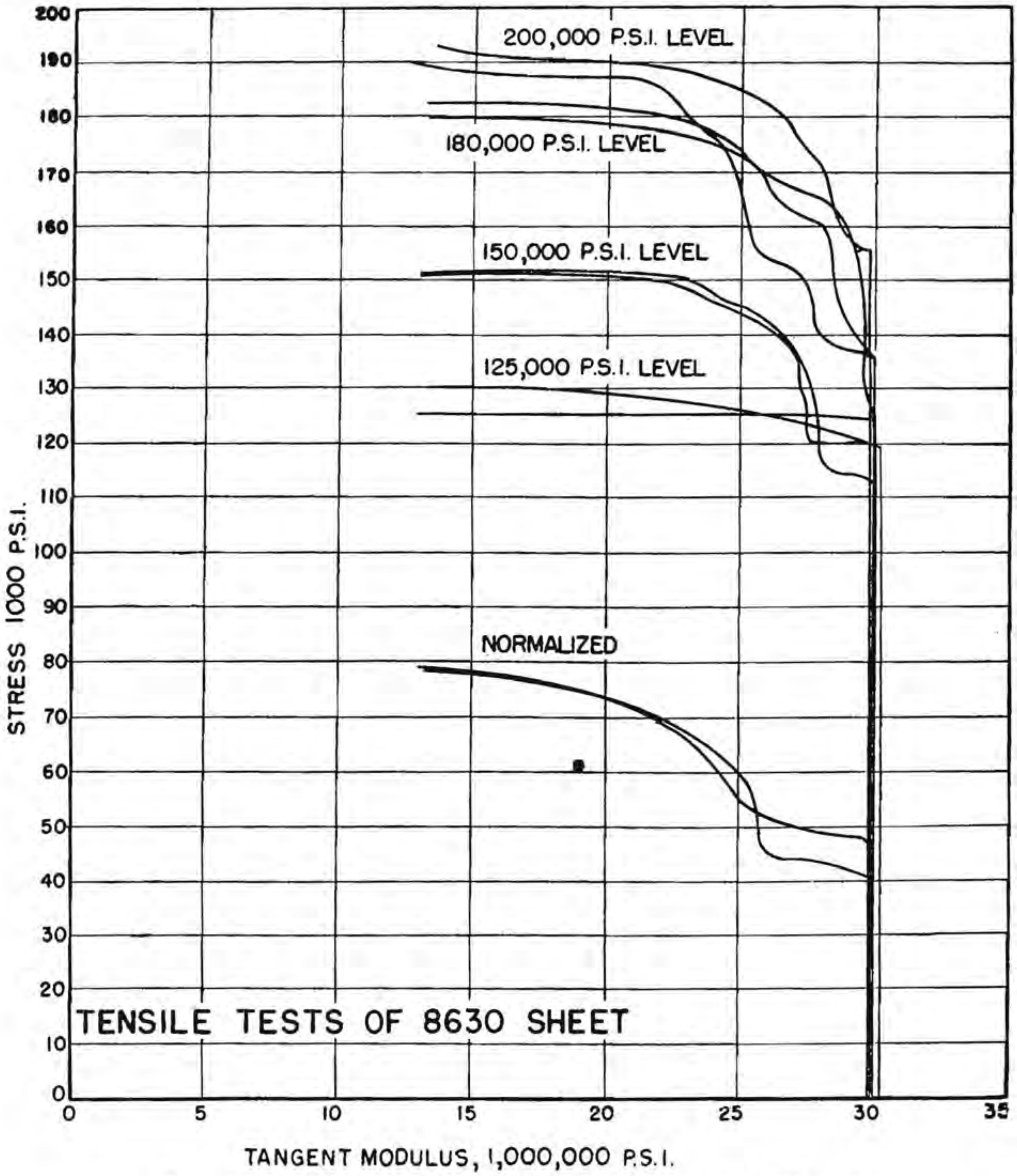


Figure 2.113 (b). Typical tangent modulus curves of alloy steel (1,000,000 p. s. i)

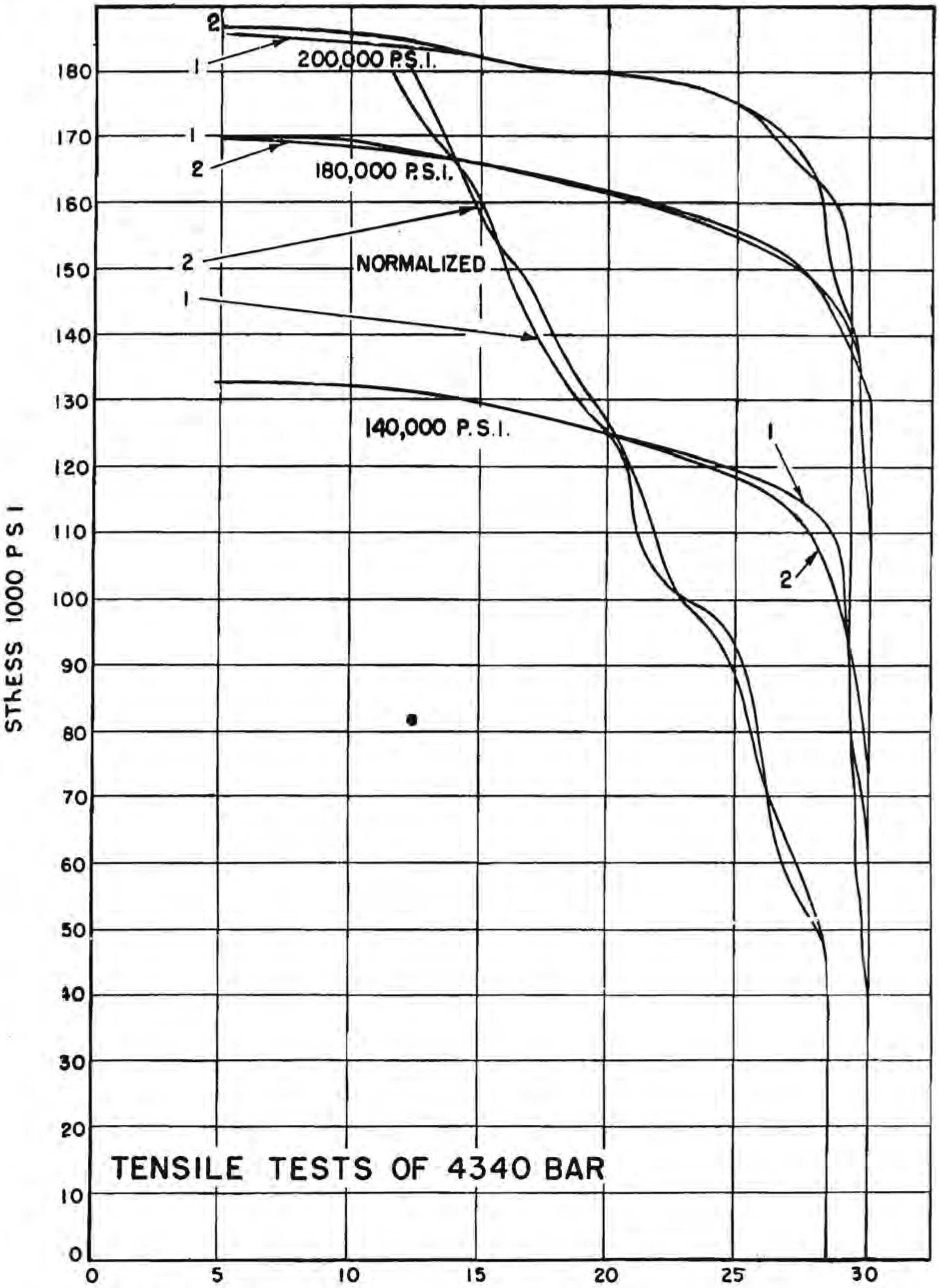


Figure 2.113 (b). Typical tangent modulus curves of alloy steel (1,000,000 p. s. i.)—Continued.

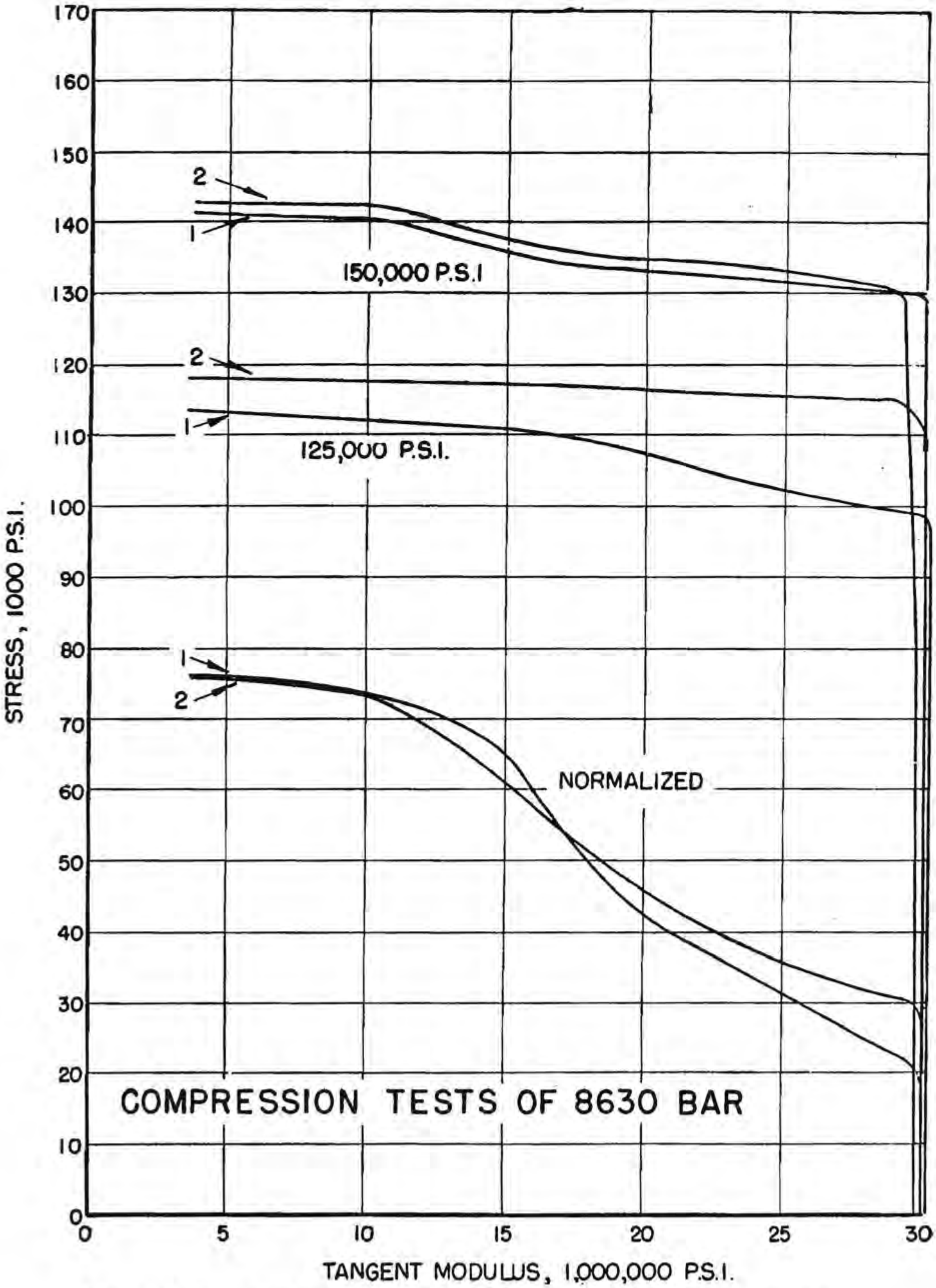


Figure 2.113 (b). Typical tangent modulus curves of alloy steel (1,000,000 p. s. i.)—Concluded.

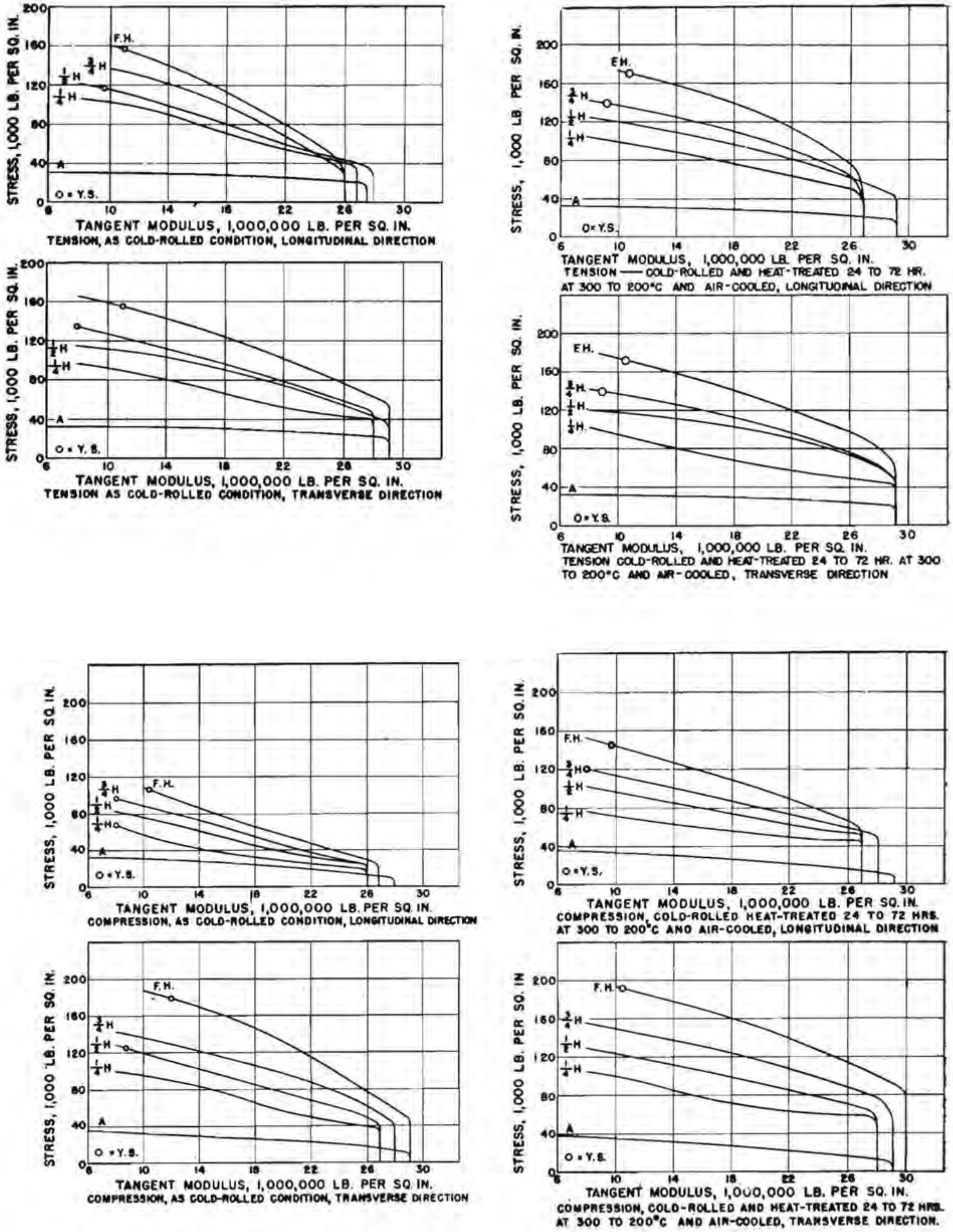


Figure 2.113 (c). Tangent modulus curves derived from stress-strain curves for corrosion-resisting (stainless) steel sheet and plate.

2.12 Temperature Effects

2.121 *Low temperature.* In general, the effects of low temperature on ferrous alloys are increases in the strength properties and decreases in ductility and impact strength. These effects vary depending upon the alloy and heat treatment. The usual effect of low temperature on the fatigue properties of ferrous material is an increase of the fatigue strength at any given life. In some cases the presence of stress concentrations may cause a reduction in fatigue strength at low temperature as compared to normal temperature. Additional information on these subjects is available in references 2.121 (*a*) and 2.121 (*b*).

2.122 *Elevated temperature*

2.1221 *Static properties.* The effect of elevated temperature is to decrease the strength properties of ferrous materials. Little specific information is available on this subject.

2.12211 *Strength at temperature*

2.12212 *Effect of exposure.* Exposure of quenched and tempered steels of SAE 4130, 8630, and 4640 and similar types to temperatures below their respective tempering temperatures will have no appreciable effect on the room - temperature properties. Exposure at their tempering temperature will decrease their room-temperature properties slightly if the exposure time is more than a few hours. Exposure above the tempering temperatures will, of course, be equivalent to a retemper and will decrease the room-temperature properties an amount dependent upon the temperature and time exposed.

Exposure of types 301, 302, 304, 321, and 347 austenitic steels in any condition (annealed, ¼, ½, ¾, or full hard) to temperatures up to 800° F. for periods up to 100 hours will not decrease room-temperature properties. The effect of exposure to temperatures above 800° F, on room-temperature properties, is not known.

2.1222 *Fatigue properties.* Direct stress fatigue strength data for SAE 4340 steel unnotched specimens at temperatures up to 1,000° F. are given in figures 2.1222 (*a*) through (*c*). These data were obtained in the same type of test as the room-temperature data presented in figure 2.112 (*a*). The notched specimen data at the same temperatures are presented in figures 2.1222 (*d*) through (*f*). The effect of temperature on fatigue strength may be seen by comparing the fatigue strengths at the elevated temperatures in figures 2.1222 (*a*) through (*c*) with the fatigue strengths obtained at room

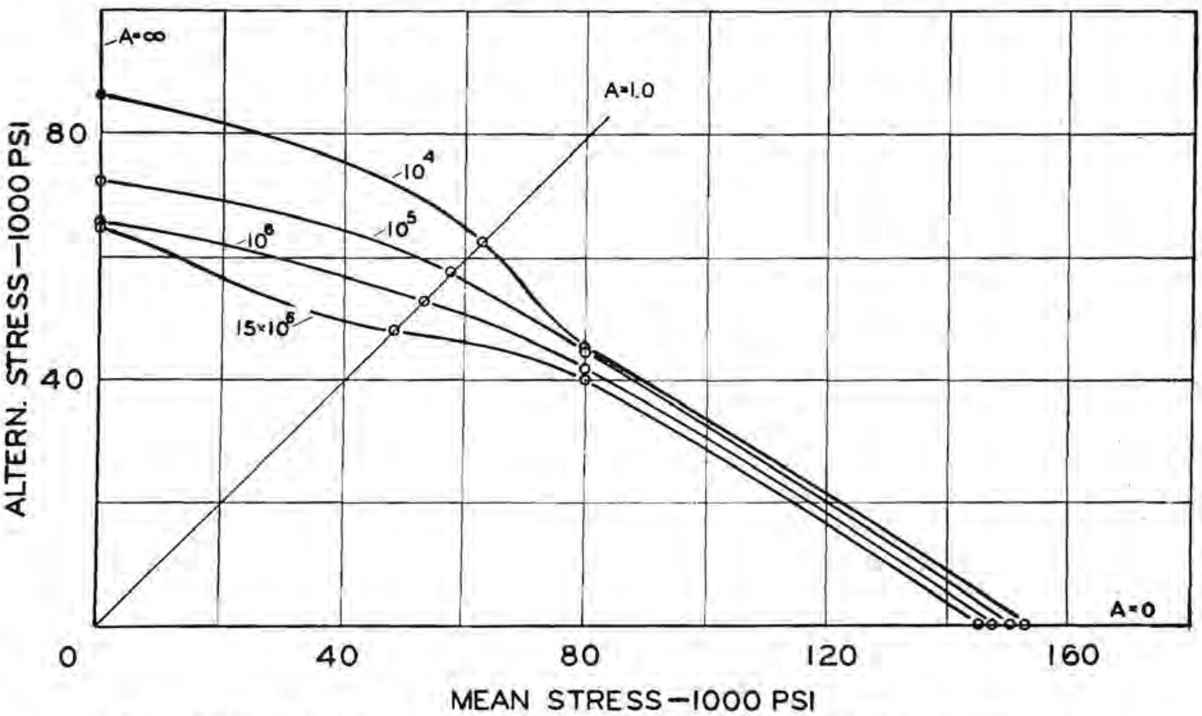


Figure 2.1222 (a). Fatigue properties of 4340 steel—600° F., unnotched; F_{tu}*=158,000 p. s. i*

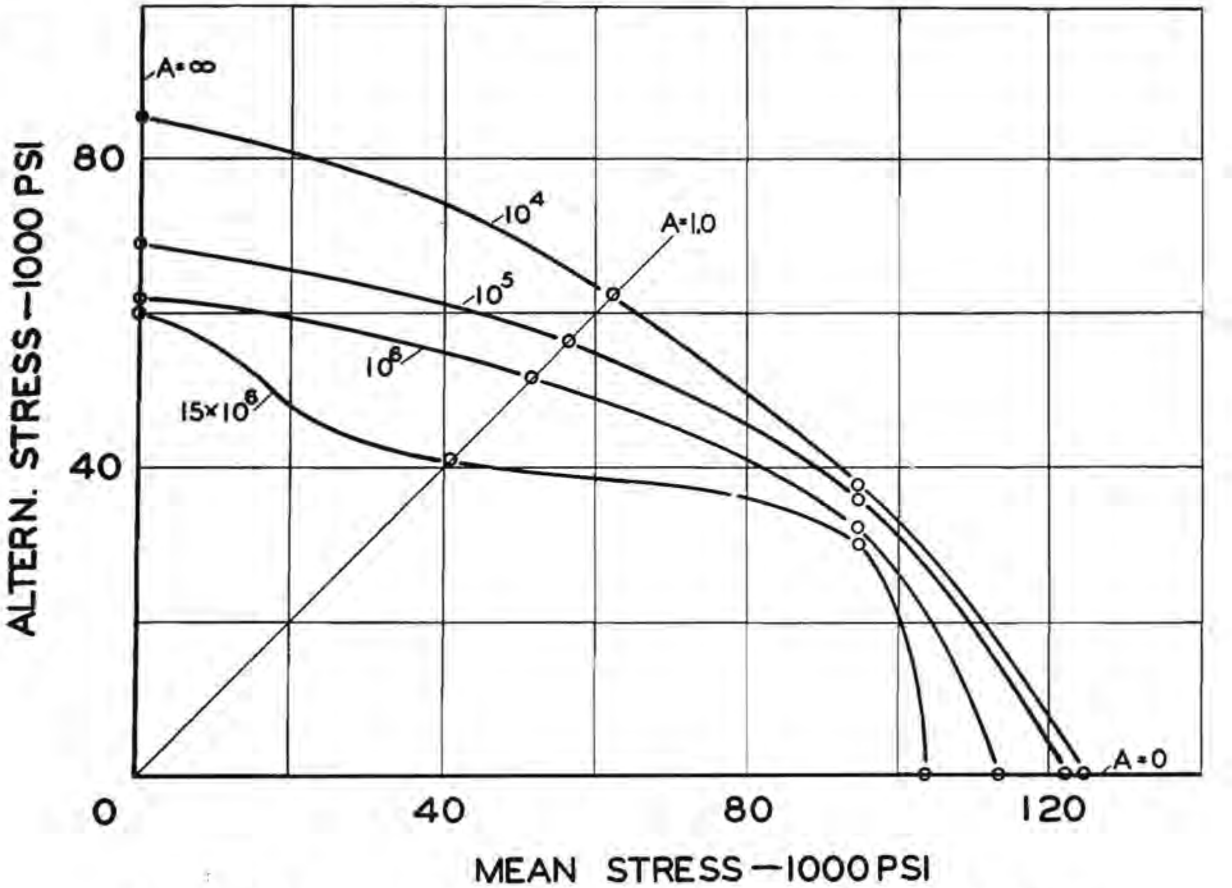


Figure 2.1222 (b). Fatigue properties of 4340 steel—800° F., unnotched; F_{tu}=158,000 p. s. i.

temperature in figure 2.112 (*a*). The effect of elevated temperatures on the notched fatigue strength and the notch sensitivity can be seen by comparing the fatigue strengths in figures 2.1222 (*d*) through (*f*) with the room-temperature notched fatigue strengths in figure 2.112 (*b*).

Although at room temperature the endurance limit for ferrous metals is considered to be 10 million cycles, this is not always true at elevated temperatures. At elevated temperatures the creep of the metal influences the fatigue life. Therefore, the time at temperature as well as the number of load cycles influences the failure, and it is possible that failures may occur beyond 10 million cycles.

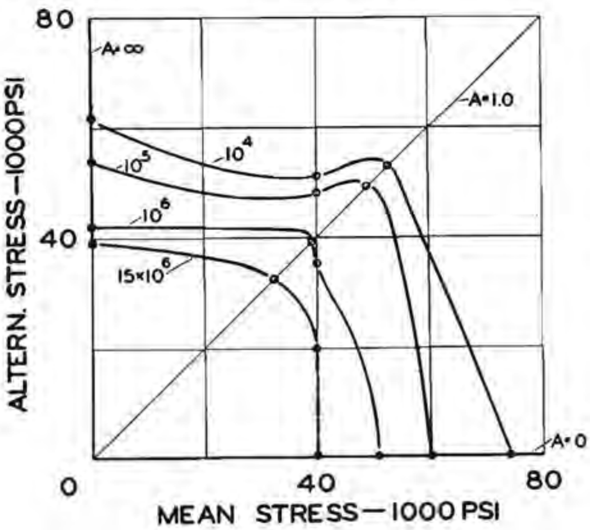


Figure 2.1222 (c). Fatigue properties of 4340 Steel—1,000° F., unnotched, F_{tu}=158,000 p. s. i.

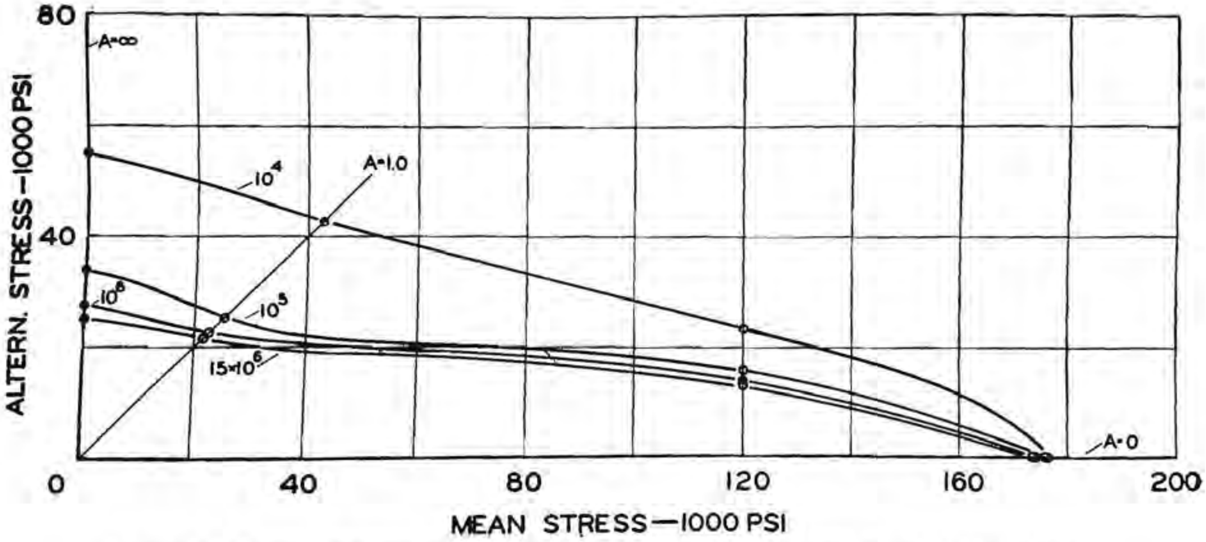


Figure 2.1222 (d). Fatigue properties of 4340 steel—600° F., notched; F_{tu}=158,000 p. s. i.

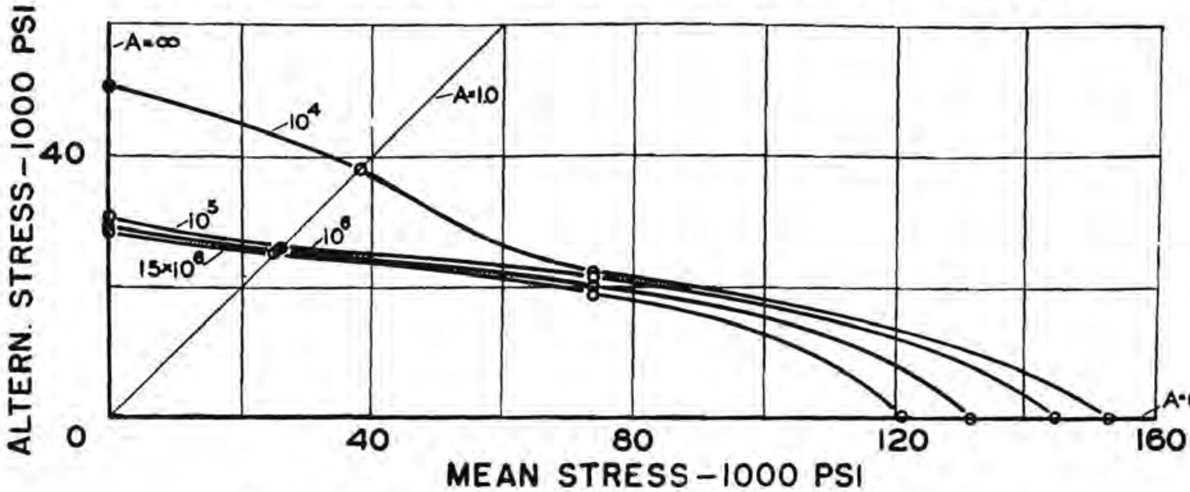


Figure 2.1222 (e). Fatigue properties of 4340 steel—800° F., notched; F_{tu}=158,000 p. s. i.

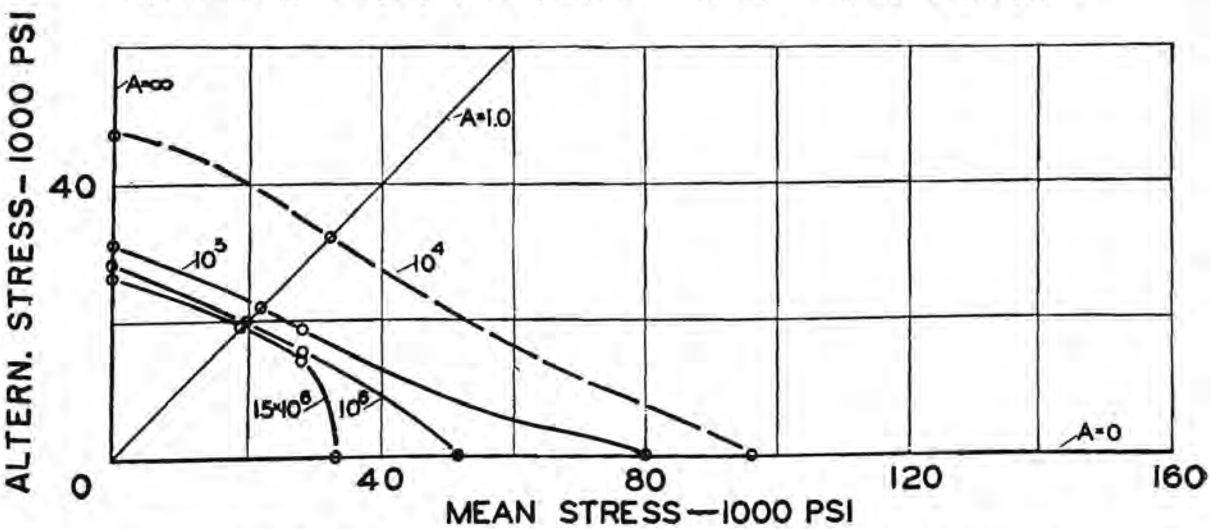


Figure 2.1222 (f). Fatigue properties of 4340 steel—1,000° F., notched; F_{tu}=158,000 p. s. i.

2.1223 *Creep and stress rupture properties.*

2.12231 *Short time creep.* Figures 2.12231 (*a*) through (*d*) present the effect of short times at temperature on the creep properties of SAE 1010 low carbon steel sheet. These tests were made as described in reference 3.12231. The percentage reduction in strength shown in the figures can be applied to the allowable tensile

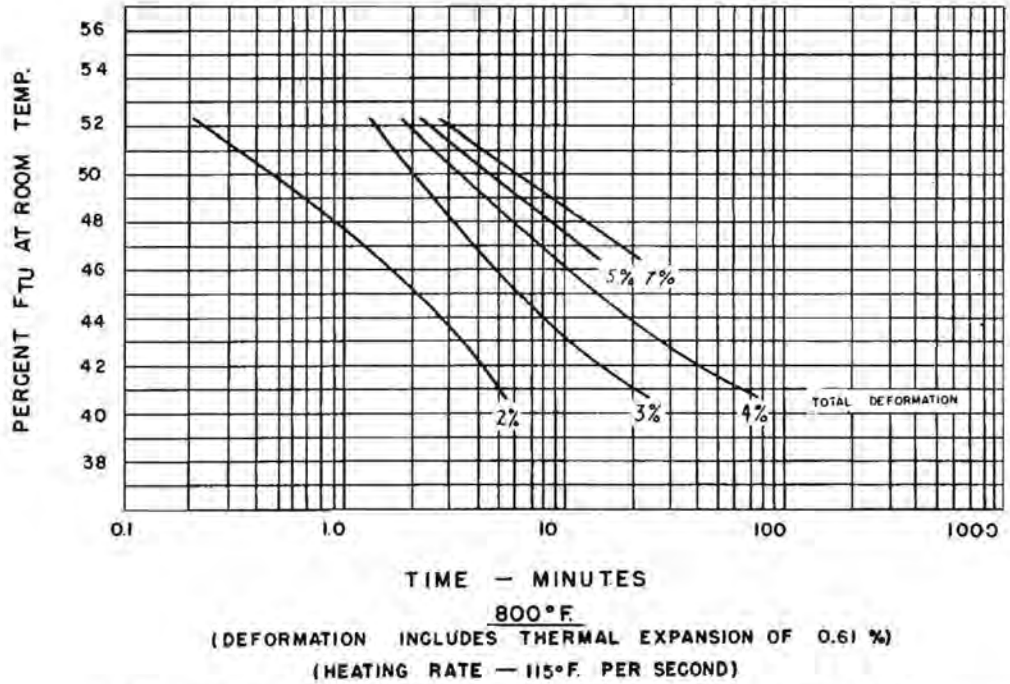


Figure 2.12231 (a). Short time creep curves for 1010 carbon steel sheet 800°F.

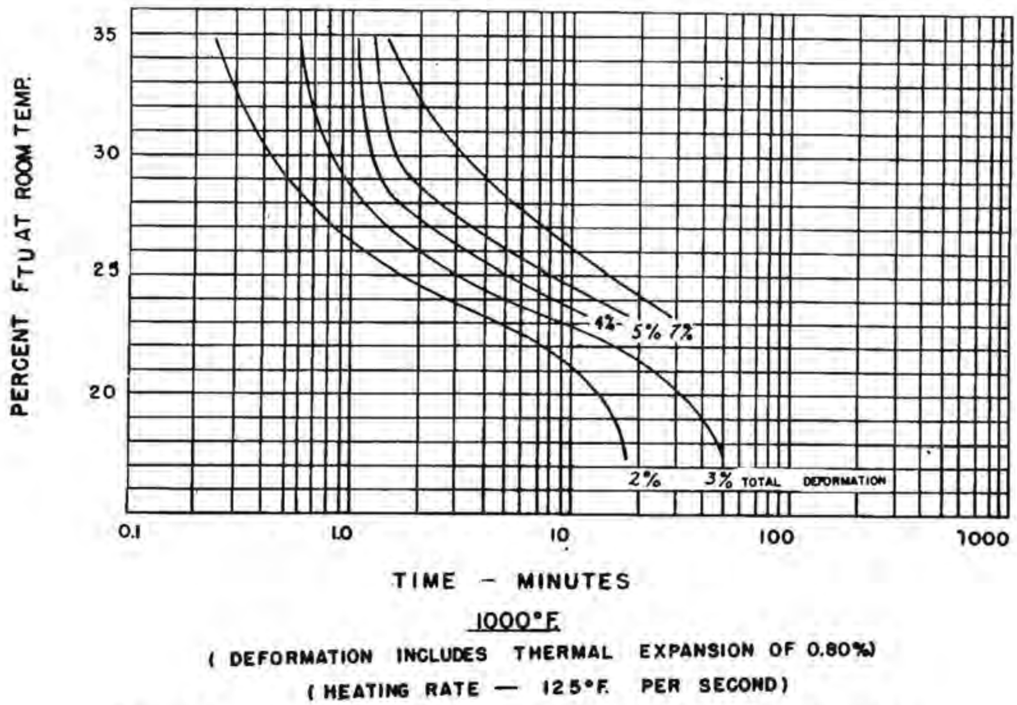


Figure 2.12231 (b). Short time creep curves for 1010 carbon steel sheet 1000°F.

and compressive strengths given in table 2.111 (*a*).

2.13 CRITERIA FOR DESIGN MECHANICAL PROPERTIES. The criteria for the design mechanical properties given on tables 2.111 (a), 2.111 (*b*), and 2.111 (*c*) are described in references 2.111 (*a*) and 2.111 (*b*).

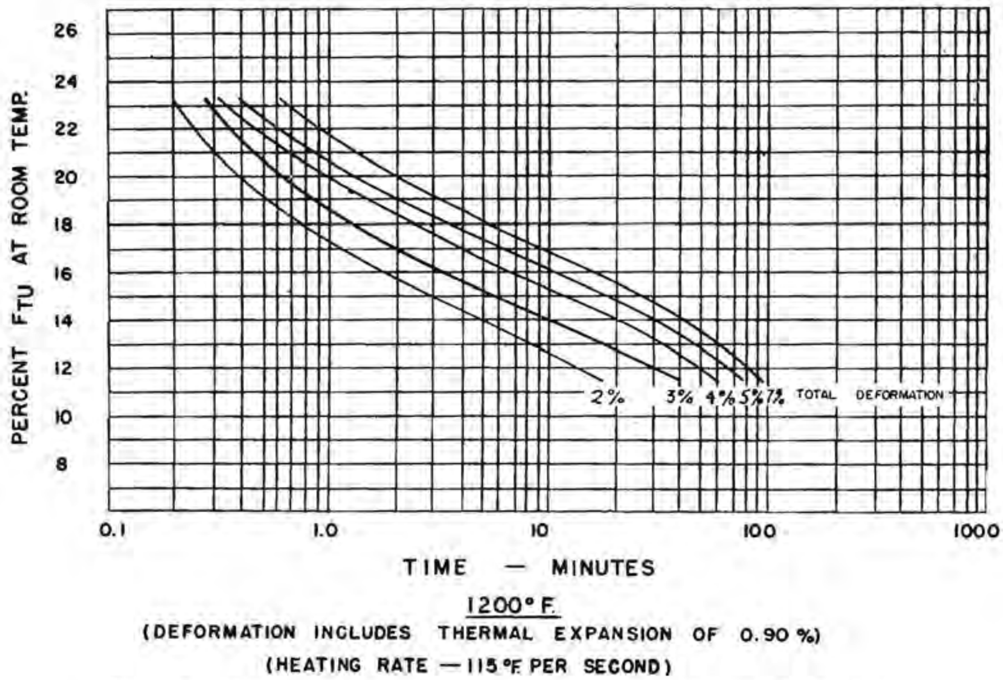


Figure 2.12231 (c). Short time creep curves for 1010 carbon steel sheet 1200°F.

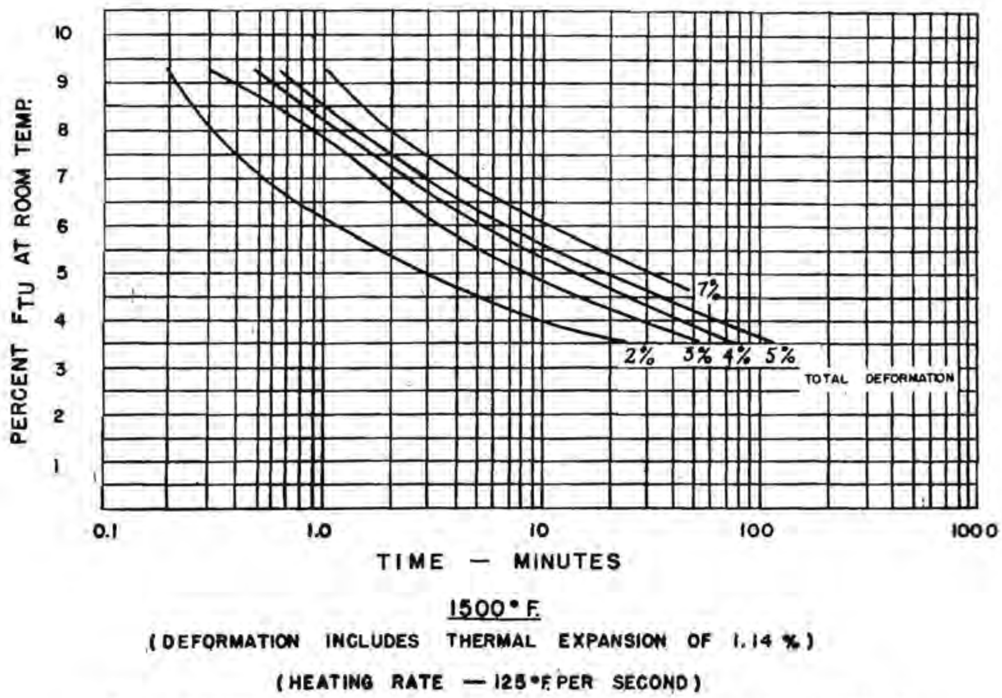


Figure 2.12231 (d). Short time creep curves for 1010 carbon steel sheet 1500°F.

2.2 Columns

2.21 PRIMARY FAILURE. The general formulas for primary instability are given in section 1.38. For convenience, these formulas are repeated in table 2.21 in simplified form applicable to round steel tubes. These formulas also can be used for columns having cross sections other than those of round tubes when local instability is not critical.

2.22 LOCAL FAILURE. Table 2.21 also contains notes concerning the local instability of round tubes. The local failure stresses for columns having cross sections of other shapes are given in the allowable stress curves of this chapter.

2.221 *Effects of welding.* The primary failure stress of a column having welded ends can be determined from the formulas of table 2.21 without regard for the effects of welding. These stresses, however, should not exceed a "cut-off" stress which accounts for the effects of welding on the local failure of the column. See section 2.612 for the effects of welding.

2.23 COLUMN STRESS CURVES. Curves of the allowable column stresses for various types of steel tubing are given in figure 2.23 (*a*), (*b*), and (*c*). The allowable stress is plotted against the effective slenderness ratio which is defined by the formula:

$$\frac{L'}{\rho}=\frac{L}{\rho\sqrt{c}} \quad \text{(2.231)}$$

Table 2.21. Column Formulas for Round Steel Tubes

Material	F_{ty}—ksi	F_{co}—ksi	Short columns		Transitional [b] L'/ρ	Long columns [a]	Local failure
			Column formula [a]	Basic equation			
1025	36	36	$36{,}000-1.172(L'/\rho)^2$	1.383	122	$286\times10^6/(L'/\rho)^2$	([c])
4130	[d] 75	79.5	$79{,}500-51.9(L'/\rho)^{1.5}$	1.384	91	$286\times10^6/(L'/\rho)^2$	([c])
Heat-treated[d] alloy steel	[e] 103	113	$113{,}000-11.15(L'/\rho)^2$	1.383	73	$286\times10^6/(L'\rho)^2$	([c])
Heat-treated[e] alloy steel	132	145	$145{,}000-18.36(L'/\rho)^2$	1.383	63	$286\times10^6/(L'/\rho)^2$	([c])
Heat-treated[e] alloy steel	163	179	$179{,}000-27.95(L'/\rho)^2$	1.383	56	$286\times10^6/(L'/\rho)^2$	([c])

[a] $L'/p=L/\rho\sqrt{c}$: L'/ρ shall not exceed 150 without specific authority from the procuring or certificating agency.

[b] Transitional L/ρ is that above which columns are "long" and below which they are "short." These are approximate values.

[c] Not necessary to investigate for local instability when $D/t<50$.

[d] This value is applicable when the material is furnished in condition *N* (MIL-T-6736) but the yield strength is reduced when normalized subsequent to welding to 60,000 p. s. i.

[e] See "Mechanical properties," tables 2.111.

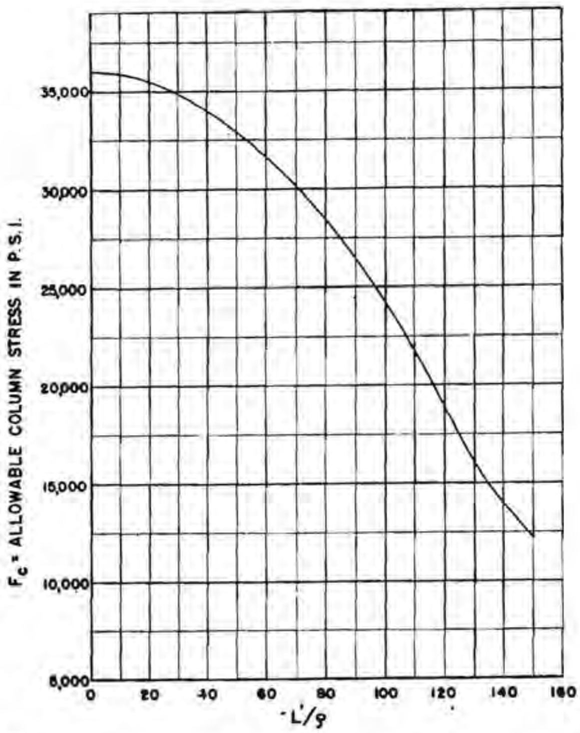


Figure 2.23 (a). *Allowable column stress for 1025 steel round tubing.*

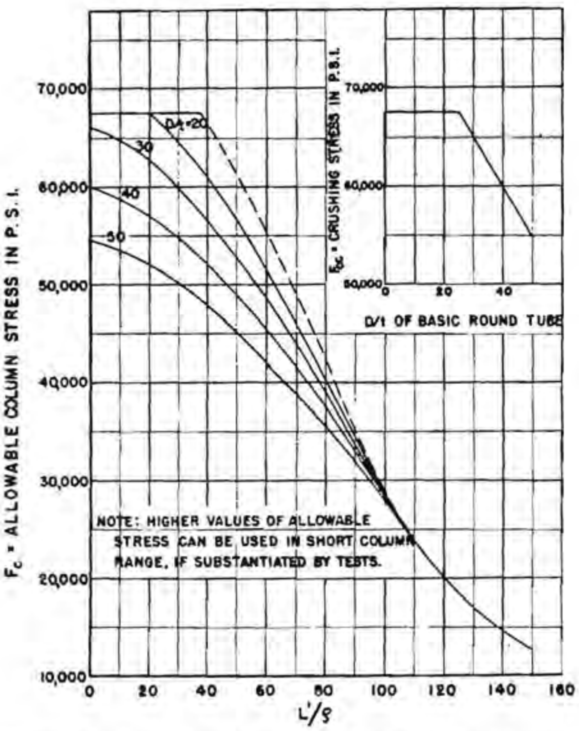


Figure 2.23 (b). *Allowable column and crushing stresses for chrome molybdenum streamline tubing* F_{ty}=75,000 *p. s. i.*

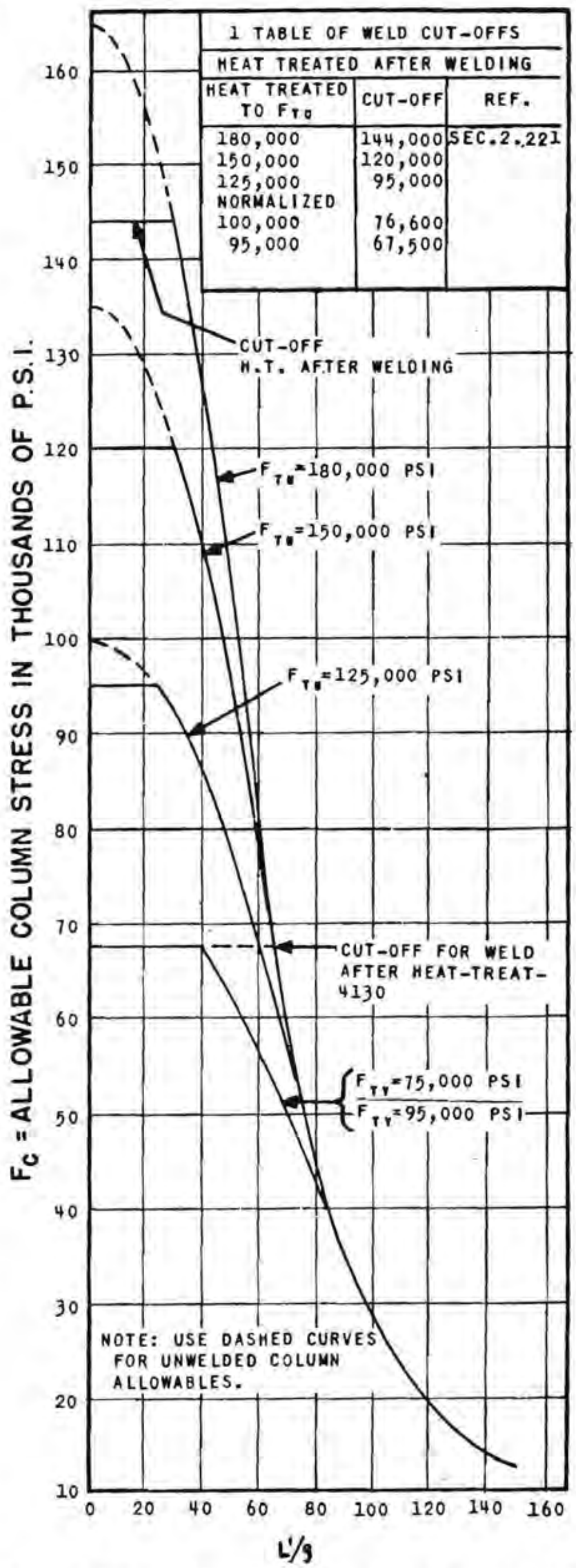


Figure 2.23 (c). *Allowable column stress for heat-treated alloy steel round tubing.*

2.24 COLUMN LOAD CURVES. The allowable column loads on round tubes versus length as given in reference 2.24 are satisfactory for general use.

2.3 Beams

2.31 GENERAL. See equation 1.323; section 1.525; and reference 1.71 for general information on stress analysis of beams.

2.32 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). For solid sections, it usually can be assumed that F_b equals the ultimate tensile stress. This assumption is conservative and higher values may be used if substantiated by test data.

2.321 *Round tubes.* For round tubes, the value of F_b will depend on the D/t ratio, as well as the ultimate tensile stress. Figure 2.321 gives the bending modulus of rupture for chrome molybdenum steel tubing.

2.322 *Unconventional cross sections.* Sections other than solid or tubular should be tested to determine the allowable bending stress.

2.33 BUILT-UP BEAMS. Built-up beams usually will fail due to local failures of the component parts. In welded steel tube beams, the allowable tensile stresses should be reduced properly for the effects of welding.

2.34 THIN-WEB BEAMS. The allowable stresses for thin-web beams will depend on the nature of the failure and are determined from the allowable stresses of the web in tension and of the flanges and stiffeners in compression.

2.4 Torsion

2.41 GENERAL. The torsion failure of steel tubes may be due to plastic failure of the metal, elastic instability of the walls, or to an intermediate condition. Pure shear failure usually will not occur within the range of wall thicknesses commonly used for aircraft tubing.

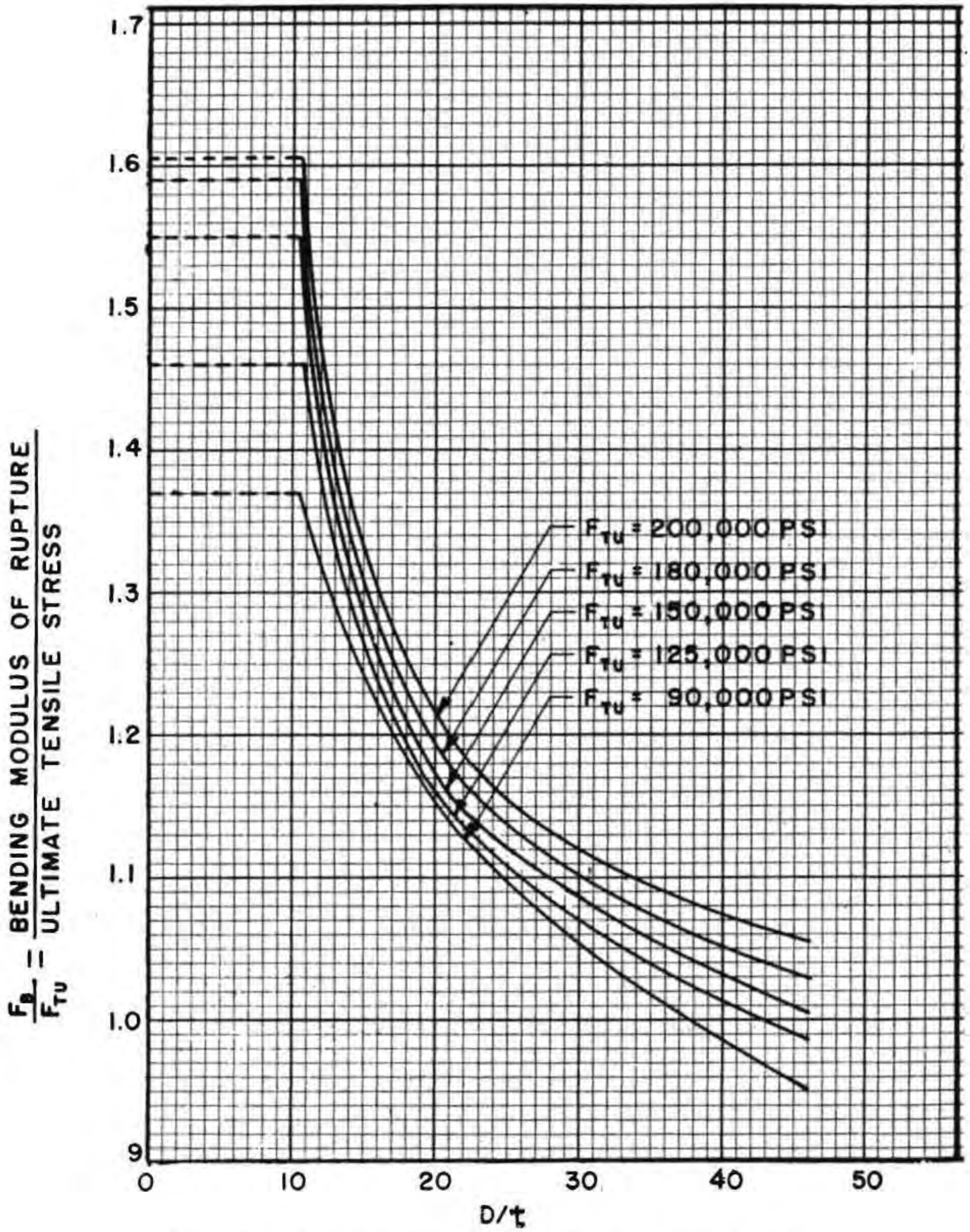


Figure 2.321. Bending modulus of rupture—chrome molybdenum steel tubing.

2.42 ALLOWABLE TORSIONAL SHEAR STRESSES. In the range of low value of $\frac{D}{t}$, no theoretical formula is applicable directly. The results of tests have been used to determine the empirical curves of figure 2.42 (*a*) and (*b*).

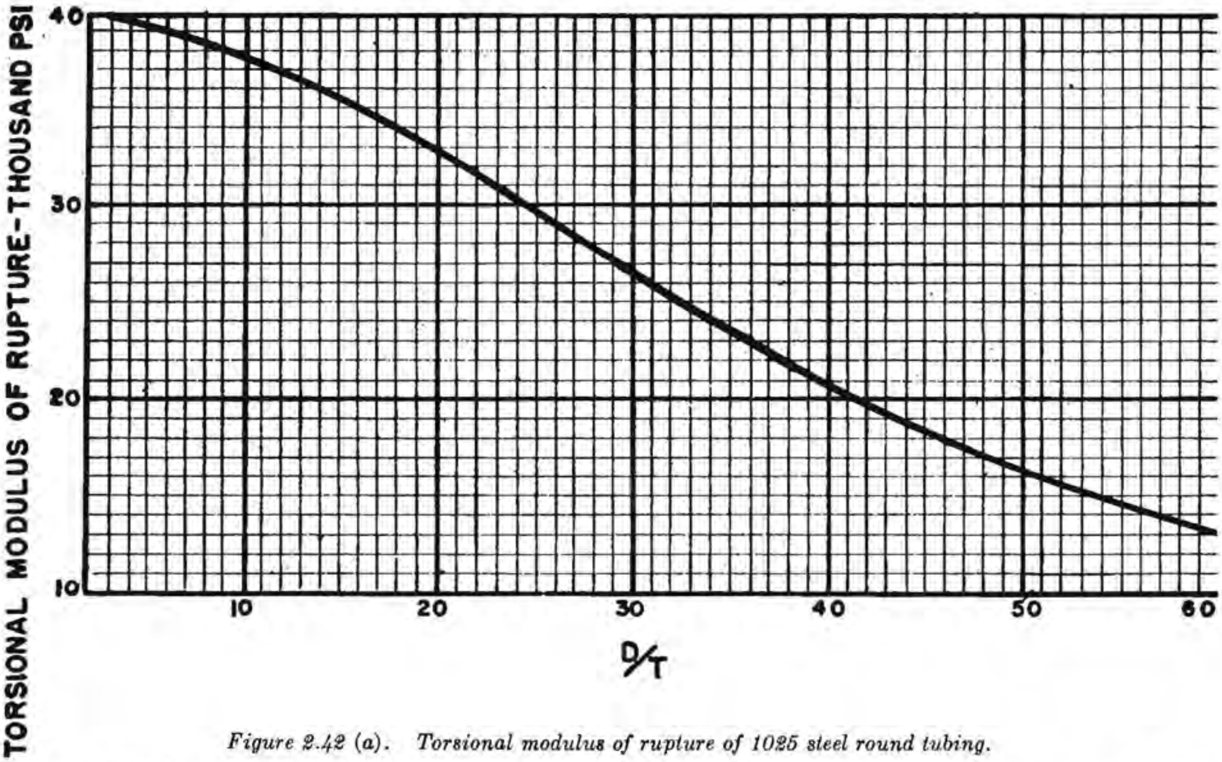


Figure 2.42 (a). Torsional modulus of rupture of 1025 steel round tubing.

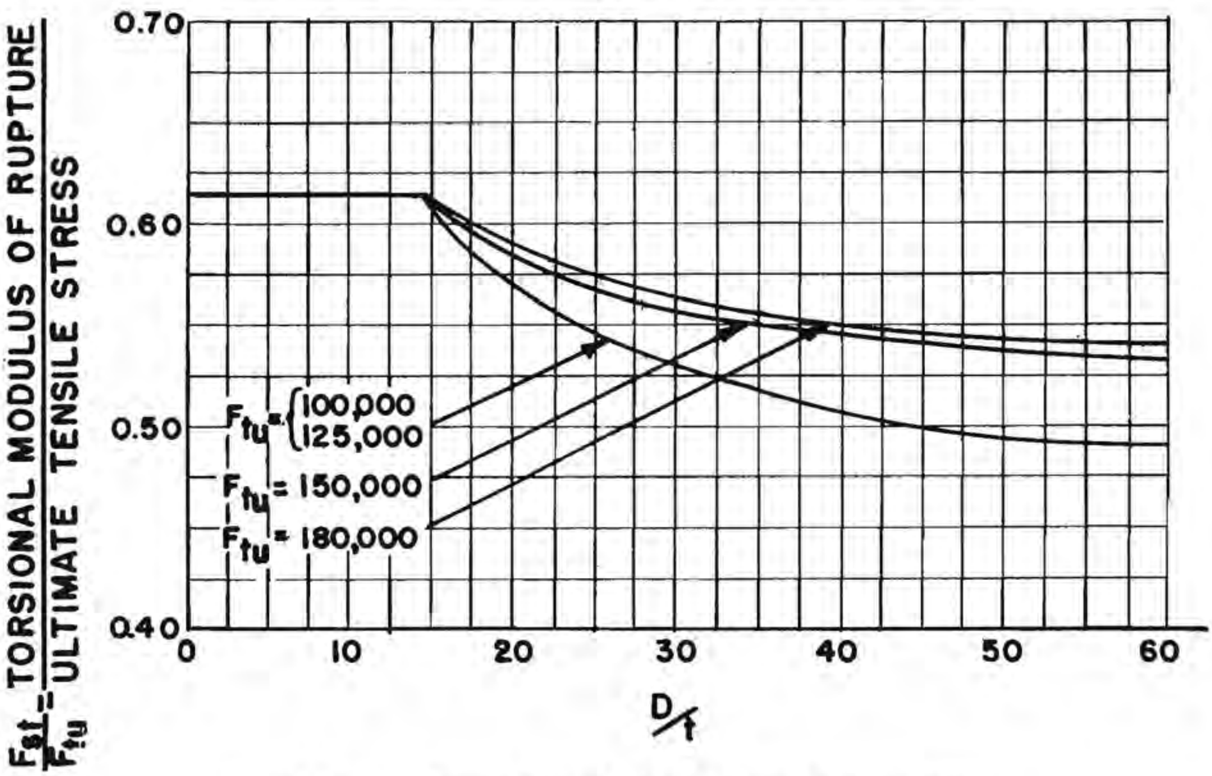


Figure 2.42 (b). Torsional modulus of rupture of round alloy steel tubing.

2.5 Combined loadings

2.51 ROUND TUBES IN BENDING AND COMPRESSION. The general theory of failure under combined loadings is given in section 1.535. In the case of combined bending and compression it is necessary to consider the effects of secondary bending; that is, bending produced by the axial load acting in conjunction with the lateral deflection of the column. In general, equation 1.5353, can be used in the following form for safe values:

$$\frac{f_b'}{F_b}+\frac{f_c}{F_{cy}}=1.0 \quad \text{(2.511)}$$

$$\text{M. S.}=\frac{1}{R_b+R_c}-1 \quad \text{(2.511a)}$$

Where

f_b'=Maximum bending stress including effects of secondary bending.

F_b=Bending modulus of rupture.

f_c=Axial compressive stress.

F_{cy}=Compressive yield stress.

In no case shall the axial compressive stress, f_c, exceed the allowable, F_c, for a simple column.

2.52 TUBES IN BENDING AND TORSION. Equation 1.5353, can be used in the following forms for safe values:

$$\left(\frac{f_b}{F_b}\right)^2+\left(\frac{f_s}{F_{st}}\right)^2=1.0 \quad \text{(2.521)}$$

Round tubes: $R_b^2+R_s^2=1.0$ (2.521a)

$$\text{M}=\frac{1}{\sqrt{(R_b)^2+(R_s)^2}}-1 \quad \text{(2.521b)}$$

Streamline tubes: $R_b+R_s=1.0$ (2.522)

$$\text{M. S.}=\frac{1}{R_b+R_s}-1 \quad \text{(2.522a)}$$

f_s=Shear stress.

F_{st}=Torsional modulus of rupture.

Higher values can be used if substantiated by adequate test data.

2.53 TUBES IN BENDING COMPRESSION, AND TORSION. The bending stresses should include the effects of secondary bending due to compression. The following empirical equation will serve as a working basis, pending a more thorough investigation of the subject.

$$\left(\frac{f_b'}{F_b}\right)^2+\left(\frac{f_s}{F_{st}}\right)^2=\left(1-\frac{f_c}{F_{cy}}\right)^2 \quad \text{(2.531)}$$

$$\text{M. S.}=\frac{1}{R_c+\sqrt{(R_b)^2+(R_s)^2}}-1 \quad \text{(2.531.}a\text{)}$$

In no case shall the axial compressive stress, f_c, exceed the allowable stress, F_c, for a simple column.

2.6 Joints and parts

2.61 JOINTS

2.611 *Riveted and bolted joints*

2.6111 *Allowable shear and tension stresses for bolts and pins.* The allowable shear stress for bolts and pins is given in table 2.6111 (*a*). The allowable tension stress for AN bolts as well as allowable design loads are also given therein. (Interaction curves for combined shear and tension loading on AN bolts are given on fig. 2.6111.) Shear and tension allowable for NAS internal wrenching bolts are specified in table 2.6111 (*b*).

Table 2.6111 (a). Shear and Tensile Strengths, Areas, and Moments of Inertia of Steel Bolts and Pins

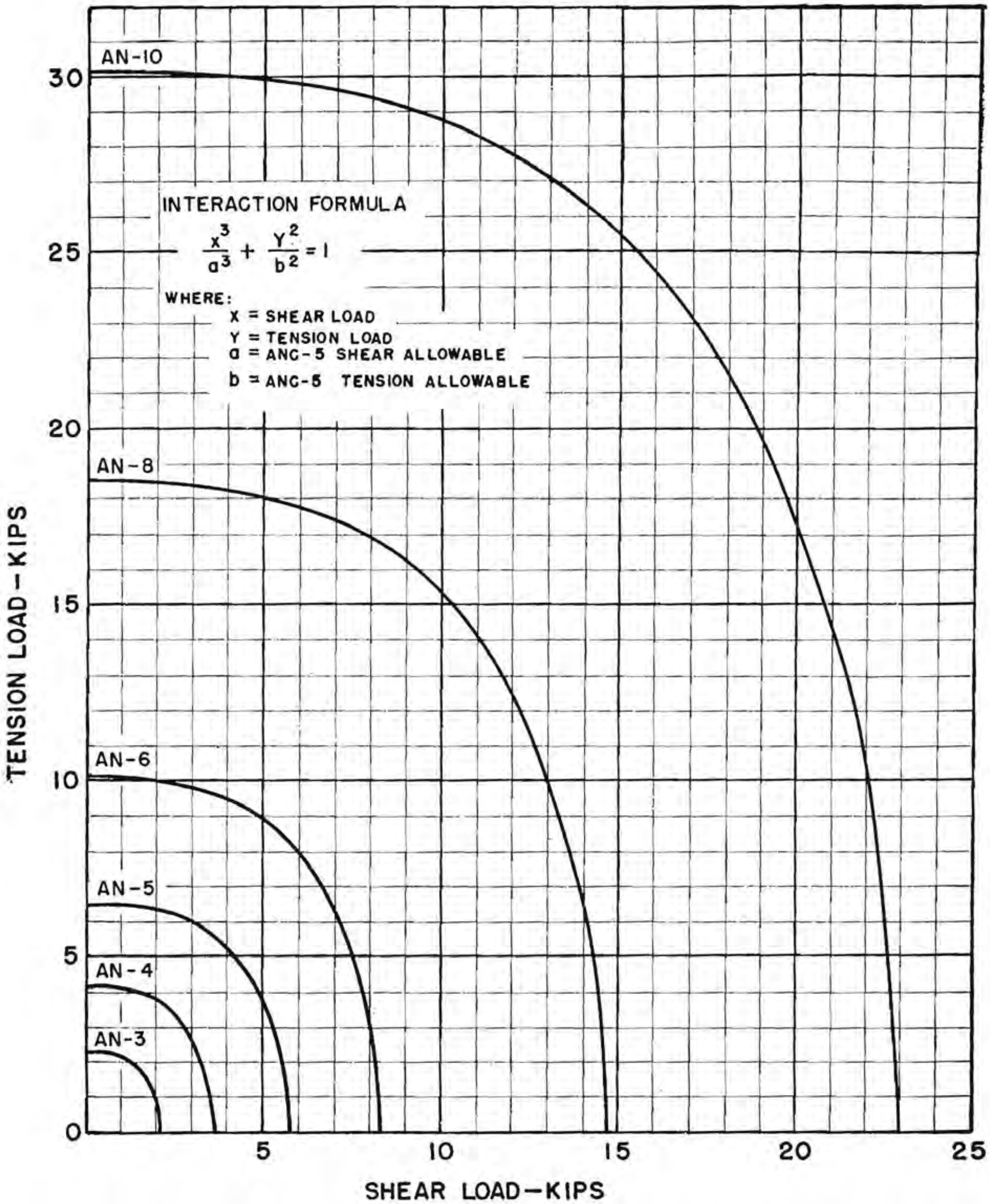
Material				Low-carbon steel	Heat-treated steel			AN standard bolt designation specification MIL-B-6812
Tensile strength, kips per square inch				55	100	125	125	
Shear strength, kips per square inch				35	65	75	75	
Size of pin or bolt	Machine screw size (No.)	Area of solid section (square inch)	Moment of inertia of solid (in.⁴)	Allowable single shear strength (pounds) at full diameter			Tension (pounds) (in thread)	
1/16		0.003068	0.00000075	107	199	230		
3/32		.006902	.00000379	242	449	518		
0.112	4	.009852	.00000772	345	640	739		
1/8		.012272	.00001198	430	798	920		
0.138	6	.014957	.00001781	523	972	1,122		
5/32		.01918	.00002926	671	1,247	1,438		
0.164	8	.02112	.00003549	739	1,372	1,584		
3/16		.02761	.00006066	966	1,794	2,070		
0.190	10	.02835	.00006399	992	1,842	2,126	2,210	AN-3.
0.216	12	.03664	.0001069	1,282	2,381	2,748		
7/32		.03758	.0001125	1,315	2,442	2,818		
1/4		.04908	.0001918	1,717	3,190	3,680	4,080	AN-4.
5/16		.07669	.0004682	2,684	4,984	5,750	6,500	AN-5.
3/8		.1105	.0009710	3,868	7,183	8,280	10,100	AN-6.
7/16		.1503	.001797	5,261	9,770	11,250	13,600	AN-7.
1/2		.1963	.003069	6,871	12,760	14,700	18,500	AN-8.
9/16		.2485	.004914	8,697	16,152	18,700	23,600	AN-9.
5/8		.3068	.007492	10,738	19,942	23,000	30,100	AN-10.
3/4		.4418	.01553	15,463	28,717	33,150	44,000	AN-12.
7/8		.6013	.02878	21,046	39,085	45,050	60,000	AN-14.
1		.7854	.04908	27,489	51,051	58,900	80,700	AN-16.
1 1/8						73,750	101,800	AN-18.
1 1/4						91,050	130,200	AN-20.

Table 2.6111 (b). Shear and Tensile Strengths of Internal Wrenching Bolts

Material		Heat-treated alloy steel (160,000-180,000 p. s. i.)		Material		Heat-treated alloy steel (160,000-180,000 p. s. i.)	
Specification		MIL-S-8503 and MIL-S-6049	AN-QQ-S-690 and MIL-S-5000	Specification		MIL-S-8503 and MIL-S-6049	AN-QQ-S-690 and MIL-S-5000
Size	Standard	Ultimate tensile strength (minimum pounds)	Double shear strength (minimum pounds)	Size	Standard	Ultimate tensile strength (minimum pounds)	Double shear strength (minimum pounds)
1/4	NAS 144	5,000	9,300	3/4	NAS 152	55,600	83,900
5/16	NAS 145	8,200	14,600	7/8	NAS 154	76,200	144,200
3/8	NAS 146	12,700	21,000	1	NAS 156	102,500	149,200
7/16	NAS 147	17,100	28,600	1 1/8	NAS 158	128,800	188,900
1/2	NAS 148	23,400	37,300	1 1/4	NAS 172	162,600	233,200
9/16	NAS 149	29,800	47,200	1 3/8	NAS 174	200,300	282,100
5/8	NAS 150	38,000	58,300	1 1/2	NAS 176	241,200	335,800

NOTES

Navy contractors must obtain approval of structural applications involving internal wrenching bolts prior to their use in design. Internal wrenching nuts or equivalent should be used in applications depended upon to develop the tabulated tensile loads.



NOTE. Curves not applicable where shear nuts are used. Curves are based on the results of combined load tests of bolts with nuts finger-tight.

Figure 2.6111. Combined shear and tension on AN steel bolts.

2.6112 *Allowable bearing stresses*

2.61121 *Joints having no motion.* The basic values of the allowable stresses for various steels may be found in tables 2.111 (*a*) and (*b*). These stresses are applicable only when the D/t ratio (diameter of rivet over thickness of sheet) is less than 5.5. When this ratio is equal to or greater than 5.5, the allowable bearing strengths must be substantiated by tests covering both yield and ultimate strengths of the joint. The unit bearing strength of steel sheets on bolts and pins is given in table 2.61121. Unit bearing strength on steel rivets may be obtained from table 3.6111 (*d*). These values are to be used only for the design of the connecting elements of rigid joints when there is no possibility of relative movement between the parts joined without deformation of these parts.

Table 2.61121. Unit Bearing Strengths of Sheets on Bolts and Pins, F_{br}=100,000 p. s. i., (Pounds)

Size of rivets	1/16	3/32	1/8	5/32	3/16	1/4	5/16	3/8	1/2	5/8	3/4	7/8	1
Plate sizes	Bearing strength of plate												
0.028	175	263	350	------	------	------	------	------	------	------	------	------	------
0.035	219	328	438	547	656	------	------	------	------	------	------	------	------
0.049	306	459	612	766	919	1, 225	------	------	------	------	------	------	------
0.058	362	544	725	906	1, 087	1, 450	1, 812	------	------	------	------	------	------
0.065	406	609	812	1, 016	1, 219	1, 625	2, 031	------	------	------	------	------	------
0.072	450	675	900	1, 125	1, 350	1, 800	2, 250	2, 700	------	------	------	------	------
0.083	519	778	1, 038	1, 297	1, 556	2, 075	2, 594	3, 112	------	------	------	------	------
0.095	594	891	1, 188	1, 484	1, 781	2, 375	2, 969	3, 563	4, 750	------	------	------	------
0.120	750	1, 125	1, 500	1, 875	2, 250	3, 000	3, 750	4, 500	6, 000	7, 500	------	------	------
3/16	1, 172	1, 758	2, 344	2, 930	3, 516	4, 688	5, 859	7, 031	9, 375	11, 719	14, 063	16, 406	18, 750
1/4	1, 563	2, 344	3, 125	3, 906	4, 688	6, 250	7, 813	9, 375	12, 500	15, 625	18, 750	21, 875	25, 000

2.61122 *Joints having motion.* For joints having motion the allowable bearing stresses for the various steels to be found in tables 2.111 (*a*) and (*b*) are to be reduced by dividing by the factors of safety specified in table 2.61122 (*a*) (designated as "bearing factors"), or are to be used in accordance with table 2.61122 (*b*).

Table 2.61122 (a).[a] *Bearing Factors for Plain*[b] *Bearings*[c] *Having no or Infrequent*[d] *Relative Rotation Under Design Loads*

Infrequent relative rotation under design loads	Shock [e] or vibration	Factor [f]
None [g]	None	1.0
Yes	do	2.0
None [g]	Yes	2.0
Yes	do	2.5

[a] The factors given in this table are applicable to other materials as well as to steel.

[b] Plain bearings as against antifriction bearings (ball bearings, etc.).

[c] Bearings are distinguished from fittings, in general, in that a bearing is a pin-jointed fitting which permits relative movement between the parts joined other than that due to deformation of the parts under load.

[d] Infrequent rotation is considered to be rotation of less than 100 revolutions per hour. For rotations in the order of 100 revolutions per hour and up, see table 2.61122 (*b*).

[e] Shock is considered to occur in such structures as landing gears, gun mounts, hoisting, towing and mooring connections.

[f] It should be noted that the fitting factors specified by the procuring or certifying agency also apply to the bearing surfaces. If the applicable fitting factor exceeds the bearing factor, the former shall be used in lieu of (not in addition to) the latter, and vice versa.

[g] No relative rotation under design loads; to illustrate, some landing gear joints have no relative rotation under landing loads, although they have relative rotation during retraction.

2.6113 *Blind rivets.* Table 2.6113 contains ultimate and yield allowable single shear strengths for protruding and flush-head monel blind rivets in corrosion-resistant sheet. These strengths are applicable only when the grip lengths and rivet-hole tolerances are as recommended by the rivet manufacturer.

The strength values were established from test data obtained from tests of specimens having edge distances e/D equal to or greater than 2.0. Where e/D values less than 2.0 are used, tests to substantiate yield and ultimate strengths must be made. Ultimate strength values of protruding and flush blind rivets were obtained from the average failing load of test specimens divided by 1.15. Yield strength values were obtained from average yield load test data wherein the yield load is defined as the load at which the following permanent set across the joint is developed:

(*a*) 0.005 inches up to and including 3/16-inch diameter rivets.

(*b*) 2.5 percent of the rivet diameter for rivet sizes larger than 3/16-inch diameter.

Blind rivets should not be used in applications where appreciable tensile loads on the rivets will exist. Reference should be made to the requirements of the applicable procuring or certificating agency relative to the use of blind rivets.

Table 2.61122 (b). Ultimate Bearing Stress for Plain Lubricated Bearings Having Frequent Relative Motion

Type of bearing	Shock or vibration	Lubrication	Pounds per square inch
Free fits, frequent relative movement approximately 100 revolutions per hour (or equivalent) per flight.	None	Grease	15,000
Free fits, subject to very frequent relative movement, with 3 or more bearings in line, sealed or protected.	do	do	12,000
Free fits, subject to very frequent relative movement, with 3 or more bearings in line, unprotected from dirt.	do	Light grease	8,000
Free fits, subject to very frequent relative movement, with 3 or more bearings in line, unprotected from dirt.	Yes	Oil	1,500

Table 2.6113. Ultimate and Yield Strengths for Blind Monel Cherry Rivets in Corrosion Resistant Sheet (Pounds)[a]

ULTIMATE STRENGTHS

Installation	Protruding head				100° double dimpled [b]			100° machine countersunk [c]		
Rivet type	CR563				CR562					
Sheet material	18-8 (½ Hard)									
t [d] \ D	⅛	5/32	3/16	¼	⅛	5/32	3/16	⅛	5/32	3/16
0.008	150	180	220	------	280	315	------	------	------	------
0.012	230	300	350	------	320	455	*610	------	------	------
0.020	380	510	600	------	400	620	680	------	------	------
0.025	460	620	750	1, 090	450	705	830	------	------	------
0.032	550	770	960	1, 380	510	810	980	*420	------	------
0.040	620	900	1, 160	1, 660	570	900	1, 135	*420	*535	------
0.051	660	1, 000	1, 340	1, 960	------	------	------	510	550	------
0.064	680	1, 090	1, 460	2, 190	------	------	------	620	735	------
0.072	700	1, 140	1, 500	2, 270	------	------	------	625	840	*1, 020
0.081	710	1, 180	1, 520	2, 340	------	------	------	625	940	1, 110
0.091	720	1, 190	1, 540	2, 410	------	------	------	------	1, 030	1, 200
0.102	------	------	1, 560	2, 480	------	------	------	------	1, 100	1, 420
0.125	------	------	1, 580	2, 590	------	------	------	------	1, 160	1, 470
Rivet shear strength [e]	775	1, 190	1, 720	3, 110	775	1, 190	1, 720	------	------	------

YIELD STRENGTHS

t \ D	⅛	5/32	3/16	¼	⅛	5/32	3/16	⅛	5/32	3/16
0.008	150	180	220	------	230	235	------	------	------	------
0.012	230	300	350	------	320	362	320	------	------	------
0.020	380	510	600	------	400	620	650	------	------	------
0.025	460	620	750	1, 090	450	705	808	------	------	------
0.032	550	770	920	1, 380	510	810	980	80	------	------
0.040	620	850	1, 035	1, 660	570	900	1, 135	291	283	------
0.051	660	930	1, 162	1, 938	------	------	------	446	455	------
0.064	680	1, 010	1, 282	2, 135	------	------	------	541	610	412
0.072	700	1, 048	1, 334	2, 235	------	------	------	572	690	604
0.081	710	1, 081	1, 391	2, 323	------	------	------	593	776	811
0.091	720	1, 110	1, 450	2, 410	------	------	------	608	869	991
0.102	------	------	1, 507	2, 480	------	------	------	621	903	1, 150
0.125	------	------	1, 580	2, 590	------	------	------	644	920	1, 334

[a] The strength values listed are based on the results of laboratory tests conducted under optimum conditions and should be used with caution.

[b] In dimpled installations allowables shall not be obtained by extrapolation for skin gages other than those shown.

[c] In the case of machine countersunk joints where the lower sheet is thinner than the upper, the bearing allowable for the lower sheet-rivet combination should be computed.

[d] Sheet gage is that of the thinnest sheet for protruding head and double dimpled installations. For machine countersunk installations sheet gage is that of the upper sheet.

[e] Rivet shear strengths computed using nominal hole size and the following values for rivet and pin materials.

Rivet—R monel, annealed—F_{su}=55,000 p. s. i.
Pin—R monel, cold worked—F_{su}=65,000 p. s. i.

Yield values of the sheet-rivet combinations marked thus (*) are less than ⅔ of the indicated ultimate values. Other sheet-rivet combinations may be used subject to specific approval of the procuring or certificating agency.

2.6114 *Hollow-end rivets.* If hollow-end rivets with solid cross sections for a portion of the length (AN 450) are used, the strength of these rivets may be taken equal to the strength of solid rivets of the same material, provided that the bottom of the cavity is at least 25 percent of the rivet diameter from the plane of shear, as measured toward the hollow end, and further provided that they are used in locations where they will not be subjected to appreciable tensile stresses.

2.6115 *High shear rivets.* The allowable shear load for "Hi-Shear" rivets (NAS-177, 178, and 179) is the same as that specified for the standard aircraft bolts heat-treated to 125,000 p. s. i. and given in table 2.6111 (*a*). Allowable single shear strengths for annealed 18-8 steel rivets are given in table 2.6115.

Table 2.6115.[a] Allowable Ultimate Single Shear Strengths 18-8.[b] Corrosion Resistant Steel Rivets (Pounds)

Diameter	Load
1/8	973
5/32	2150
3/16	3880
5/16	6140
3/8	8800

[a] Material as described in Specification MIL-S-7720 annealed before driving.
[b] The values given in the table above were computed using an allowable shear stress of 75,000 p. s. i. and nominal hole sizes from table 2.6111 (*c*).

2.6116 *Lockbolts.* Allowable loads for lockbolts are given in section 3.6116.

2.612 *Welded joints.* Whenever possible, joints to be welded should be so designed that the welds will be loaded in shear.

2.6121 *Fusion welds.—arc and gas.* In the design of welded joints the strength of both the weld metal and the adjacent parent metal must be considered. The allowable strength for the adjacent parent metal is given in paragraph 2.61211 and the allowable strength for the weld metal is given in paragraph 2.61212. The weld metal section shall be analyzed on the basis of its loading, allowables, dimensions, and geometry.

2.61211 *Effect on adjacent parent metal when fusion (arc or gas) processes are employed.* Joints—welded after heat treatment: The allowable stresses near the weld are given in tables 2.61211 (*a*) and (*b*).

Materials heat treated after welding: The allowable stresses in the parent metal near a welded joint may equal the allowable stress for the material in the heat treated condition as given in tables 2.111 (*a*) through (*d*).

Table 2.61211 (a). Allowable Ultimate Tensile Stresses Near Fusion Welds in 4130, 4140, 4340, or 8630 Steels

[Section thickness 1/4 inch or less]

Type of joint	Welded after heat treated or normalized after weld (p. s. i.)
Tapered joints of 30° or less [a]	90,000
All others	80,000

[a] Gussets or plate inserts considered 0° taper with center line.

Table 2.61211 (b). Allowable Bending Modulus of Rupture Near Fusion Welds in 4130, 4140, 4340, or 8630 Steels

Type of weld	Welded after heat treated or normalized after weld
Tapered welds of 30° or less.[a]	F_b, fig. 2.321 for $F_{tu}=90{,}000$ p. s. i.
All others	0.9 of the values of F_b from fig. 2.321 for $F_{tu}=90{,}000$ p. s. i.

[a] Gussets or plate inserts considered 0° taper with center line.

2.61212 *Allowable strength–weld metal.* Allowable weld metal strengths are shown in table 2.61212. The use of MIL-E-8697 electrodes which respond to quench-and-temper heat treatment shall be subject to the specific approval of the qualifying or certificating agency. Design allowable stresses for the weld metal are based on 85 percent of the respective minimum tensile ultimate test values.

Table 2.61212. Strengths of Welded Joints

Material	Heat treatment subsequent to welding	Welding rod or electrode	F_{su}	F_{tu}
Carbon and alloy steels	None	MIL-R-5632, class 1 MIL-E-6843, classes E-6010 and E-6013.	32,000	51,000
Alloy steel	None	MIL-R-5632, class 2	43,000	72,000
Alloy steels	Stress relieved	MIL-E-8697, classes E-10013, E-10016, E-10015.	50,000	85,000
Do	do	MIL-E-8697, class E-12015, class E-12016	60,000	100,000
Do	Quench and temper	MIL-E-8697, class HT125	63,000	105,000
Do	do	MIL-E-8697, class HT150	75,000	125,000
Do	do	MIL-E-8697, class HT180	90,000	150,000

2.61213 *Welded cluster.* In welded structure where seven or more members converge, the allowable stress shall be determined by dividing the normal allowable stress by a materials factor of 1.5, unless the joint is reinforced in a manner for which specific authority has been obtained from the certificating or procuring agency. A tube that is continuous through a joint should be assumed as two members.

2.61214 *Flash welds.* The tensile ultimate allowable stresses and bending allowable modulus of rupture for flash welds are given in tables 2.61214 (*a*) and (*b*). A higher efficiency may be permitted in special cases by the applicable procuring or certificating agency upon approval of the manufacturers process specification.

Table 2.61214 (a). Allowable Ultimate Tensile Stresses for Flash Welds in Steel Tubing

Normalized tubing—not heat treated (including normalizing) after welding	Heat treated tubing welded after heat treatment	Tubing heat treated (including normalizing) after welding	
		F_{tu} of unwelded material in heat treated condition	Allowable ultimate tensile stress of welds
1.0 F_{tu} (based on F_{tu} of normalized tubing).	1.0 F_{tu} (based on F_{tu} of normalized tubing).	<100,000 100,000 to 150,000 >150,000	0.9 F_{tu} 0.6 F_{tu}+30,000 0.8 F_{tu}

Table 2.61214 (b). Allowable Bending Modulus of Rupture for Flash Welds in Steel Tubing

Normalized tubing—not heat treated (including normalizing) after welding	Heat-treated tubing welded after heat treatment	Tubing heat treated (including normalizing) after welding	
F_b from fig. 2.321 using values of F_{tu} listed below			
1.0 F_{tu} for normalized tubing	1.0 F_{tu} for normalized tubing	F_{tu} of unwelded material in heat treated condition. <100,000 100,000 to 150,000 >150,000	Ultimate tensile stress for use in fig. 2.321 for F_b of welded area. 0.9 F_{tu} 0.6 F_{tu}+30,000 0.8 F_{tu}

2.6122 *Spot welding.* The permissibility of the use of spot welding on structural steel parts is governed by the requirements of the procuring or certificating agency. Maximum design shear strengths for spot welds in various steel alloys are given in table 2.6122 (*a*). Table 2.6122 (*b*) gives the minimum allowable edge distance for the spot welds in steel alloys; these values may be reduced for nonstructural applications, or for applications not depended upon to develop full tabulated weld strength.

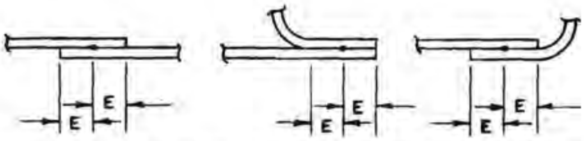
Table 2.6122 (a). Spotweld Maximum Design Shear Strengths for Uncoated Steels [a] and Nickel Alloys

Nominal thickness of thinner sheet	Material ultimate tensile strength (150 *ksi* and above)	Material ultimate tensile strength (70 *ksi* to 150 *ksi*)	Material ultimate tensile strength (below 70 *ksi*)
Inch	*Pounds*	*Pounds*	*Pounds*
0.006	70	57	----------
0.008	120	85	70
0.010	165	127	92
0.012	220	155	120
0.014	270	198	142
0.016	320	235	170
0.018	390	270	198
0.020	425	310	225
0.025	580	425	320
0.030	750	565	403
0.032	835	623	453
0.040	1, 168	850	650
0.042	1, 275	920	712
0.050	1, 700	1, 205	955
0.055	1, 982	1, 308	1, 130
0.060	2, 265	1, 558	1, 310
0.064	2, 550	1, 727	1, 437
0.070	2, 975	1, 982	1, 628
0.072	3, 048	2, 067	1, 685
0.080	3, 540	2, 405	1, 960
0.090	4, 100	2, 810	2, 290
0.094	4, 288	2, 975	2, 443
0.100	4, 575	3, 200	2, 645
0.109	4, 955	3, 540	2, 938
0.114	5, 177	3, 695	3, 084
0.125	5, 665	4, 052	3, 440

[a] Refers to plain carbon steels containing not more than 0.20 percent carbon and to austenitic steels.

The thickness ratio of the thickest sheet to the thinnest outer sheet in the combination should not exceed 3 to 1.

Table 2.6122 (b). Minimum Edge Distances for Spot-welded Joints [a]



Thickness thinner sheet [b]	Edge distance E	Thickness thinner sheet [b]	Edge distance E
Inch	*Inch*	*Inch*	*Inch*
0.016	3/16	0.060	11/32
0.020	3/16	0.070	3/8
0.025	7/32	0.080	13/32
0.030	1/4	0.090	7/16
0.035	1/4	0.100	7/16
0.040	9/32	0.120	1/2
0.045	5/16	0.125	9/16
0.050	5/16	0.157	5/8

[a] For edge distances less than those specified above, appropriate reductions in the spotweld allowable loads shall be made. These reductions shall be subjected to approval by the procuring or certificating agency.

[b] Intermediate gages will conform to the requirement for the next thinner gage shown.

2.61221 *Reduction in tensile strength of parent metal due to spotwelding.* In applications of spotwelding where ribs, intercostals, or doublers are attached to sheet splices or at other points on the sheet panels, the allowable ultimate tensile strengths of type 302 stainless steel spotwelded sheet shall be determined by multiplying the ultimate tensile sheet strength obtained from table 2.111 (*d*) by the appropriate efficiency factor shown on figures 2.61221 (*a*), (*b*), and (*c*). The minimum values of the basic sheet efficiency in tension should not be considered applicable to cases of seam welds.

Allowable ultimate tensile strengths for spotwelded sheet gages of less than 0.012 inch shall be established on the basis of tests acceptable to the procuring or certificating agency.

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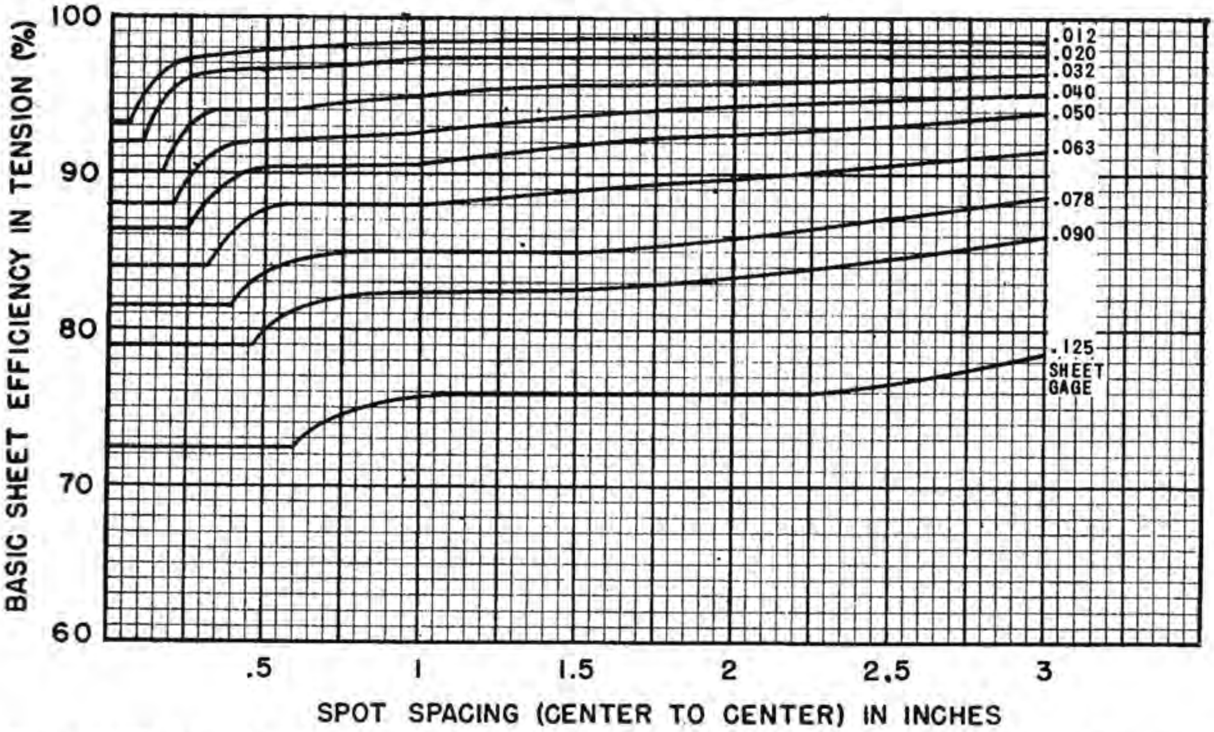


Figure 2.61221 (a). Efficiency of the parent metal in tension for spotwelded 302–A, 347–A, and 302–¼H corrosion resisting steel.

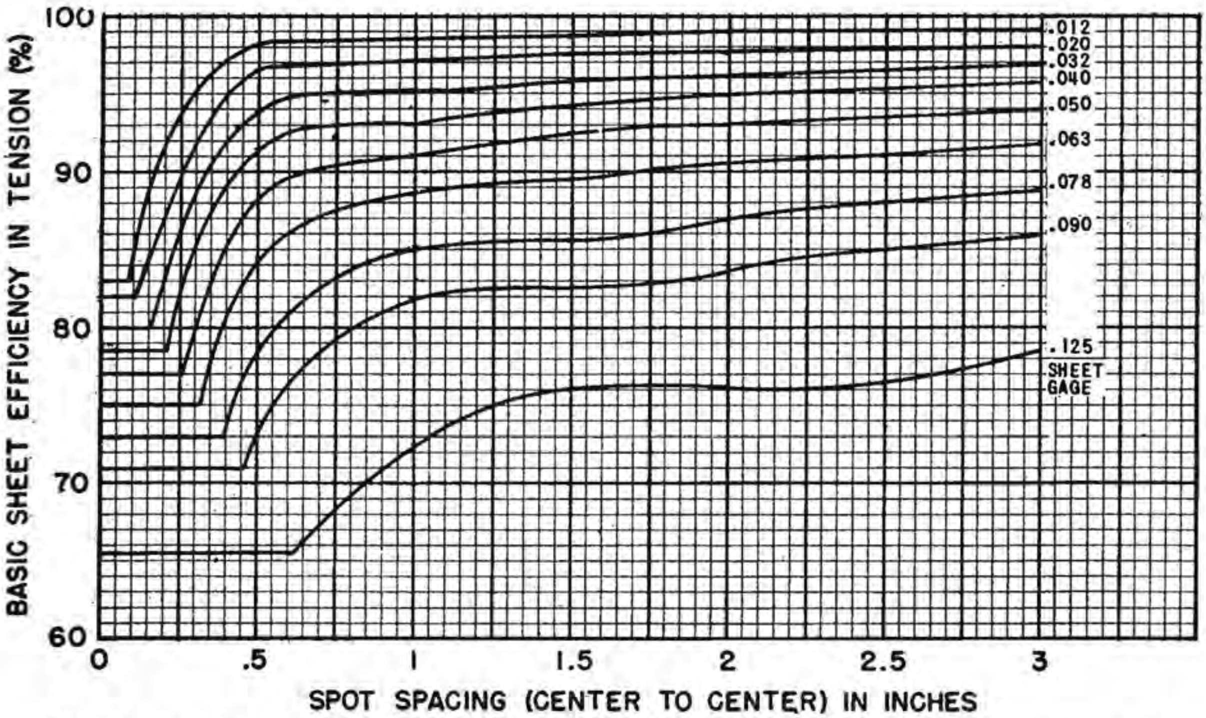


Figure 2.61221 (b). Efficiency of the parent metal in tension for spotwelded 302–½H corrosion resisting steel.

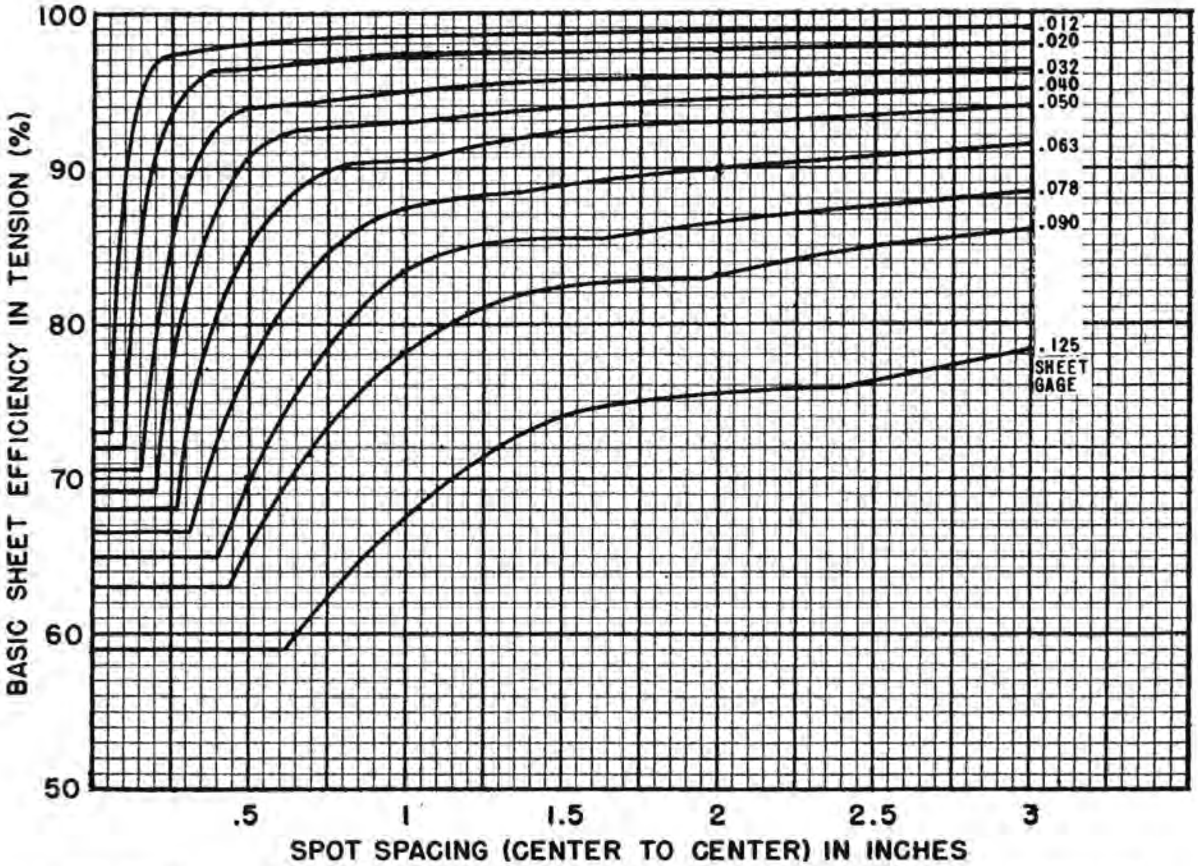


Figure 2.61221 (c). Efficiency of the parent metal in tension for spotwelded 302–H corrosion resisting steel.

2.613 *Adhesive bonded joints.* Joints may in some instances be made to advantage by the use of an adhesive suitable for the structural bonding of metals. This subject is discussed in Reference 2.613.

2.614 *Brazed joints of steel and high melting-point nonferrous alloys.* Brazing is defined as a weld wherein coalescence is produced by heating to suitable temperatures above 800° F. and by using a nonferrous filler metal having a melting point below that of the base metal. The filler metal is distributed through the joint by capillary attraction.

The effect of the brazing process upon the strength of the parent or base metal shall be considered in the structural design. Where copper furnace brazing or silver 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) reheat-treated during or after brazing.	Mechanical properties corresponding to heat-treatment performed.

2.6141 *Copper brazing.* The allowable shear stress for design shall be 15,000 p. s. i., for all conditions of heat treatment. Higher values may be allowed upon approval by the procuring or certificating agency.

2.6142 *Silver brazing.* The allowable shear stress for design shall be 15,000 p. s. i., provided that clearances or gaps between parts to be brazed do not exceed 0.010 inch. Silver brazed areas should not be subjected to temperatures exceeding 900° F. Acceptable brazing alloys, with the exception of class 3, are listed in Federal Specification QQ–S–561d. Deviation from these specified allowable values or alloys may be allowed upon approval of the procuring or certificating agency.

2.62 PARTS

2.621 *Bursting strength of tubes.* The bursting strength of corrosion-resistant steel tubing may be calculated for normal temperature conditions from the formulas found in Specifications MIL–T–8504 (annealed tubing) or MIL–T–6845 (¼ hard tubing).

2.622 *Antifriction bearings.* For antifriction bearings the following load should not exceed the manufacturer's non-Brinell rating:

(*a*) For Air Forces and civil use—limit load.

(*b*) For Navy use—the design yield load.

Needle and tapered-roller antifriction bearings may be used subject to the procuring or certificating agency's approval.

2.623 *Antifriction bearing control pulleys.* Information on the strengths of antifriction bearing control pulleys is given in table 2.623. Two requirements for pulley design must be met:

1. Pulley strength as limited by the resultant load on the pulley bearing.
2. Pulley strength as limited by the pressure on the pulley sheave produced by a cable under load.

For an ultimate factor of safety of 1.5 or less, the ultimate strength is not critical and the pulleys need be checked for the design yield strengths only.

2.624 *Cable and cable connections*

2.6241 *Cable connections.* The following efficiencies shall be used in the design of cable connections.

(*a*)[1] For swaged connections manufactured in accordance with specifications approved by the applicable procuring or certificating agency, 100 percent.

(*b*)[2] Five tuck and Nicopress[3] type splice—flexible cable, 75 percent.

(*c*) Shackle and ferrule loop terminal—hard wire, 85 percent.

(*d*) Wrapped and soldered splice—19-strand wire, 90 percent.

[1] Terminals used for swaged connections shall be designed to preclude failure at a load less than the minimum cable strength given in table 2.6242.

[2] Nicopress type splice may be used in place of the five-tuck splice in secondary applications in which the cable diameter is ⅜ inch or smaller.

[3] For civil aircraft Nicopress terminals may be used up to full rated load of the cable when the cable is looped around a thimble.

Table 2.623. Static Yield Strengths for Control Pulleys

AN pulley [a]	Resultant radial strength	Cable strengths for cable diameter indicated (see notes [b] [c])							Thrust on flange
		1/16	3/32	1/8	5/32	3/16	7/32	1/4	
219–2	480	307	460						37
219–3	480	307	460						37
219–4	920	307	460						37
219–5	920	307	460						37
220–1	500			830	1,040	1,250			87
220–2	1,680			830	1,040	1,250			87
220–3	2,500			830	1,040	1,250			87
220–4	2,500			830	1,040	1,250			87
221–1	2,800					2,620	3,060	3,500	125
221–2	4,900					2,620	3,060	3,500	125
221–3	7,000					2,620	3,060	3,500	125

[a] For material, see Specification MIL–P–7034.

[b] The cable strengths are the limiting values for the pulley sheaves and not for the cables themselves. However, for a factor of safety of 1.5 or less, cable strength is not critical if MIL–C–1511 specification cable is used. Cable breaking strength may be found in table 2.6242.

[c] Limit endurance strengths: The endurance limit is 50,000 revolutions and approximately (7,850×sheave diameter) reversals when using the largest cable size specified above, 90° angle of wrap, and a resultant radial strength equal to ¼ the resultant radial strength given in the table above.

2.6242 *Strength and load-deformation data for aircraft cable.* Information on strengths of steel cable is given in table 2.6242 and load-deformation data in figure 2.6242. The data in figure 2.6242 represent average curves obtained from a series of tensile tests on long lengths of prestretched 7 by 19 aircraft cable (prestretched 60 percent of rated strength), corrosion-resistant MIL–C–5424 and carbon steel MIL–C–1511. It will be noted that three stages or ranges are shown; (3) a slack range which is not eliminated by the prestretching, (1) a short transitional elastic range and (2) an apparent true elastic range. For design purposes (1) and (2) are also shown as a combined elastic range. The data are mainly for the corrosion-resistant cable but can be converted to those for carbon steel by multiplying by the ratio of modulus of elasticity for the corrosion-resistant steel to that of carbon steel. This relation is also shown by the comparative data on the chart for tests on both types of cables of 3/16 inch diameter. It is realized that the load-deformation characteristics of cable may be affected by several variables, yet it is believed that the data in figure 2.6242 are satisfactory.

Table 2.6242. Strength of Steel Cable [a]

Diameter in inches		1 x 7 and 1 x 19		7 x 7, 7 x 19, and 6 x 19 (IWRC)			
		Nonflexible, carbon		Flexible, carbon		Flexible, corrosion resisting	
		MIL-C-6940		MIL-C-1511		MIL-C-5424	
		Weight in pounds per 100 feet	Breaking strength (pounds)	Weight in pounds per 100 feet	Breaking strength (pounds)	Weight in pounds per 100 feet	Breaking strength (pounds)
0. 031	1/32	0. 30	185				110
0. 047	3/64	0. 52	375				
0. 062	1/16	0. 78	500	0. 75	480	0. 75	480
0. 078	5/64	1. 21	800				
0. 094	3/32	1. 75	1, 200	1. 53	920	1. 53	920
0. 109	7/64	2. 60	1, 600				
0. 125	1/8	3. 50	2, 100	2. 90	2, 000	2. 90	1, 760
0. 156	5/32	5. 50	3, 300	4. 50	2, 800	4. 44	2, 400
0. 187	3/16	7. 70	4, 700	6. 50	4, 200	6. 47	3, 700
0. 218	7/32	10. 00	6, 300	8. 60	5, 600	9. 50	5, 000
0. 250	1/4	13. 50	8, 200	11. 00	7, 000	12. 00	6, 400
0. 281	9/32			13. 90	8, 000	14. 56	7, 800
0. 312	5/16	20. 65	12, 500	17. 30	9, 800	17. 71	9, 000
0. 344	11/32			20. 70	12, 500		
0. 375	3/8			24. 30	14, 400	26. 45	12, 000
0. 437	7/16			35. 60	17, 600	35. 60	16, 300
0. 500	1/2			45. 80	22, 800	45. 80	22, 800
0. 562	9/16			59. 00	28, 500	59. 00	28, 500
0. 625	5/8			71. 50	35, 000	71. 50	35, 000
0. 750	3/4			105. 20	49, 600	105. 20	49, 600
0. 875	7/8			143. 00	66, 500	143. 00	66, 500
1. 000	1			187. 00	85, 400	187. 00	85, 400
1. 125	1 1/8			240. 00	106, 400	240. 00	106, 400
1. 250	1 1/4			290. 00	129, 400	290. 00	129, 400
1. 375	1 3/8			330. 00	153, 600	330. 00	153, 600
1. 500	1 1/2			420. 00	180, 500	420. 00	180, 500

[a] The strength values listed were obtained from straight tension tests and do not include the effects of wrapped ends.

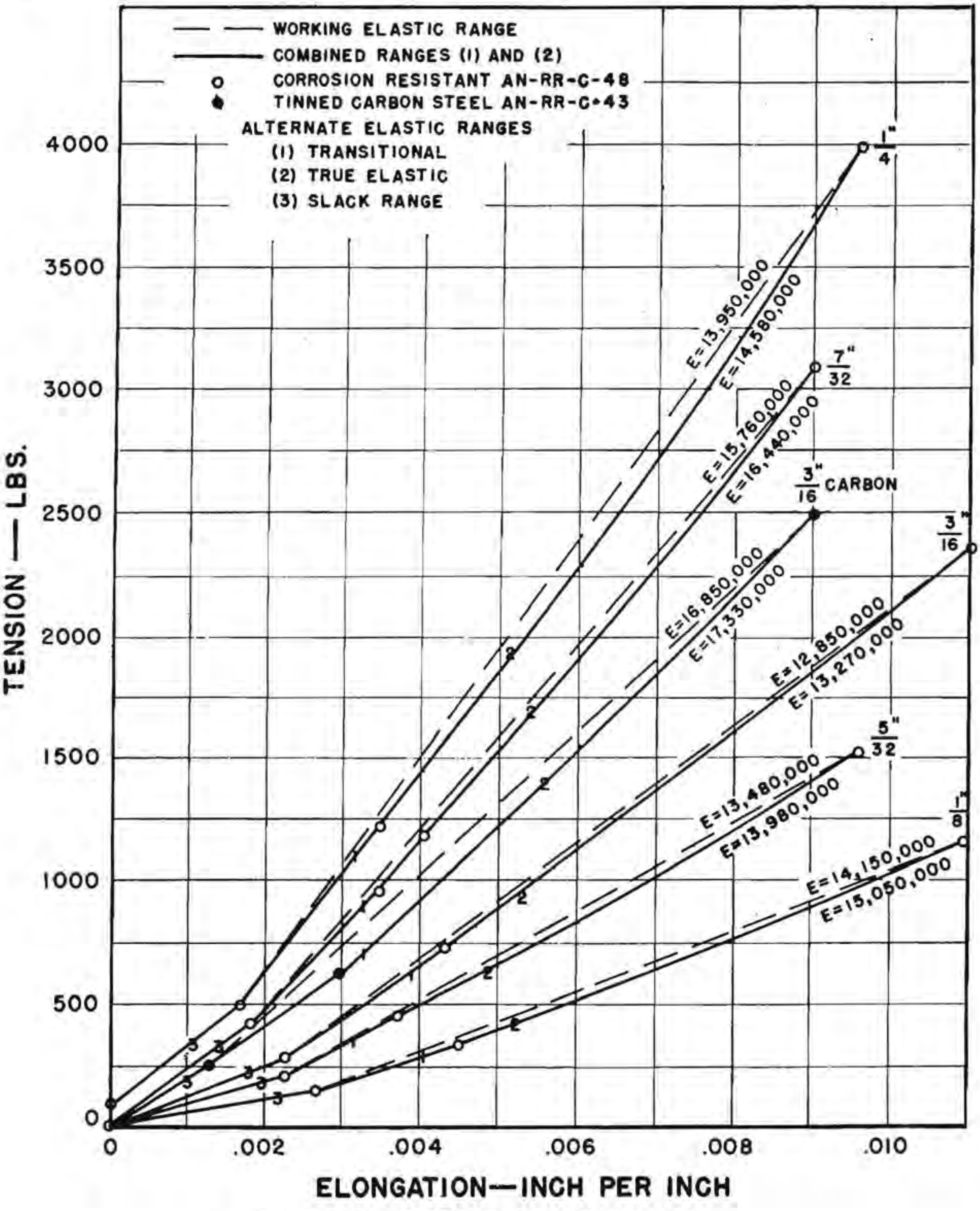


Figure 2.6242. Load-deformation data for steel cable.

CHAPTER 3

ALUMINUM ALLOYS

3.1 General Properties

3.11 NORMAL (ROOM) TEMPERATURE PROPERTIES

3.111 *Design Mechanical Properties.* The design mechanical properties at normal (room) temperature for various aluminum alloys are listed in tables 3.111 (*a*) through (*o*). The values in the A column are those values which the material producer has indicated to be the minimum he expects for the given material. The only strength values considered "guaranteed" values are those F_{tu} and F_{ty} values appearing in column marked "A" and which have been published by the material producer for the grain direction accepted for commercial guarantees. The remaining values in the "A" column are "derived" values; that is, sufficient tests have been made to ascertain that if a given material meets the specified ultimate tensile strength values, that material will have compression, shear and bearing strengths (F_{cy}, F_{su}, F_{bru}, and F_{bry}) equal to or exceeding the values listed.

Values appearing in the B columns are values which materials producers have indicated will be met or exceeded by 90 percent of the material supplied by them. This assurance is based on actual results of tensile tests conducted over a period of time on sufficient "heats" or "runs" of material to show statistically that 90 percent of the material provided manufacturers will meet or exceed the listed F_{tu} and F_{ty} values. As in the case of other properties "derived" from F_{tu} appearing in the A columns, other properties appearing in the B column are derived values equal to or exceeding the values listed. It should be noted that the A and B values for tensile and yield strengths and elongation are based on a statistical analysis of production sampling data obtained from specimens taken in accordance with procurement specification requirements and may not be representative of the entire cross section of the piece in material appreciably thicker than the test specimen. Use of the values in the B column is permitted in design by the Air Force, Navy, and Civil Aeronautics Administration, subject to certain limitations as specified by each agency; refer-

Conversion Table for Old and New Aluminum Alloy Designations

Old	*New*	*Old*	*New*	*Old*	*New*
2S	1100	24S	2024	75S	7075
3S	3003	A51S	6151	Alclad XA78S	Alclad X7178
Alclad 14S	Alclad 2014	52S	5052	XA78S	X7178
14S	2014	A54S	5154	X79S	X7079
17S	2017	56S	5056	K183	5083
A17S	2117	XC56S	X5356	K186	5086
F18S	2618	61S	6061	R301	Alclad 2014
Alclad 24S	Alclad 2024	62S	6062		
		Alclad 75S	Alclad 7075		

ence should be made to the specific requirements of the applicable agency before using the B values in design. Tensile and compressive strengths have been given in both the longitudinal and transverse directions (parallel and perpendicular, respectively, to the direction of rolling, extruding, etc.) wherever data are available. Shear and bearing strengths have been given without reference to direction and may be assumed to be the same in all directions. 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.

In designing parts to be machined from large extrusions of 75S heat-treated and aged alloy, cognizance should be taken of the fact that, because of mass effect in quenching the properties at the center of large sections of this alloy are generally lower than those midway between the center and the surface from which location the inspection samples are taken. The values given in table 3.111 (*h*) for longitudinal tensile and compressive properties and for shear and bearing strengths are based on the properties at the center for thicknesses less than 1.500 inches and on the properties midway between center and surface for thicknesses 1.500 and over. These values are representative of the average property of the complete cross section. The values for transverse tensile and compressive properties are based on the properties at the center of the extrusion for all section thicknesses. Statistical studies have shown that the typical longitudinal properties at the center for 75S–T6 extrusions of section thickness 1.500–4.000 inches and up to 32 square inches area will be 94 and 91 percent, respectively, of the tensile ultimate and yield strength properties midway between the surface and center. It was further established that applying these ratios to the pertinent guaranteed minimums tabulated in table 3.111 (*h*) gave values most of which were equal to or below the minimum center properties of all the large section extrusions tested. The above reductions should be applied when designing a part machined from large extrusions of 75S–T6 alloy except when the part is heat treated and aged after rough machining.

Table 3.111 (*n*) contains values of percent elongation for the materials in table 3.111 (*a*) through (*l*). These values have been taken directly from the applicable specifications or material producers' data. It will be noted that several values are given for some of the individual columns of certain tables. In these cases the values are listed in table 3.111 (*o*) and correspond for the most part to portions of the overall thickness range for the column as it appears in the corresponding table 3.111 (*a*) through (*l*). An exception is table 3.111 (*k*) where the multiple values arise from a difference in test method; the higher value is for the elongation (in 2 inches) of a specimen from a separately forged test bar or prolongation of the forging, whereas the lower value is the elongation (in 2 inches) of a specimen cut from the forging.

The effects of notches, holes, and stress raisers on the static properties of aluminum alloys (see sec. 1.526) are given in references 3.111 (*a*) through (*e*).

Most of the transverse properties given in this document apply to the longer of the two transverse dimensions (width). There is some evidence that the short transverse properties, measured at right angles to the above usual direction of testing transverse properties, are lower than the tabulated values. Sufficient data are not available, however, to permit the establishment of a quantitative relationship between the transverse properties in these two directions. Where sections are to be critically loaded in the transverse direction through the shorter direction (thickness), the need for correction of design allowables shall be evaluated in a manner acceptable to the procuring or certificating agency.

Some short tranverse properties of 75S plate and of 14S and 75S hand forged stock, however, have been established and are tabulated in tables 3.111 (*d*), (*e*), and (*j*), respectively.

In the definition of bearing values, D is equal to the hole diameter and e is equal to the edge distance measured from the hole center to the edge of the material in the direction of applied stress. Values of $e/D=2.0$ shall be used for larger values of edge distance; values of e/D less than 1.5 shall be substantiated by adequate tests subject to the approval of the procuring or certificating agency. For values of edge distance between $e/D=2/0$ and $e/D=1.5$, linear interpolation may be employed.

Table 3.111 (a). Design Mechanical Properties of Bare 24S Sheet and Plate (Kips per Square Inch)

Type		Sheet and plate																	Coiled sheet	
Alloy		24S																		
Specification		QQ-A-355																		
Condition		Heat treated by user [a]					Heat treated										Heat treated and rolled		Heat treated	
Thickness		<0.250	0.250–0.500	0.501–1.000	1.001–2.000	2.001–3.000	<0.250		0.250–0.500		0.501–1.000		1.001–2.000		2.001–3.000		≤ 0.500		≤ 0.064	
Basis		A	A	A	A	A	A	B	A	B	A	B	A	B	A	B	A	B	A	B
F_{tu}	L	62	64	62	60	56	65	68	65	67	63	68	61	64	-	-	70	72	62	66
	T	62	64	62	60	56	64	67	64	66	62	67	60	63	56	59	69	71	62	66
F_{ty}	L	40	38	38	38	38	48	51	46	49	44	48	42	46	-	-	60	62	40	41
	T	40	38	38	38	38	42	44	40	43	40	44	40	44	40	44	52	54	40	41
F_{cy}	L	40	38	38	38	38	40	42	38	41	38	42	38	42	-	-	49	51	40	41
	T	40	38	38	38	38	45	47	43	46	43	47	42	46	-	-	56	58	40	41
F_{su}		37	38	37	36	34	40	42	40	41	38	41	36	38	-	-	43	44	37	40
F_{bru}	$(e/D=1.5)$	93	96	93	-	-	98	102	98	101	95	102	-	-	-	-	105	108	93	99
	$(e/D=2.0)$	118	122	118	-	-	124	129	124	127	120	129	-	-	-	-	133	137	118	126
F_{bry}	$(e/D=1.5)$	56	53	53	-	-	69	71	64	69	62	67	-	-	-	-	84	88	56	57
	$(e/D=2.0)$	64	61	61	-	-	79	82	74	78	70	77	-	-	-	-	96	100	64	66
E		10,500																		
E_c		10,700																		
G		4,000																		
w		0.100																		
Commercial designations		24S–T4	24S–T42				24S–T3		24S–T4								24S–T36		24S–T4	

[a] Heat treat by user refers to all material supplied in the annealed temper and heat treated by the user, and to all material re-heat-treated by user regardless of the temper in which the material was supplied.

Table 3.111 (b). Design Mechanical Properties of Clad 24S Sheet and Plate (Kips per Square Inch)

Type	Sheet and plate																						Coiled sheet			
Alloy	Clad 24S																									
Specification	QQ-A-362																									
Condition	Heat treated by user [a]						Heat treated												Heat treated and rolled				Heat treated			
Thickness	<0.064	0.064–0.249	0.250–0.499	0.500–1.000 [b]	1.001–2.000 [b]	2.001–3.000 [b]	0.010–0.063		0.064–0.249		0.250–0.499		0.500–1.000 [b]		1.001–2.000 [b]		2.001–3.000 [b]		0.019–0.063		0.064–0.500		0.012–0.063		0.064	
Basis	A	A	A	A	A	A	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
F_{tu} L	56	59	62	60	58	54	60	62	63	65	63	65	61	65	59	62	----	----	63	66	67	69	58	61	61	63
T	56	59	62	60	58	54	59	61	62	64	62	64	60	64	58	61	54	57	62	65	66	68	58	61	61	63
F_{ty} L	34	36	38	36	36	36	45	47	46	48	46	48	42	46	40	44	----	----	55	58	58	60	37	38	38	40
T	34	36	38	36	36	36	39	41	40	42	40	42	38	42	38	42	38	42	48	50	50	52	37	38	38	40
F_{cy} L	34	36	38	36	36	36	37	39	38	40	38	40	36	40	36	40	----	----	46	48	48	49	37	38	38	40
T	34	36	38	36	36	36	42	44	43	45	43	45	41	45	40	44	----	----	51	54	54	56	37	38	38	40
F_{su}	34	35	37	36	----	----	38	39	40	41	40	41	37	39	----	----	----	----	40	42	42	43	35	37	37	38
F_{bru} $(e/D=1.5)$	84	89	93	90	----	----	90	93	95	98	95	98	92	98	----	----	----	----	95	99	101	104	87	92	92	95
$(e/D=2.0)$	106	112	118	114	----	----	114	118	120	124	120	124	116	124	----	----	----	----	120	125	127	131	110	116	116	120
F_{bry} $(e/D=1.5)$	48	50	53	50	----	----	64	67	64	69	64	69	59	64	----	----	----	----	77	81	81	84	52	53	53	56
$(e/D=2.0)$	54	58	61	58	----	----	73	76	74	78	74	78	67	74	----	----	----	----	88	93	93	96	59	61	61	64
E PRI	10,500	10,500					10,500				10,500								10,500				10,500			
E SEC	9,500	10,000	10,000	10,000	10,000	10,000	9,500		10,000		10,000		10,000		10,000		10,000		9,500		10,000		9,500		10,000	
E_c PRI	10,700	10,700					10,700				10,700								10,700				10,700			
E_c SEC	9,700	10,200	10,200	10,200	10,200	10,200	9,700		10,200		10,200		10,200		10,200		10,200		9,700		10,200		9,700		10,200	
G																										
w	0.100	0.100					0.100				0.100								0.100				0.100			
Commercial designations	Alclad 24S–T4	Alclad 24S–T42					Alclad 24S–T3				Alclad 24S–T4								Alclad 24S–T36				Alclad 24S–T4			

[a] Heat treat by user refers to all material supplied in the annealed temper and heat treated by the user, and to all material re-heat-treated by the user regardless of the temper in which the material was supplied.

[b] Specification minimums for clad material 0.500 inch thick and heavier are for the core material inasmuch as a round test specimen is required for testing. The values given here for thickness 0.500 inch and greater have been adjusted to represent the average properties across the whole section including the cladding.

Table 3.111 (c). Design Mechanical Properties of Clad 24S Sheet (Kips per Square Inch)

Type		Sheet							
Alloy		Clad 24S							
Specification		AN-A-12, QQ-A-362							
Condition		Heat treated and aged		Heat treated, cold worked and aged					
Thickness		<0.064	≥0.064	<0.064	≥0.064	<0.064	≥0.064	<0.064	≥0.064
Basis		A		A		A		A	
F_{tu}	L	60	62	64	67	67	70	70	72
	T	60	62	62	65	----	----	66	70
F_{ty}	L	47	49	57	59	63	66	66	69
	T	47	49	54	56	----	----	62	66
F_{cy}	L	47	49	55	57	62	65	63	66
	T	47	49	55	57	----	----	63	66
F_{su}		36	37	38	39	39	40	40	41
F_{bru} $(e/D=1.5)$		90	93	96	100	100	105	105	106
F_{bru} $(e/D=2.0)$		114	118	122	127	127	133	133	135
F_{bry} $(e/D=1.5)$		66	69	78	83	88	92	91	95
F_{bry} $(e/D=2.0)$		75	78	90	94	101	106	104	109
E	PRI	10,500							
	SEC	9, 500	10, 000	9, 500	10, 000	9, 500	10, 000	9, 500	10, 000
E_c	PRI	10,700							
	SEC	9, 700	10, 200	9, 700	10, 200	9, 700	10, 200	9, 700	10, 200
G									
w		0.100							
Commercial designation		Alclad 24S–T6		Alclad 24S–T81		Alclad 24S–T84		Alclad 24S–T86	

Table 3.111 (d). Design Mechanical Properties of 14S and R301 Sheet and Plate (Kips per Square Inch)

Type		Sheet and plate																
Alloy		Clad 14S, R-301								14S								
Specification		QQ-A-255								---								
Condition		Heat treated and aged								Heat treated and aged								
Thickness		≤0.039		0.040–0.499		0.500–1.000		1.001–1.500		0.040–0.499		0.500–1.000		1.001–1.500		1.501–2.000	2.001–3.000	3.001–4.000
Basis		A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	A	A
F_{tu}	L	64	64	65	67	65	67	64	65	68	70	68	70	67	68	65	63	59
	T	63	63	64	66	64	66	64	65	67	69	67	69	67	68	65	63	59
	ST	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	58	54
F_{ty}	L	56	56	58	60	58	60	57	60	60	62	60	62	59	62	59	57	55
	T	55	55	57	59	57	59	57	60	59	61	59	61	59	62	59	57	55
	ST	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	53	51
F_{cy}	L	56	56	58	60	58	60	59	62	60	62	60	62	61	64	61	59	57
	T	57	57	59	61	59	61	59	62	61	63	61	63	61	64	61	59	57
	ST	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	59	57
F_{su}		39	39	39	40	39	40	39	40	41	42	41	42	41	41	40	39	37
F_{bru}	$e/D=1.5$	96	96	98	101	98	101	---	---	102	105	102	105	---	---	---	---	---
	$e/D=2.0$	122	122	124	127	124	127	---	---	129	133	129	133	---	---	---	---	---
F_{bry}	$e/D=1.5$	78	78	81	84	81	84	---	---	84	87	84	87	---	---	---	---	---
	$e/D=2.0$	90	90	93	96	93	96	---	---	96	99	96	99	---	---	---	---	---
E		10,400																
E_c		10,600																
G		3,950																
w		0.101																
Commercial designations.		Alclad 14S–T6 R301–T6								14S–T6								

Table 3.111 (e). Design Mechanical Properties of 75S Sheet and Plate (Kips per Square Inch)

Type		Sheet and plate																
Alloy		75S																
Specification		QQ-A-283																
Condition		Heat treated and aged																
Thickness		0.016–0.039		0.040–0.249		0.250–0.500		0.501–1.000		1.001–2.000		2.001–2.500		2.501–3.000		3.001–3.500	3.501–4.000
Basis		A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	A
F_{tu}	L	76	78	77	79	77	79	79	82	78	80	73	75	70	72	68	66
	T	76	78	77	79	77	79	77	80	77	79	73	75	70	72	68	66
	ST	----	----	----	----	----	----	----	----	----	----	67	69	64	66	64	62
F_{ty}	L	66	69	67	70	67	69	69	72	68	71	62	65	60	62	58	56
	T	65	68	65	69	66	68	66	69	66	69	62	65	60	62	58	56
	ST	----	----	----	----	----	----	----	----	----	----	61	63	59	60	56	54
F_{cy}	L	67	70	68	71	69	71	69	72	68	71	65	67	63	65	62	60
	T	70	73	71	74	69	71	69	72	68	71	65	67	63	65	62	60
	ST	----	----	----	----	----	----	----	----	----	----	64	66	62	63	62	60
F_{su}		46	47	46	47	46	47	47	49	46	47	43	45	41	43	40	39
$F_{bru}(e/D=1.5)$		114	117	116	119	108	110	110	115	----	----	----	----	----	----	----	----
$F_{bru}(e/D=2.0)$		144	148	146	150	139	142	142	147	----	----	----	----	----	----	----	----
$F_{bry}(e/D=1.5)$		92	97	94	98	87	90	90	94	----	----	----	----	----	----	----	----
$F_{bry}(e/D=2.0)$		106	110	107	112	100	104	104	108	----	----	----	----	----	----	----	----
E	PRI	10,300															
	SEC	----															
E_c	PRI	10,500															
	SEC	----															
G		3,900															
w		0.101															
Commercial designations		75S-T6															

Type		Sheet and plate																
Alloy		Clad 75S																
Specification		QQ-A-287																
Condition		Heat treated and aged																
Thickness		0.016–0.039		0.040–0.249		0.250–0.499		0.500–1.000 [a]		1.001–2.000 [a]		2.001–2.500 [a]		2.501–3.000 [a]		3.001–3.500 [a]	3.501–4.000 [a]
Basis		A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	A
F_{tu}	L	70	73	72	74	72	74	74	76	73	75	68	70	65	67	63	61
	T	70	73	72	74	72	74	72	74	72	73	68	70	65	67	63	61
	ST	----	----	----	----	----	----	----	----	----	----	62	64	60	61	60	58
F_{ty}	L	61	64	63	65	63	65	64	67	63	66	58	60	56	58	54	52
	T	60	63	62	64	62	64	62	64	61	64	58	60	56	58	54	52
	ST	----	----	----	----	----	----	----	----	----	----	57	59	55	56	52	50
F_{cy}	L	62	65	64	66	64	67	64	67	63	66	60	62	59	60	58	56
	T	64	67	66	68	64	67	64	67	63	66	60	62	59	60	58	56
	ST	----	----	----	----	----	----	----	----	----	----	60	61	58	60	58	56
F_{su}		42	44	43	44	43	44	44	45	44	44	40	42	38	40	37	36
$F_{bru}(e/D=1.5)$		105	110	108	111	101	104	104	106	----	----	----	----	----	----	----	----
$F_{bru}(e/D=2.0)$		133	139	137	141	130	133	133	137	----	----	----	----	----	----	----	----
$F_{bry}(e/D=1.5)$		85	90	88	91	82	84	83	87	----	----	----	----	----	----	----	----
$F_{bry}(e/D=2.0)$		98	102	101	104	94	98	96	100	----	----	----	----	----	----	----	----
E	PRI	10,300															
	SEC	9,500															
E_c	PRI	10,500															
	SEC	9,700															
G		----															
w		0.101															
Commercial designations		Alclad 75S-T6															

[a] Specification minimums for clad material 0.500 inch thick and heavier are for the core material inasmuch as a round test specimen is required for testing. The values given here for thickness 0.500 inch and greater have been adjusted to represent the average properties across the whole section including the cladding.

Table 3.111 (f). Design Mechanical Properties of 52S and 61S Sheet (Kips per Square Inch)

Type		Sheet					
Alloy		52S				61S	
Specification		QQ-A-318				QQ-A-327	
Condition		¼ hard	½ hard	¾ hard	Full hard	Heat treated	Heat treated and aged
Thickness		0.013–0.249	0.008–0.249	0.008–0.161	0.008–0.161	<0.25	<0.25
Basis		A	A	A	A	A	A
F_{tu}	*L*	31	34	37	39	30	42
	T	31	34	37	39	30	42
F_{ty}	*L*	21	24	29	33	16	36
	T	20	23	29	33	16	35
F_{cy}	*L*	20	23				35
	T	21	24				36
F_{su}		19	20	22	23	20	27
F_{bru} $(e/D=1.5)$		50	54	59	62	48	67
F_{bru} $(e/D=2.0)$		65	71	78	82	63	88
F_{bry} $(e/D=1.5)$		29	34	41	46	22	50
F_{bry} $(e/D=2.0)$		34	38	46	53	26	58
E		10, 100				9, 900	
E_c		10, 200				10, 100	
G		3, 850				3, 800	
w		0. 096				0. 098	
Commercial designations		52S-H32	52S–H34	52S–H36	52S-H38	61S–T4	61S–T6

Table 3.111 (g). Design Mechanical Properties of Aluminum Alloy Rolled Bar and Rod, Tubing, and Shapes (Kips per Square Inch)

Type		Rolled bar, rod, and shapes							Tubing			
Alloy		14S	17S	24S		61S	75S		24S			61S
Specification		QQ-A-266	QQ-A-351	QQ-A-268		QQ-A-325	QQ-A-282		WW-T-785			WW-T-789
Condition		Heat treated and aged	Heat treated			Heat treated and aged			Heat treated		Heat treated by user [a]	Heat treated and aged
Thickness and cross-section area		$\gtrsim 3/16$ in., <36 in.^{2}	≲3.000	≲3.000		≲3.000	≲3.000		0.018 to 0.500		0.018 to 0.500	0.025 to 0.500
Basis		A	A	A	B	A	A	B	A	B	A	A
F_{tu}	L	65	55	62	64	42	77	80	64	70	62	42
	T	62	----	50	52	----	70	73	----	----	----	----
F_{ty}	L	55	32	40	43	35	66	70	42	46	40	35
	T	53	----	37	40	----	60	63	----	----	----	----
F_{cy}	L	55	32	40	43	35	66	70	42	46	40	35
	T	53	----	37	40	----	60	63	----	----	----	----
F_{su}		38	33	37	38	25	46	48	39	42	39	27
F_{bru} $(e/D=1.5)$		98	83	93	96	----	100	104	93	105	96	67
F_{bru} $(e/D=2.0)$		124	105	118	122	----	123	128	118	133	122	88
F_{bry} $(e/D=1.5)$		77	45	56	60	----	86	90	59	64	56	49
F_{bry} $(e/D=2.0)$		88	51	64	69	----	92	98	67	74	64	56
E		10,500	10,400	10,500		9,900	10,300		10,500			9,900
E_c		10,700	10,600	10,700		10,100	10,500		10,700			10,100
G		4,000	3,950	4,000		3,800	3,900		4,000			3,800
w		0.101	0.101	0.100		0.098	0.101		0.100			0.098
Commercial designations		14S-T6	17S-T4	24S-T4		61S-T6	75S-T6		24S-T3		24S-T4	61S-T6

[a] Heat treat by user refers to all material supplied in the annealed temper and heat treated by the user, and to all material re-heat-treated by the user regardless of the temper in which the material was supplied.

Table 3.111 (h). Design Mechanical Properties of 14S and 75S Extruded Bar, Rod, and Shapes (Kips per Square Inch)

Type		Extruded bar, rod, and shapes											
Alloy		14S											
Specification		QQ-A-261											
Condition		Heat treated and aged											Heat treated and aged by user [a]
Thickness [b]		Up to 0.499		0.500–0.749		0.750–1.499		1.500–2.999		3.000–4.499		≧0.750	Up to 4.499
Cross-sectional area		≦25 square inches										≧25, ≦32 square inches	Up to 32 square inches
Basis		A	B	A	B	A	B	A	B	A	B	A	A
F_{tu}	L	60	61	64	68	68	73	68	73	68	73	68	60
	T	60	61	64	67	63	66	61	63	58	61	55	56
F_{ty}	L	53	57	58	62	60	65	60	65	60	65	58	53
	T	53	57	55	59	54	58	52	55	49	53	47	47
F_{cy}	L	55	59	60	64	62	67	62	67	62	67	--------	53
	T	53	56	58	62	57	61	57	61	57	61	--------	48
F_{su}		35	35	37	39	39	42	39	42	39	42	39	35
F_{bru} (e/D=1.5)		90	92	96	102	88	95	88	95	88	95	--------	--------
F_{bru} (e/D=2.0)		114	116	122	129	109	117	109	117	109	117	--------	--------
F_{bry} (e/D=1.5)		74	80	81	87	78	85	78	85	78	85	--------	--------
F_{bry} (e/D=2.0)		85	91	93	99	84	91	84	91	84	91	--------	--------
E		10.500											
E_c		10,700											
G		4,000											
w		0.101											
Commercial designations		14S-T6											14S-T62

Type		Extruded bar, rod, and shapes															
Alloy		75S															
Specification		QQ-A-277															
Condition		Heat treated and aged															
Thickness [b]		Up to 0.249		0.250–0.499		0.500–0.749		0.750–1.499		1.500–2.999		3.000–4.499				4.500–5.000
Cross-sectional area		≦20 square inches										≦20 square inches		>20, ≦32 square inches		≦32 square inches
Basis		A	B	A	B	A	B	A	B	A	B	A	B	A	B	A
F_{tu}	L	78	83	80	86	80	85	80	83	80	83	80	82	78	81	78
	T	75	79	74	78	73	77	70	74	65	69	59	63	59	63	58
F_{ty}	L	70	76	72	78	72	77	72	75	72	75	70	72	70	71	68
	T	65	70	64	69	63	68	61	65	55	59	49	54	49	54	47
F_{cy}	L	70	76	72	78	72	78	72	78	72	75	-----	-----	-----	-----	--------
	T	70	76	65	70	65	70	65	70	65	68	-----	-----	-----	-----	--------
F_{su}		43	46	44	47	44	47	44	46	44	46	44	45	43	44	--------
F_{bru} (e/D=1.5)		101	108	96	103	96	102	96	100	96	100	-----	-----	-----	-----	--------
F_{bru} (e/D=2.0)		125	133	128	138	128	136	128	133	128	133	-----	-----	-----	-----	--------
F_{bry} (e/D=1.5)		91	99	79	86	79	85	79	83	79	83	-----	-----	-----	-----	--------
F_{bry} (e/D=2.0)		98	106	101	109	101	108	101	105	101	105	-----	-----	-----	-----	--------
E		10,300														
E_c		10,500														
G		3,900														
w		0.101														
Commercial designations		75S-T6														

[a] Heat treat by user refers to all material supplied in the annealed temper and heat treated by the user, and to all material re-heat-treated by the user regardless of the temper in which the material was supplied.

[b] For extrusions with outstanding legs, the load-carrying ability of such legs shall be determined on the basis of the properties in the appropriate column corresponding to the leg thickness.

Table 3.111 (i). Design Mechanical Properties of 24S and 61S Extruded Bar, Rod, and Shapes (Kips per Square Inch)

Type		Extruded bar, rod, and shapes													
Alloy		24S													61S
Specification		QQ-A-267													QQ-A-270
Condition		Heat treated												Heat-treated by user	Heat-treated and aged
Thickness		Up to 0.249		0.250–0.499		0.500–0.749		0.750–1.499		1.500–2.999		3.000–4.499		Up to 4.499	Up to 3.000
Cross sectional area		≦25 square inches												≦32 square inches	
Basis		A	B	A	B	A	B	A	B	A	B	A	B	A	A
F_{tu}	L	57	61	60	62	60	62	65	70	70	74	70	74	57	38
	T	57	61	60	62	60	62	58	61	54	57	50	53	50	36
F_{ty}	L	42	47	44	47	44	47	46	54	52	54	52	54	38	35
	T	42	46	43	46	42	45	41	44	38	41	36	39	36	33
F_{cy}	L	38	41	39	42	39	42	44	52	50	52	50	52	38	35
	T	38	41	39	42	39	42	42	48	42	44	42	44	38	35
F_{su}		30	32	32	33	32	33	34	38	38	40	38	40	30	24
F_{bru} (e/D=1.5)		85	91	85	91	85	91	85	91	85	91	85	91	85	61
F_{bru} (e/D=2.0)		108	114	108	114	108	114	108	114	108	114	108	114	108	80
F_{bry} (e/D=1.5)		59	66	60	66	60	66	61	66	62	66	62	66	53	49
F_{bry} (e/D=2.0)		67	75	69	75	69	75	71	75	73	75	73	75	61	56
E		10, 500													9, 900
E_c		10, 700													10, 100
G		4, 000													3, 800
w		0. 100													0. 098
Commercial designations		24S–T4												24S–T42	61S–T6

Table 3.111 (j). Design Mechanical Properties of 14S and 75S Hand-Forged Stock (Kips per Square Inch)

Type		Hand-forged stock Length ≤3 times width				Hand-forged stock Length >3 times width				Hand-forged stock Length ≤3 times width			Hand-forged stock Length >3 times width		
Alloy		14S				14S				75S			75S		
Specification		QQ-A-367								QQ-A-367					
Condition		Heat treated and aged								Heat treated and aged by user. Any part ≤3-inch thickness cut from stock of cross-sectional area indicated					
Cross-sectional area (in.²)		≤16	≥16 <36	>36 <144	≥144 <256	≤16	≥16 <36	>36 <144	≥144 <256	≤16	≥16 <36	>36 <144	≤16	≥16 <36	>36 <144
Basis		A	A	A	A	A	A	A	A	A	A	A	A	A	A
F_{tu}	L	65	65	62	60	65	65	62	60	75	73	71	73	71	69
	T	62	62	59	57	62	62	59	57	75	71	69	73	69	67
	ST	59	59	56	54	59	59	56	54	72	68	66	70	66	64
F_{ty}	L	55	53	50	48	55	53	50	48	64	61	60	62	59	58
	T	55	53	50	48	53	51	50	48	63	60	58	61	58	56
	ST	55	53	50	48	53	51	50	48	63	60	58	61	58	56
F_{cy}	L	55	53	50	48	55	53	50	48	64	61	60	62	59	58
	T	55	53	50	48	53	51			63	60	58	61	58	56
	ST														
F_{su}		40	40	38	37	40	40			45	44	43	44	43	42
F_{bru} $(e/D=1.5)$		91	91	87	84	91	91	87	84	97	95	85	95	92	83
F_{bru} $(e/D=2.0)$		117	117	112	108	117	117	112	108	135	124	114	131	121	110
F_{bry} $(e/D=1.5)$		77	74	70	67	77	74	70	67	90	79	78	87	77	75
F_{bry} $(e/D=2.0)$		88	85	80	77	88	85	80	77	96	91	90	93	88	87
E		10, 500								10, 300					
E_c		10, 700								10, 500					
G		4, 000								3, 900					
w		0. 101								0. 101					
Commercial designations		14S–T6								75S–T6					

Table 3.111 (k). Design Mechanical Properties of Aluminum Alloy Die Forgings (Kips per Square Inch)

Type		Die forgings				
Alloy		14S		25S	A51S	75S
Specification		QQ-A-367				
Condition		Heat treated	Heat treated and aged			
Thickness		⋜4 inches				⋜3 inches
Basis		A	A	A	A	A
F_{tu}	L	55	65	55	44	75
	T	52	62	52	42	71
F_{ty}	L	30	55	33	37	65
	T	28	52	31	35	62
F_{cy}	L	30	55	33	37	65
	T	28	52	31	35	58
F_{su}		34	39	34	28	45
F_{bru} $(e/D=1.5)$		----	----	----	----	----
F_{bru} $(e/D=2.0)$		----	----	----	----	----
F_{bry} $(e/D=1.5)$		----	----	----	----	----
F_{bry} $(e/D=2.0)$		----	----	----	----	----
E		10, 500	10, 500	10, 300	10, 100	10, 300
E_c		10, 700	10, 700	10, 500	10, 300	10, 500
G		4, 000	4, 000	3, 900	3, 850	3, 900
w		0. 101	0. 101	0. 101	0. 097	0. 101
Commercial designations		14S–T4	14S–T6	25S–T6	A51S–T6	75S–T6

Table 3.111 (l). Design Mechanical Properties of Aluminum Alloy Castings (Kips per Square Inch)

Type	Sand castings [a]					Permanent mold castings [a]			
Alloy	40–E	195–T4	195–T6	220–T4	356–T6	B195–T4	B195–T6	355–T6	356–T6
Specification	QQ-A-601	QQ-A-601		QQ-A-601	QQ-A-601	QQ-A-596		QQ-A-596	QQ-A-596
Condition	Aged	Heat treated, class I	Heat treated and aged, class II	Heat treated	Heat treated and aged	Heat treated, class I	Heat treated and aged, class II	Heat treated and aged	
Basis [b]	A	A	A	A	A	A	A	A	A
F_{tu}	32	29	32	42	30	33	35	37	33
F_{ty}	20	13	20	22	20	20	22	23	22
F_{cy}	----	14	21	23	20	20	22	23	22
F_{su}	27	22	24	30	25	25	26	26	25
F_{bru} $(e/D=1.5)$	----	46	51	67	48	46	49	----	46
F_{bru} $(e/D=2.0)$	----	61	67	88	63	59	63	----	59
F_{bry} $(e/D=1.5)$	----	22	34	37	34	32	35	----	35
F_{bry} $(e/D=2.0)$	----	26	40	44	40	36	40	----	40
E					10, 300				
E_c					10, 300				
G					3, 850				
w	0. 100	0. 101	0. 101	0. 093	0. 097	0. 101	0. 101	0. 098	0. 097
Commercial designation	40–E	195–T4	195–T6	220–T4	356–T6	B195–T4	B195–T6	355–T6	356–T6

[a] Reference should be made to the specific requirements of the procuring or certificating agency in regard to the use of the above values in the design of castings.

[b] A is the mechanical property column based upon the minimum guaranteed tensile properties from separately cast test bars. The mechanical properties of production castings may be as low as 75 percent of the tabulated values.

Table 3.111 (m). Design Mechanical Properties of Heat Treated, Cold Worked and Aged 24S Alloy Extrusions and Tubing (Kips per Square Inch)

Type		Extruded shapes	Tubing
Alloy		24S	24S
Specification			
Condition		Heat treated, cold worked, and aged	Hest treated, cold worked, and aged
Cross section area (in.²)		≷0.250	
Basis		A	A
F_{tu}	L	64	68
F_{ty}	L	56	60
F_{cy}			
F_{su}			
$F_{bru}(e/D=1.5)$			
$F_{bru}(e/D=2.0)$			
$F_{bry}(e/D=1.5)$			
$F_{bry}(e/D=2.0)$			
E		10, 500	10, 500
E_c		10, 700	10, 700
G		4, 000	4, 000
w		0. 100	0. 100
Commercial designations		24S–T81	24S–T81

Table 3.111 (n). Percent Elongation for Aluminum Alloy Tables 3.111 (a) to (l) [a]

Table	Direction	Column 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
3.111 (a)	T	A	12	8	B	4	A		12		8		B		4		C	D
3.111 (b) [b]	T	E	F	11	8	B	4	E		F		11		8		B		4
3.111 (c)	T	8	8	5	5	5	5	3	3									
3.112 (d)	L	7		8		6		6		8		6		6		6	4	3
	T	7		8		6		4		8		6		4		3	2	1½
	ST																1	
3.111 (e) [c]	L	7		8		8		6		5		5		5		5		
	T	7		8		8		6		4		3		3		3	2	
	ST											1		1		1		
3.111 (f)	L	I	J	K	K	L	M											
3.111 (g)	L	8	16	14		10	7		P		P	Q						
3.111 (h)	(14S) L	7		7		7		7		7		6	7					
	(75S) L	7		7		7		7		7		7		6		6		
3.111 (i)	L	12		12		12		10		10		10		R	10			
3.111 (j)	L	10	9	7	5	10	9	7	5	9	7	4	8	6	3			
	T	6	5	3	2	4	3	2. 5	1. 5	4	3	2	3	2	1			
	ST	3	2	1	1	2	1	1	1	1	1	1	1	1	1			
3.111 (k)	L	T	U	T	V	U												
3.111 (l)	L	3	6	3	12	3	4. 5	2	1. 5	3								

[a] Letters substituted for percent elongation values indicate variation within thickness range of a particular column. See table 3.111 (o) for these values.

[b] Elongations for columns 19, 21, 23 and 25 are G, H, E and 15, respectively.

[c] Values in columns 1 through 15 also apply to comparable columns 17 through 31.

Table 3.111 (o). Percent Elongation Values for Columns Indicated in Table 3.111 (n)

Code letter from table 3.111 (*n*)	Thickness, range	Elongation, percent
A	0.010–0.020	12
	0.021–0.051	15
	0.052–0.128	17
	0.129–0.249	15
B	1.000–1.500	7
	1.501–2.000	6
C	0.020–0.031	10
	0.032–0.036	11
	0.037–0.188	12
	0.189–0.500	10
D	0.012–0.020	12
	0.021–0.051	15
	0.052–0.064	17
E	0.010–0.020	12
	0.021–0.063	15
F	0.064–0.128	15
	0.129–0.249	13
G	0.020–0.031	8
	0.032–0.040	9
	0.041–0.063	10
H	0.064–0.188	10
	0.189–0.500	9
I	0.013–0.019	4
	0.020–0.050	5
	0.051–0.113	7
	0.114–0.249	9
J	0.008–0.019	3
	0.020–0.050	4
	0.051–0.113	6
	0.114–0.249	7
K	0.008–0.031	3
	0.032–0.161	4
L	0.010–0.020	14
	0.021–0.249	16
M	0.010–0.020	8
	0.021–0.249	10
P	0.018–0.024	10
	0.025–0.049	12
	0.050–0.259	14
	0.26 –0.500	16
Q (Diameter ¼ inch–2 inches, inclusive.)	0.025–0.049	10
	0.050–0.259	12
	0.260–0.500	14
(Diameter over 2 inches up to 8 inches.)	0.025–0.049	8
	0.050–0.259	0
	0.260–0.500	12
R	Up to 0.749	12
	≥0.750	10
S	0.050–0.749	12
	0.750	10
T	Elongation (in 2 inches) separately forged coupon	16
	Elongation (in 2 inches) specimen cut from forging	11
U	Elongation (in 2 inches) separately forged coupon	10
	Elongation (in 2 inches) specimen cut from forging	7
V	Elongation (in 2 inches) separately forged coupon	14
	Elongation (in 2 inches) specimen cut from forging	10

3.112 *Fatigue properties.* Direct-stress tension-compression, rotating beam and repeated flexure fatigue strength data at room temperature for several aluminum alloys are given in figures 3.112 (*a*) through (*e*) and tables 3.112 (*a*) through (*d*). The data in the tables must be considered as average values, lying at about the center of a scatterband such as seen in figures 3.112 (*a*) through (*c*) for rotating beam tests. These scatterbands have been obtained from tests on all types of products for each alloy and include specimens taken parallel to the grain and transverse to the grain (see reference 3.112 (*a*) for the effect of grain direction on the fatigue properties of aluminum alloys). Even under carefully controlled conditions there is considerable spread in fatigue results, and these scatterbands illustrate the amount of scatter which will be encountered.

The values given in the tables and figures for smooth specimens were determined on specimens in which stress concentrations have been purposely minimized. They 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. They 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. Fabricated parts in test have been found to fail at less than 50,000 repetitions of load when the nominal stress was far below that which could be repeated many millions of times on a smooth machined specimen. See reference 3.112 (*a*) through (*f*) for information on how to use high-strength aluminum alloy, reference 3.611 (*r*) for details on the static and fatigue strengths of high-strength aluminum alloy bolted joints, reference 3.611 (*s*) for single-rivet fatigue test data, and reference 2.112 (*b*) for a general discussion of designing for fatigue.

The notched fatigue data presented in the figures and some of the accompanying tables are presented so that by comparing the notched data with that from the smooth specimens, the serious effect of a sharp notch on fatigue strength can be seen. The notch fatigue

Table 3.112 (a). Fatigue Strengths of Smooth Machined Round Specimens Under Completely Reversed Flexure

Alloy and temper	Mean fatigue strengths (reversed stress), *ksi*, at indicated number of cycles					
	10,000 cycles	100,000 cycles	1,000,000 cycles	10,000,000 cycles	100,000,000 cycles	500,000,000 cycles
14S–T6	52	39	30	24	19	18
24S–T4	56	43	31	24	21	20
75S–T6	55	40	29	24	22	22
A51S–T6	43	30	22	17	13	12
61S–T6	44	31	23	17	15	14

Table 3.112 (b). Fatigue Strengths of Sharply Notched Round Specimens Under Completely Reversed Flexure

Alloy and temper	Mean fatigue strengths (reversed stress), *ksi*, at indicated number of cycles					
	10,000 cycles	100,000 cycles	1,000,000 cycles	10,000,000 cycles	100,000,000 cycles	500,000,000 cycles
14S–T6	31	21	14	10	9	9
24S–T4	32	24	17	13	11	11
75S–T6	31	21	14	11	10	9
A51S–T6	28	16	10	7	6	6
61S–T6	29	17	12	8	7	7

Table 3.112 (c). Fatigue Strengths of Flat Sheet Specimens Under Completely Reversed Flexure

Alloy and temper	Fatigue strength (reversed stress), *ksi*, at indicated number of cycles				
	100,000 cycles	1,000,000 cycles	10,000,000 cycles	100,000,000 cycles	500,000,000 cycles
24S–T3	34	26	21	18	18
24S–T36	37	29	22	19	19
61S–T6	30	22	16	13	12
75S–T6	37	26	21	20	20
Alclad 14S–T3	31	20	17	15	15
Alclad 14S–T6	31	20	17	15	15
Alclad 24S–T3	31	19	15	13	13
Alclad 24S–T36	31	19	15	13	13
Alclad 24S–T81	31	19	15	13	13
Alclad 24S–T86	31	19	15	13	13
Alclad 75S–T6	31	19	15	13	13

strengths, like the smooth-specimen fatigue strengths, are not to be used directly as the allowable stress values for design, but are included for information.

The values for smooth specimens shown in figures 3.112 (*a*) through (*e*) and given in table 3.112 (*a*) are from tests of 0.3-inch-diameter machined specimens in R. R. Moore rotating-beam fatigue machines at Aluminum Research Laboratories. Tests of specimens up to 2-inch diameter show no appreciable size effect.

The values for notched specimens shown in figures 3.112 (*a*) through (*e*) and presented in table 3.112 (*b*) are from tests of sharply notched specimens in the same type of rotating-beam fatigue test as the smooth specimens at Aluminum Research Laboratories. Each specimen was 0.480 inch in diameter and contained a circumferential 60° V-notch, 0.075 inch deep with a radius at the base of about 0.0002 inch. The values given are nominal calculated stresses obtained by applying the simple flexure formula to the 0.330-inch-diameter cross section at the root of the notch with no correction for stress concentration. The values for the alloys shown in tables 3.112 (*a*) and (*b*) are average values of specimen used in plotting the scatterbands shown in figures 3.112 (*a*) through (*e*).

The data shown in figure 3.112 (*f*) have been obtained from direct-stress tension-compression fatigue tests conducted on several different shapes of specimens including both round and

Table 3.112 (d). Fatigue Strengths of Smooth Machined Round Specimens Under Repeated Axial Load

Alloy and temper	Stress ratio, R [a]	Fatigue strengths, ksi, at indicated number of cycles [b]				
		100,000 cycles	1,000,000 cycles	10,000,000 cycles	100,000,000 cycles	500,000,000 cycles
14S–T6	+0.5	68	59	56	54	53
	0	54	42	36	32	30
	−1.0	33	25	20	17	15
24S–T4	+0.5	66	57	53	52	51
	0	54	44	37	34	33
	−1.0	35	27	21	18	17
75S–T6	+0.5	75	63	58	56	55
	0	57	45	38	36	35
	−1.0	38	28	23	21	20
61S–T6	+0.5	44	41	38	37	36
	0	38	31	27	23	22
	−1.0	25	19	15	13	12

[a] Ratio of minimum to maximum stress. Stress considered algebraically tensile being plus (+), and compressive being negative (−).
[b] Maximum stress in cycle.

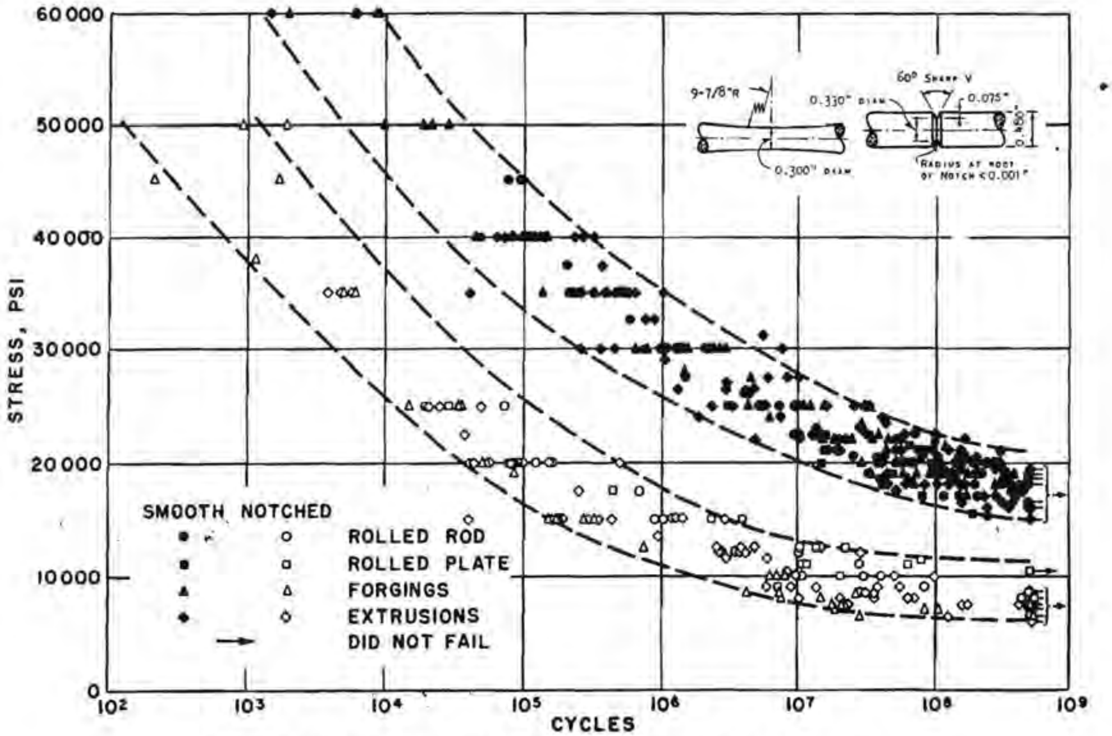


Figure 3.112 (a). Rotating-beam fatigue data for 14S–T6 products.

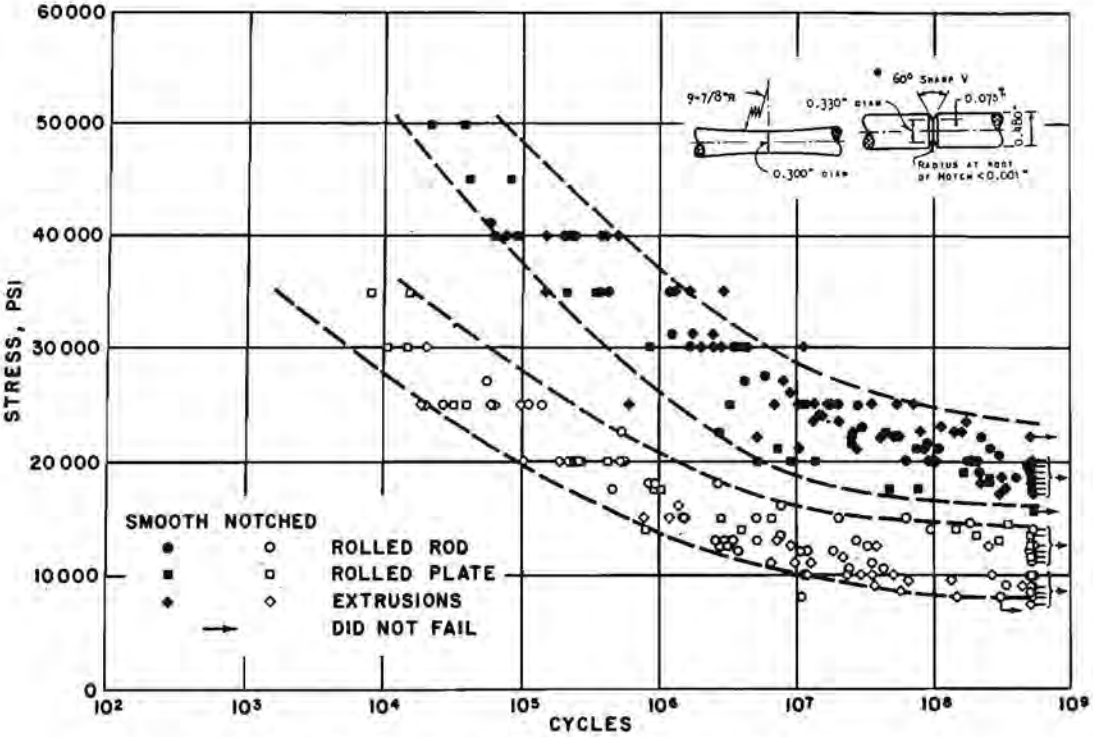


Figure 3.112 (b). Rotating-beam fatigue data for 24S–T4 products.

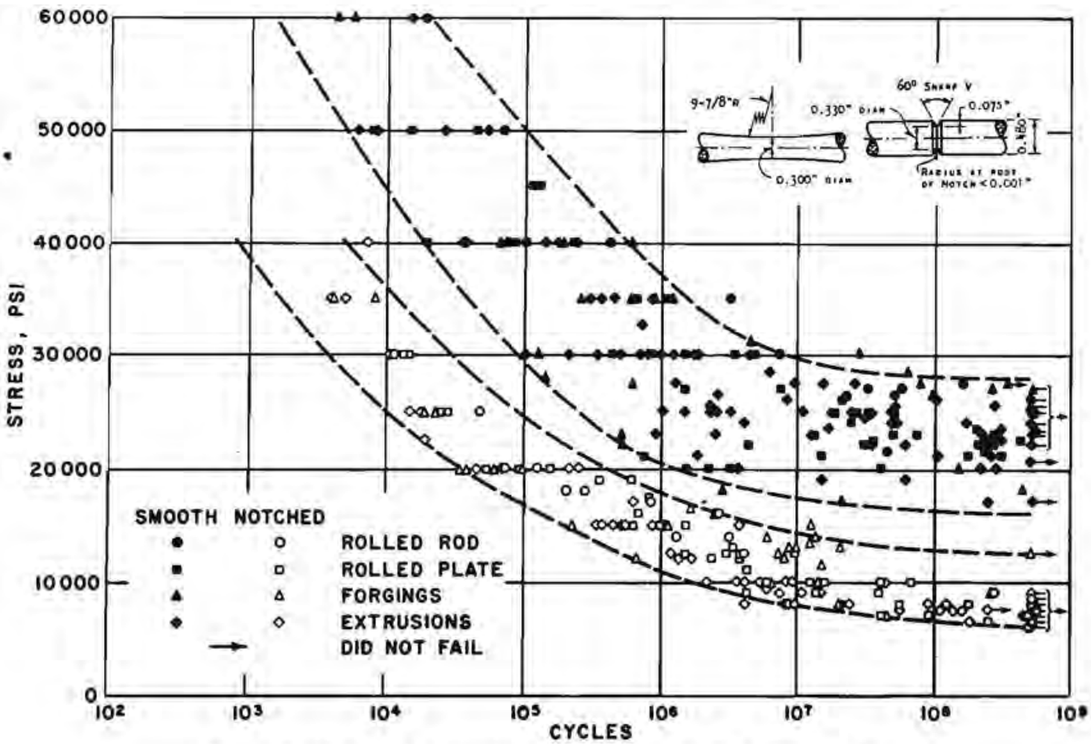


Figure 3.112 (c). Rotating-beam fatigue data for 75S–T6 products.

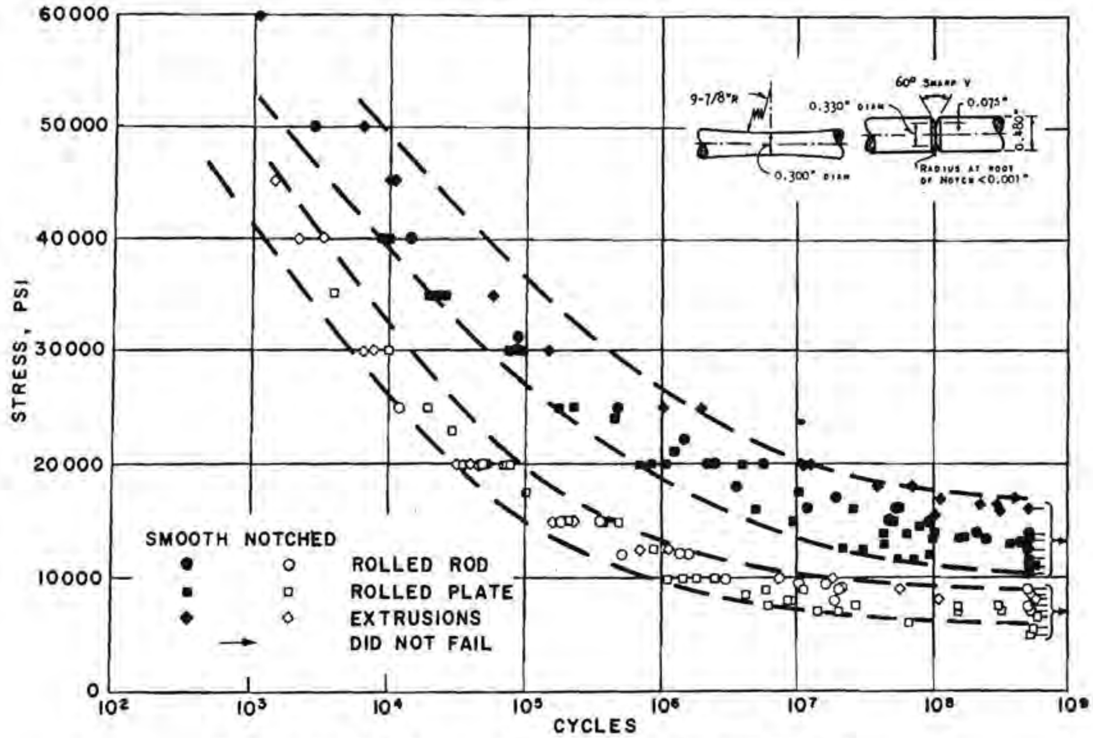


Figure 3.112 (d). Rotating-beam fatigue data for 61S–T6 products.

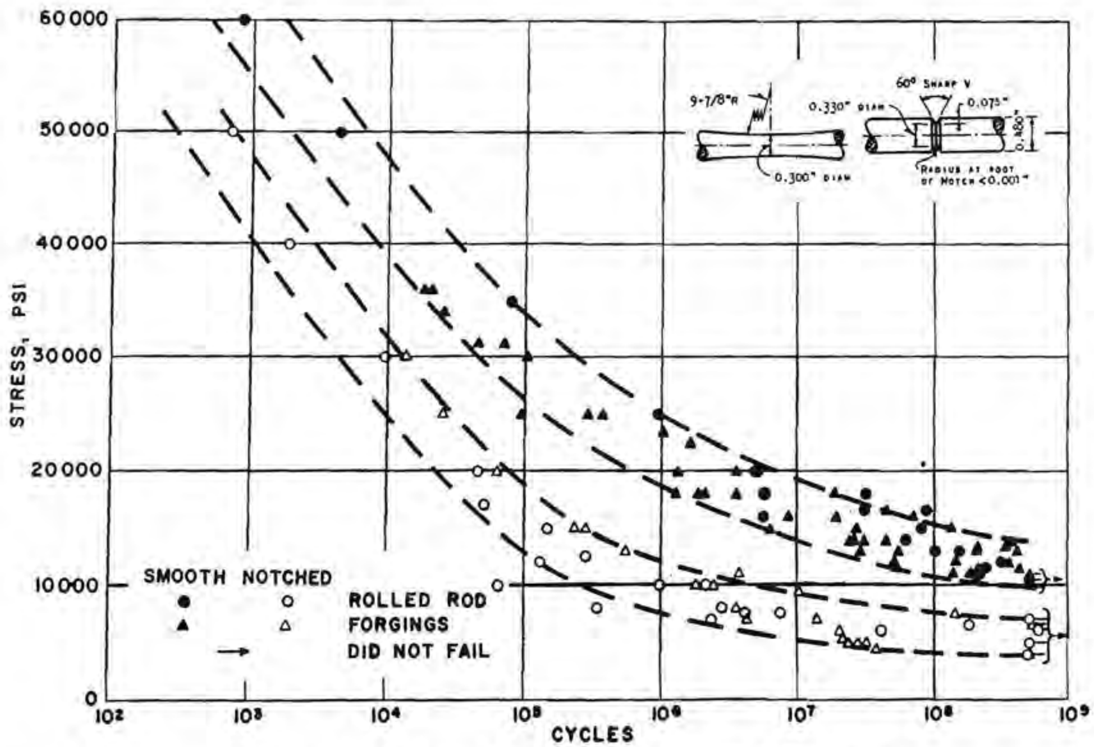


Figure 3.112 (e). Rotating-beam fatigue data for A51S–T6 products.

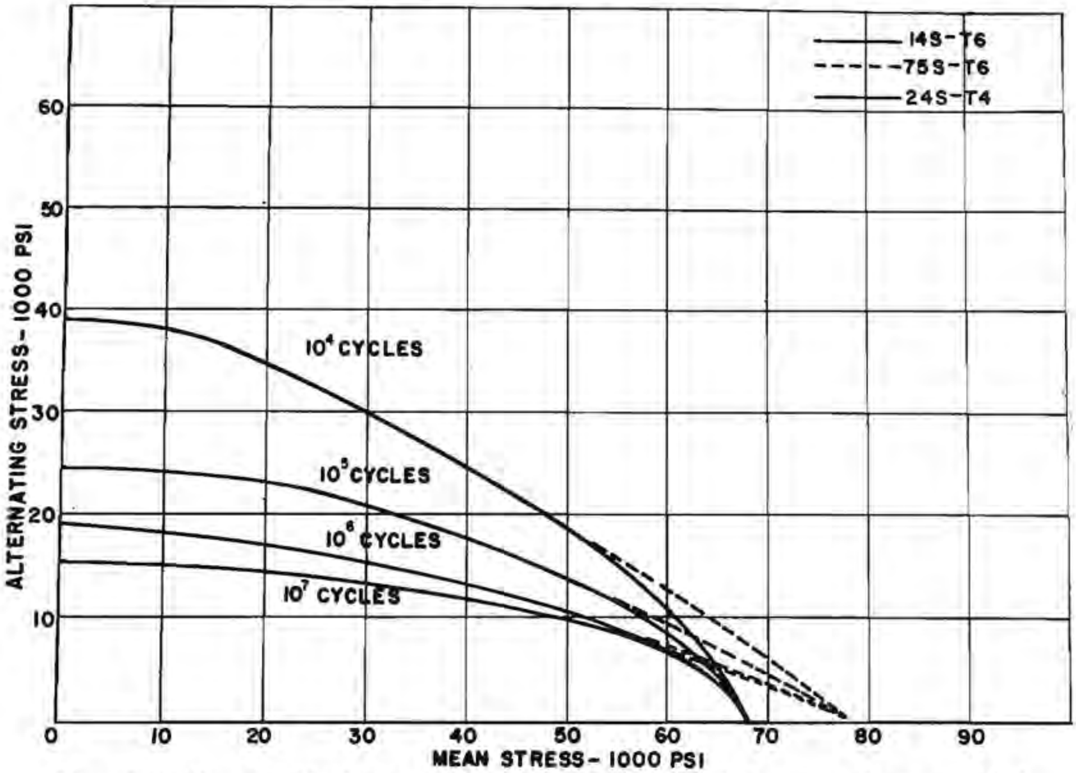


Figure 3.112 (f). Axial-load fatigue curves for rolled and extruded aluminum alloys—unnotched.

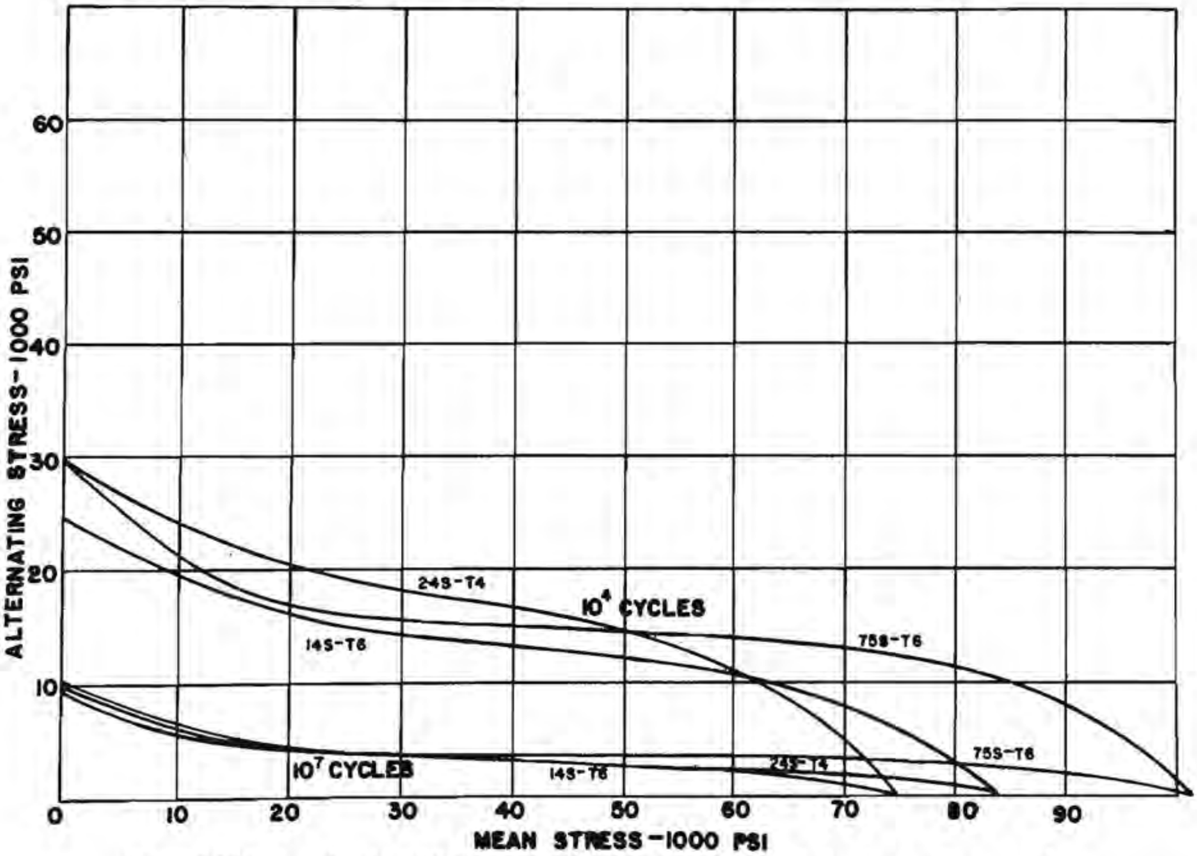


Figure 3.112 (g). Axial-load fatigue curves for rolled and extruded aluminum alloys—notched.

rectangular cross sections. The curves seen are the lower edges of the scatterbands for smooth specimens. These curves represent the minimum fatigue strengths expected in this type of test.

The data shown in table 3.112 (*d*) are also for direct-stress tension-compression fatigue tests but are for one type of specimen 0.2 inch in diameter tested in Aluminum Research Laboratory direct-stress fatigue machines. These data are the mean values from scatterbands and therefore are higher, where similar test conditions were used, than the values given in figure 3.112 (*f*). They are included to show the effect of lower mean stresses and higher cycles to failure.

The values given in table 3.112 (*c*) are from tests of 0.064-inch-thick sheet specimens with as-rolled surfaces in Aluminum Research Laboratories repeated flexure fatigue machines.

The data presented in figure 3.112 (*g*) have been obtained from tests of notched specimens in Lazan direct-stress fatigue machines. Each specimen was 0.450 inch in diameter and contained a circumferential 60° V-notch, 0.025 inch deep with a radius at the base of the notch of 0.01 inch. These curves are presented merely to illustrate the effect of a notch on the fatigue strength and are average values. The data are not available to determine the scatterband for this notch.

3.113 *Typical stress-strain and tangent modulus data.* Typical stress-strain diagrams and tangent modulus values at various stresses are given in figures 3.113 (*a*) through (*e*) for certain aluminum alloy products.

The typical stress-strain curves may be converted to other values of F_{ty} and F_{cy} by the Ramberg-Osgood method or any other analytical or graphical method which maintains the original slope and results in a curve affine with the typical curve. The stress-strain curve in the region of low strains can be predicted accurately from the formula 1.342 where an appropriate value of *E* is selected from table 3.111 (*a*) through (*o*). (See reference 3.113.)

3.12 TEMPERATURE EFFECTS.

3.121 *Low temperature.* Low temperatures generally increase the static and fatigue strengths of aluminum alloys. The ductility and impact strengths are not appreciably affected by decreasing temperatures to −320° F. (See references 2.121 (*b*) and 3.121.) The effect of temperature on the modulus of elasticity of aluminum alloys is given in table 3.121.

Table 3.121. Effect of Various Temperatures on the Modulus of Elasticity of Aluminum Alloys

Temperature, ° F.	Approximate value of modulus in terms of modulus at 75° F.	
	75S	14S, 17S, 24S, 25S, A51S, 52S, 61S
	Percent	*Percent*
−320	112	112
−112	105	105
−18	102	102
75	100	100
212	95	98
300	88	95
400	80	90
500	68	80
600	50	70

3.122 *Elevated temperature.* The data shown in figures 3.122 (*a*) through (*d*) for short-time tests are based on continuous heating, but are considered applicable to intermittent heating when the total time at temperature is the same. The data shown in figures 3.122 (*e*) through (*n*) are based on continuous heating and loading, but are also considered applicable to intermittent heating when total time at temperature is the same. However, for intermittent loading, it is probable that creep deformation will be accelerated somewhat based on net times under load. Further information on these phenomena are given in references 3.122 (*a*) and (*b*). The data included in the tables are based on specimens heated in air with no added corrosive agents. Consideration must be given to the fact that materials in service may be exposed to more corrosive atmospheres over longer periods of time under temperature variations.

3.1221 *Static properties.*

3.12211 *Strength at temperature.* Curves for computing the approximate reduction in tensile ultimate, tensile yield, and other mechanical properties for various heat-treated and heat-treated and aged aluminum alloys, held unstressed at elevated temperatures up to 700° F. for various time intervals and then tested statically at temperature, are presented in figures 3.122 (*a*) to (*d*), inclusive. The tensile-ultimate and tensile-yield data are reported in another form in figures 3.122 (*e*) to (*n*),

(Continued on page 108.)

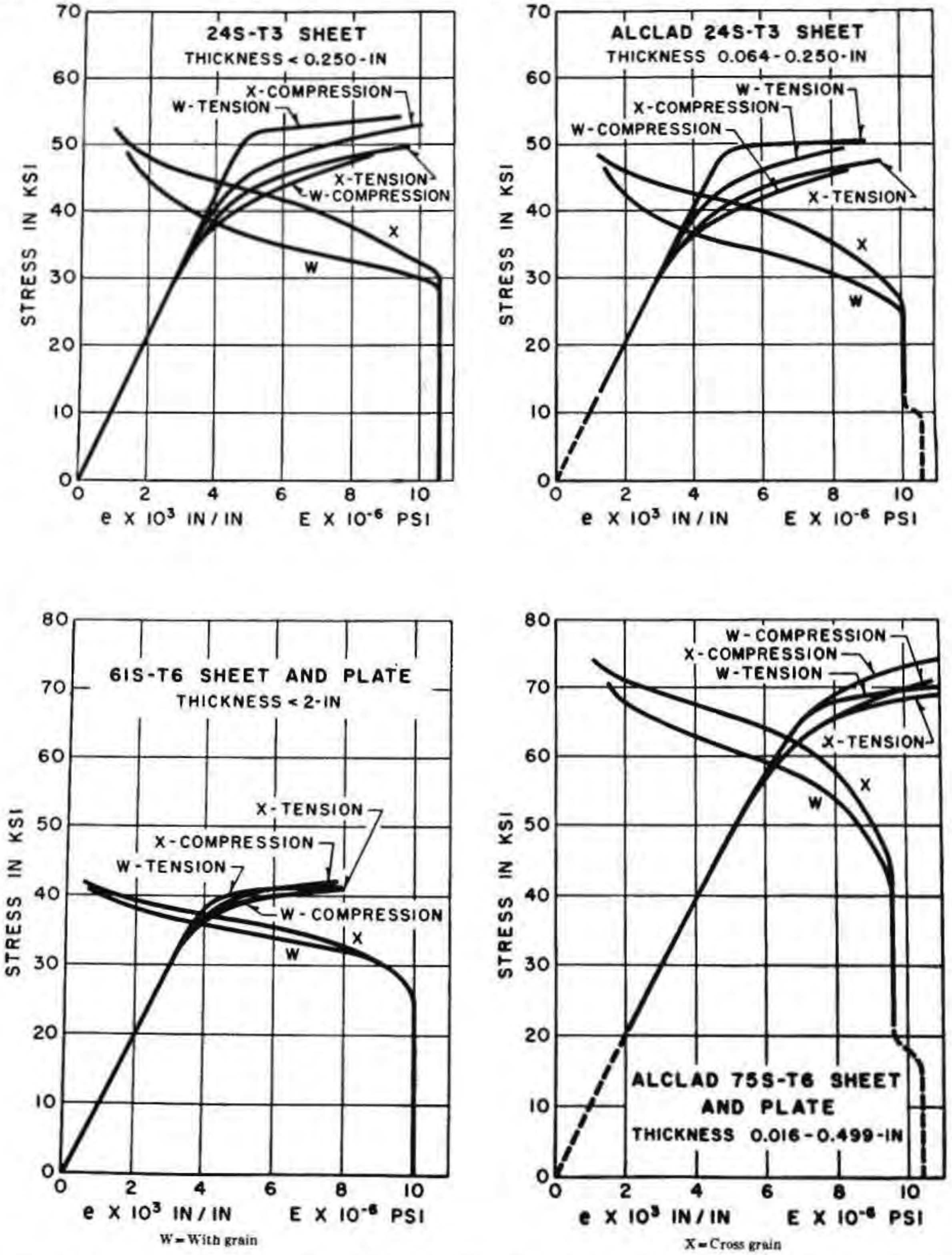


Figure 3.113 (a). Typical stress-strain and tangent compression modulus curves for various aluminum alloy sheet materials.

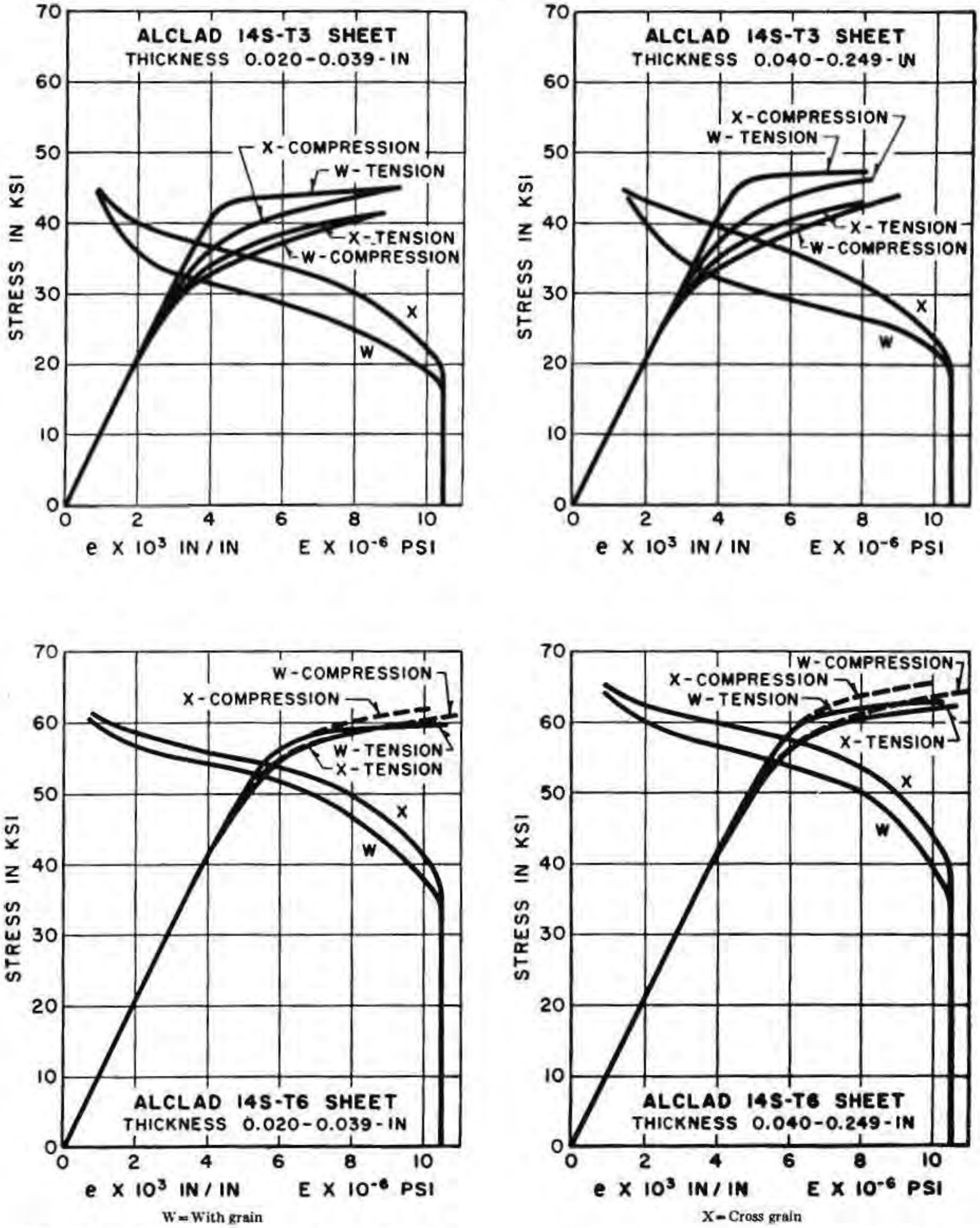


Figure 3.113 (b). Typical stress-strain and tangent compression modulus curves for 14S aluminum alloy sheet.

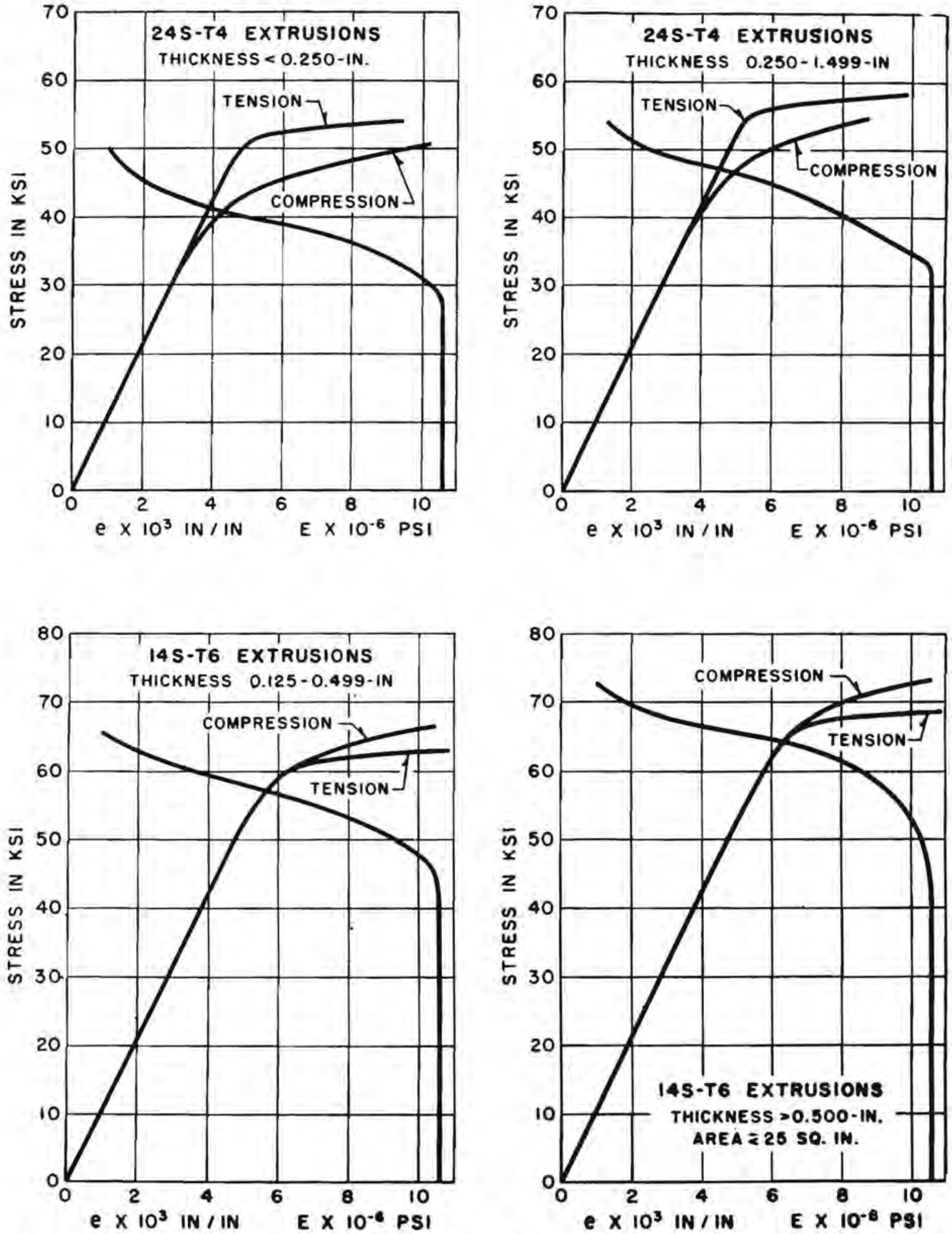


Figure 3.113 (c). Typical stress-strain and tangent modulus curves for 24S and 14S aluminum alloy extrusions.

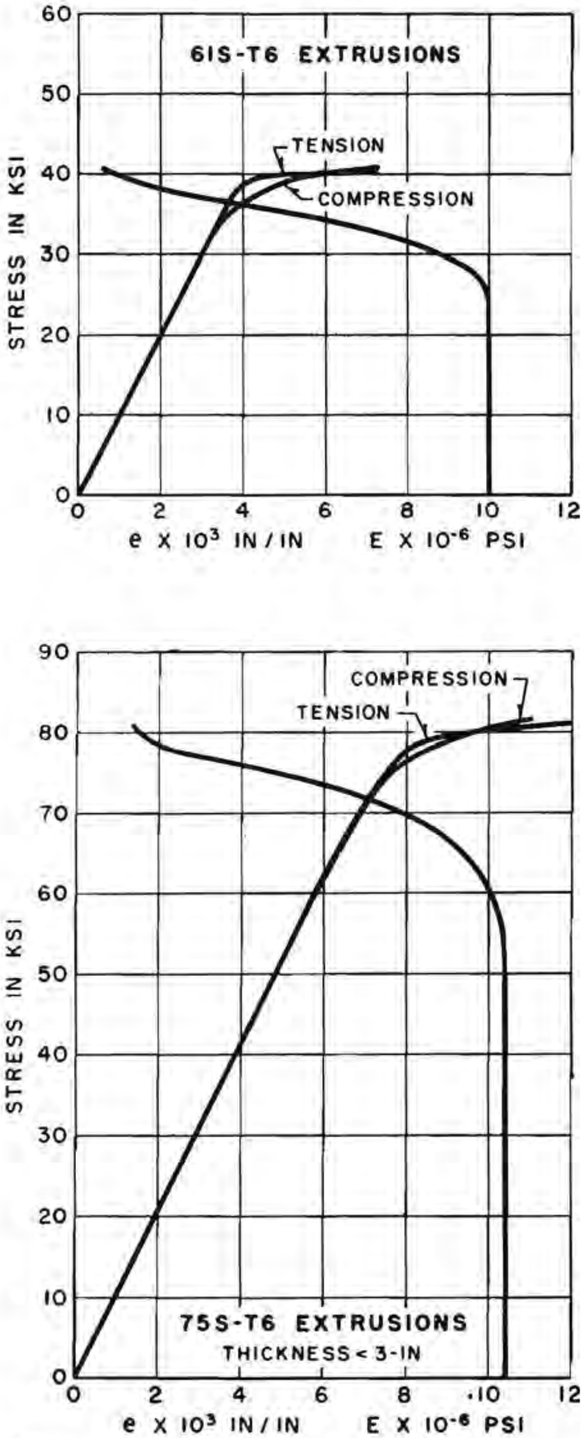


Figure 3.113 (d). Typical stress-strain and tangent modulus curves for 61S–T6 and 75S–T6.

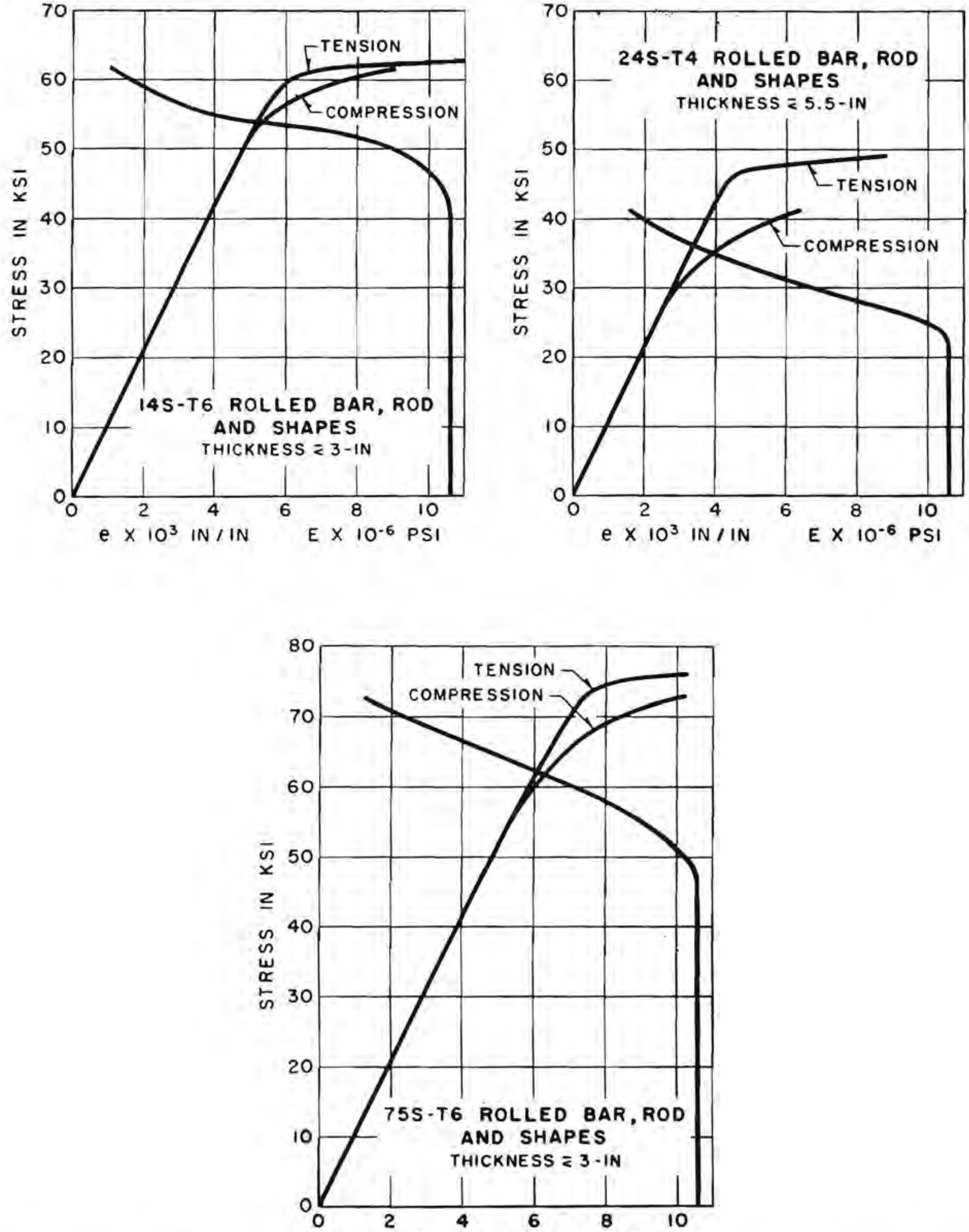
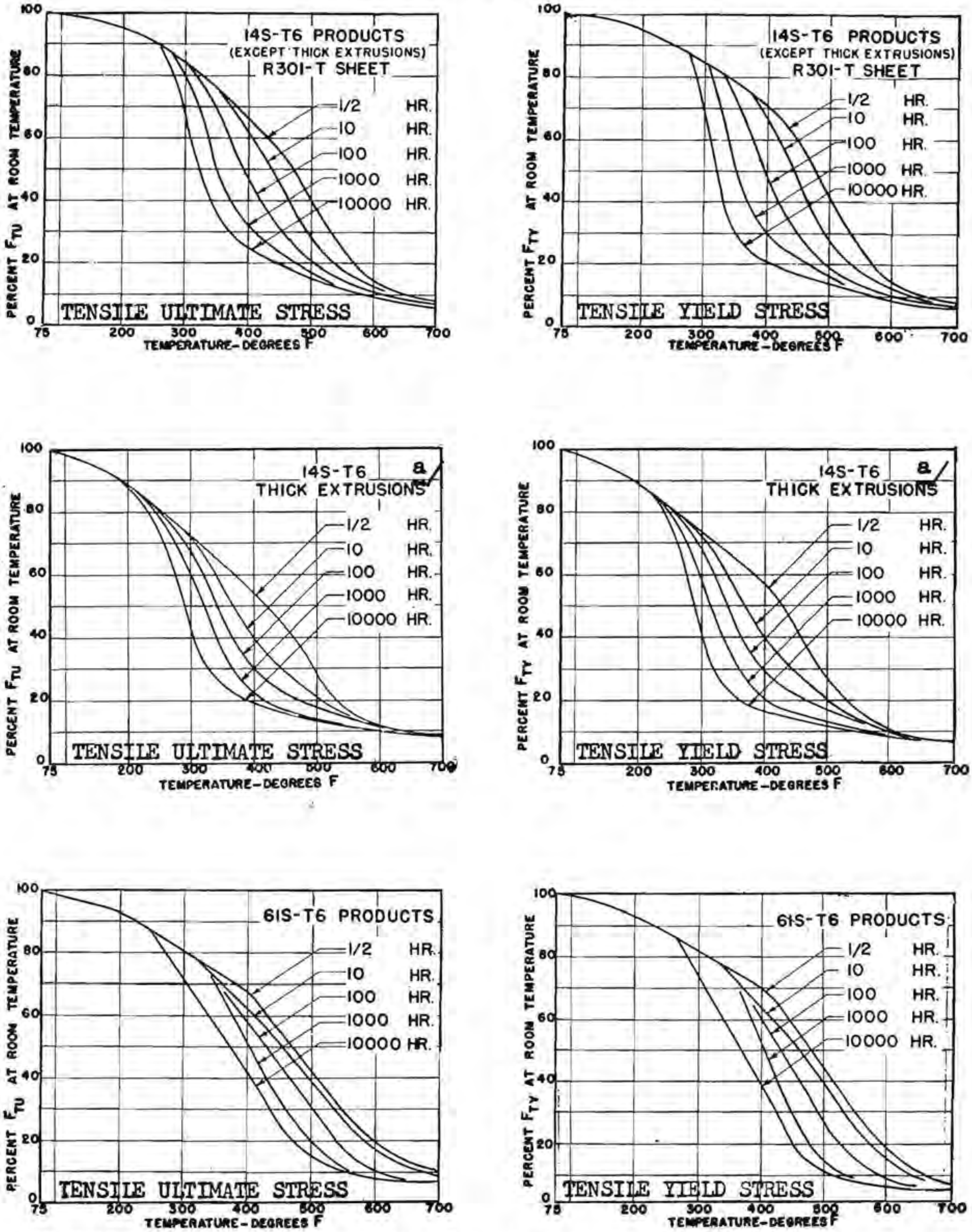


Figure 3.113 (e). Typical stress-strain and tangent modulus curves for 14S–T6, 24S–T4, and 75S–T6 aluminum alloy rolled bar, rod, and shapes.



[a] 14S-T6 thick extrusions are those 0.75 inch or more in thickness but equal to or less than 32 square inches in cross-sectional area.

Figure 3.122 (a). Tensile properties of aluminum alloy at elevated temperatures.

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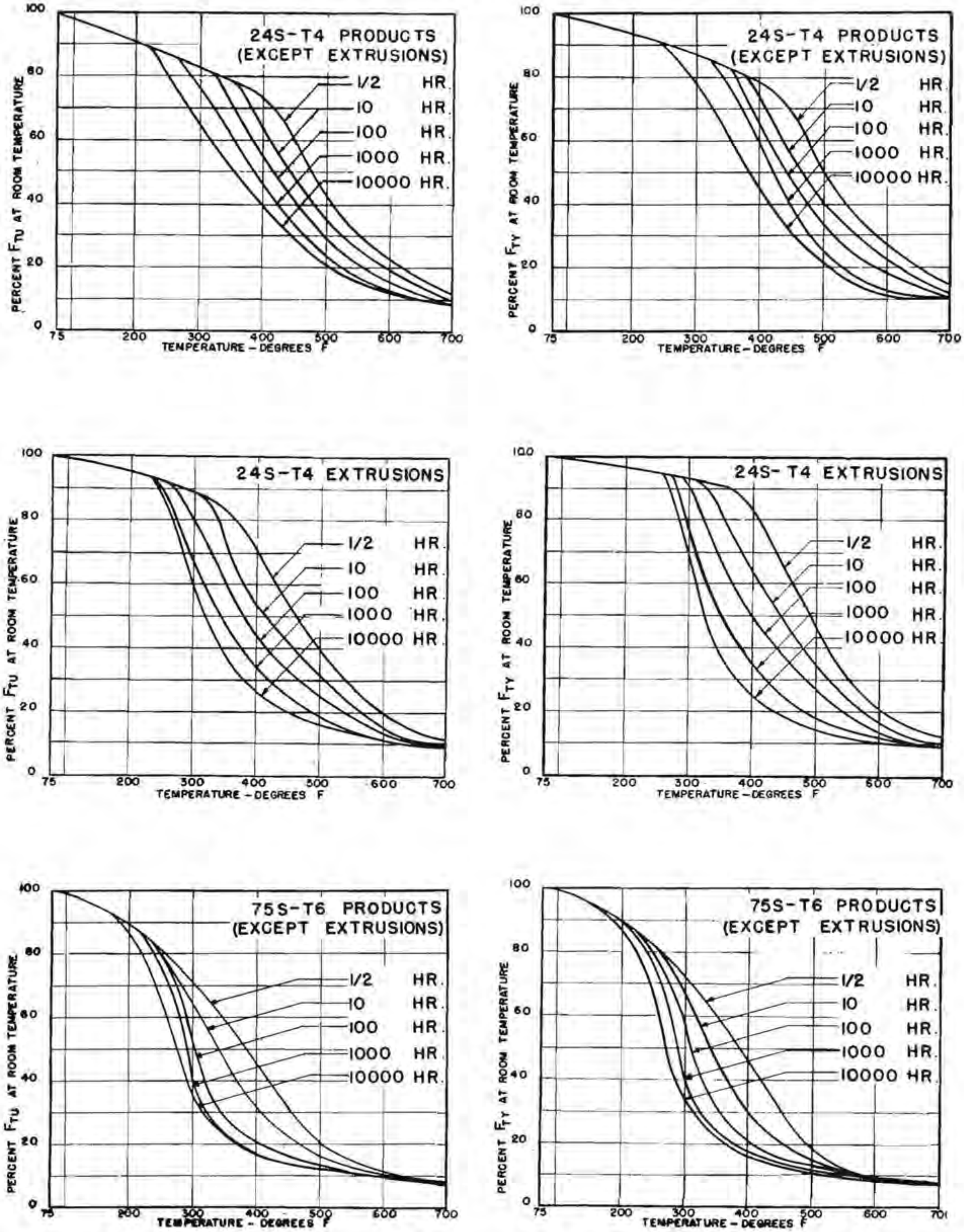
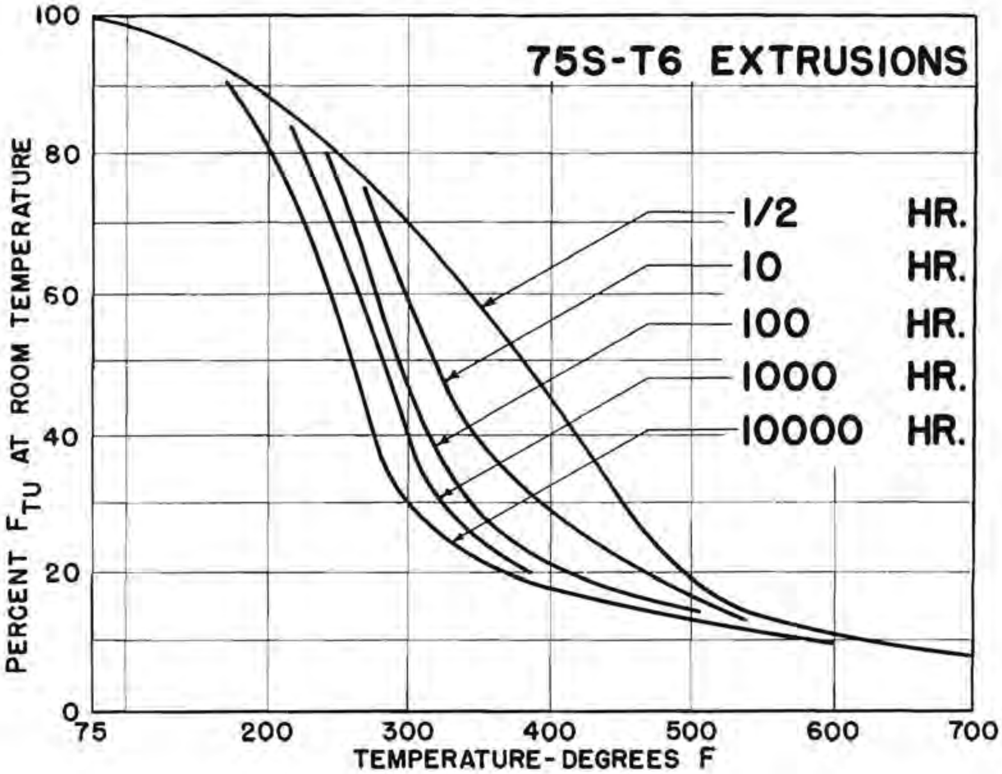


Figure 3.122 (a). Tensile properties of aluminum alloy at elevated temperatures—Continued.



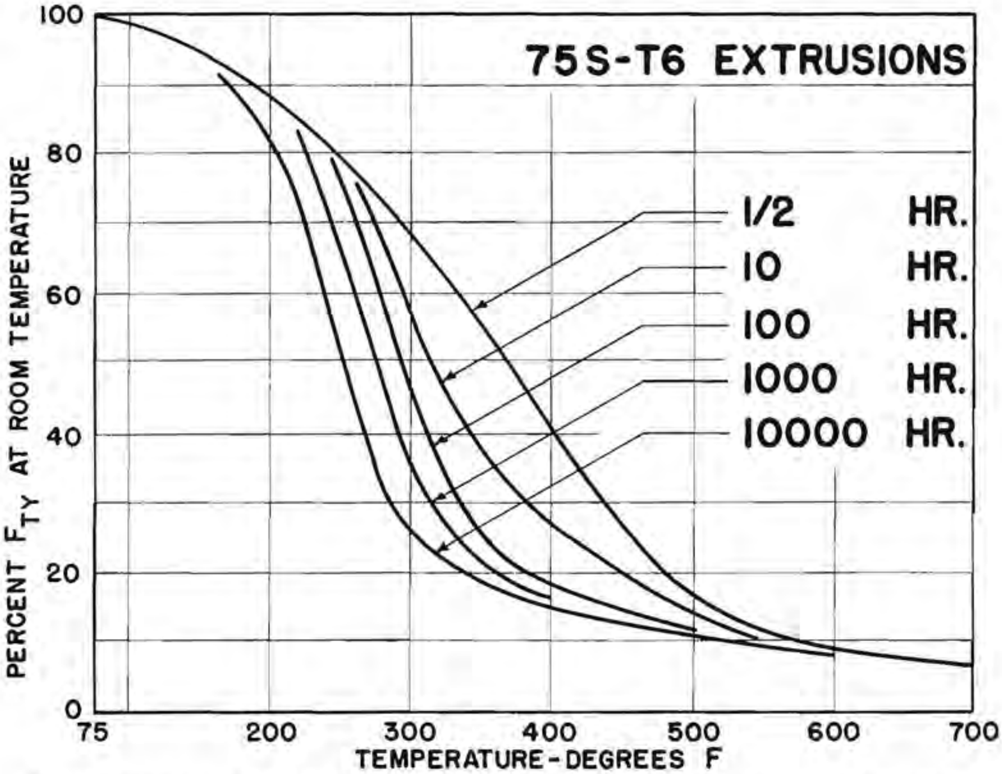
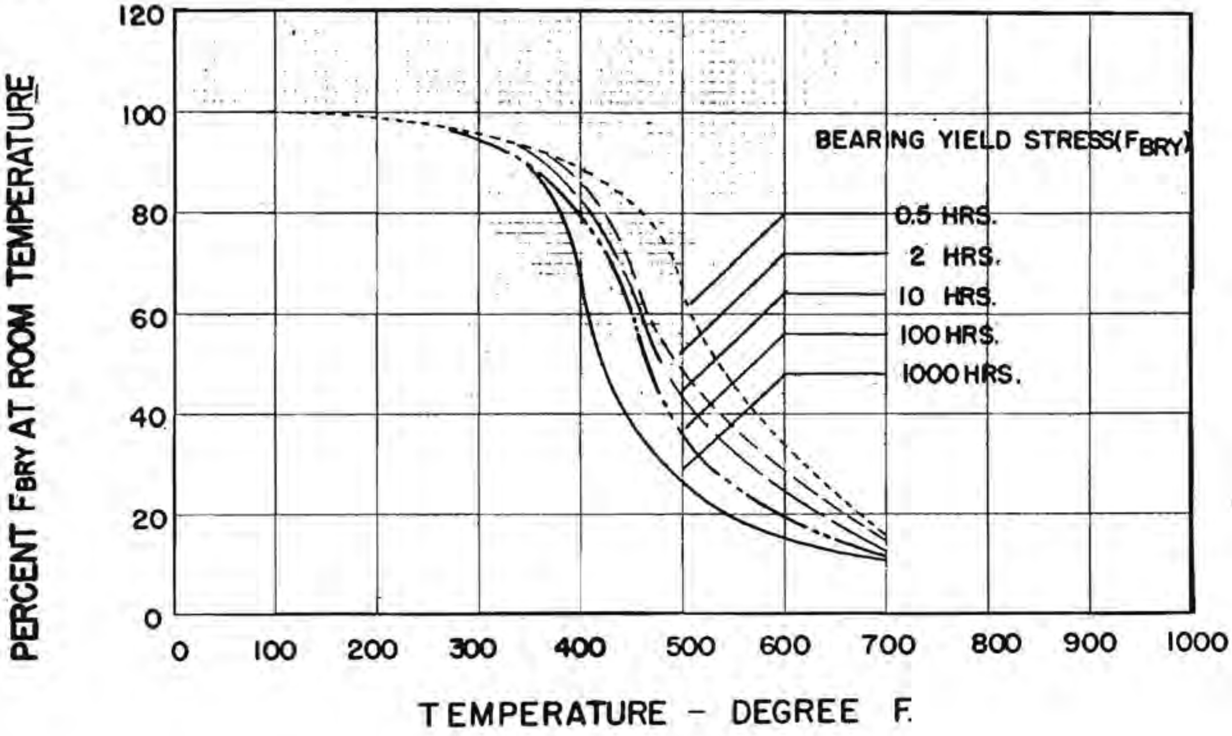


Figure 3.122 (a). Tensile properties of aluminum alloy at elevated temperatures—Concluded.



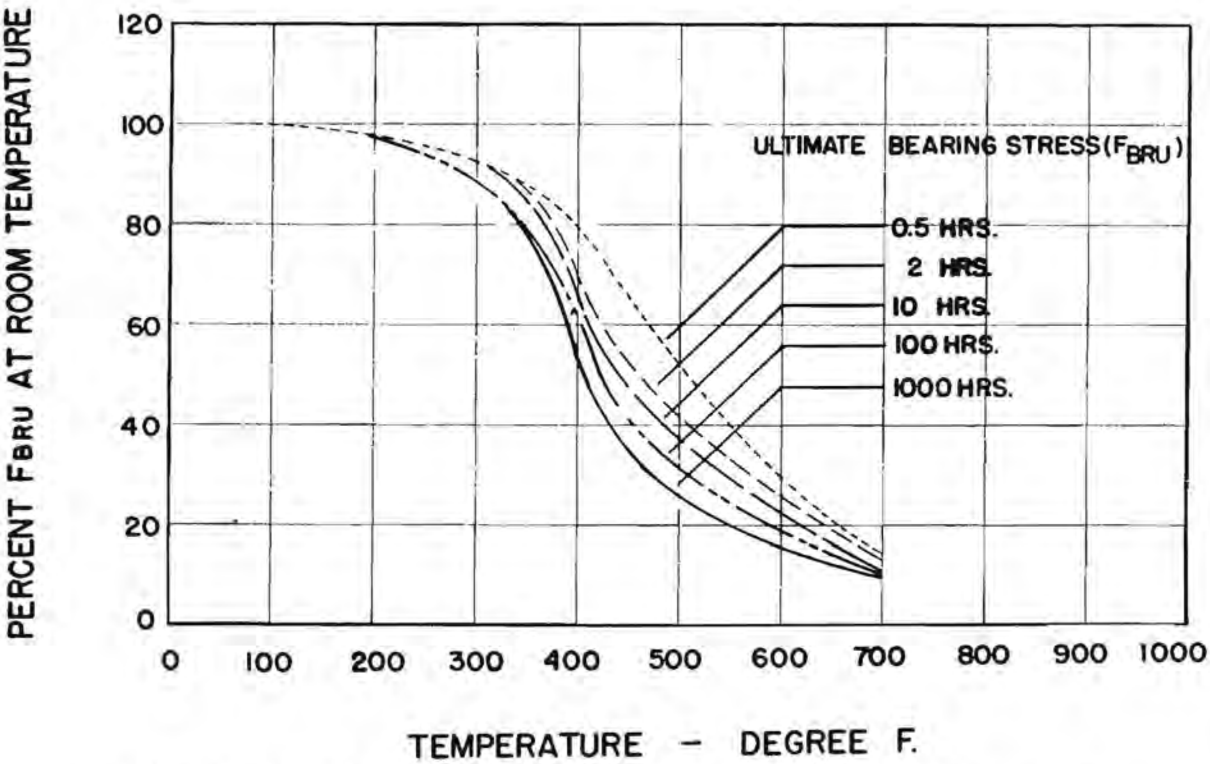
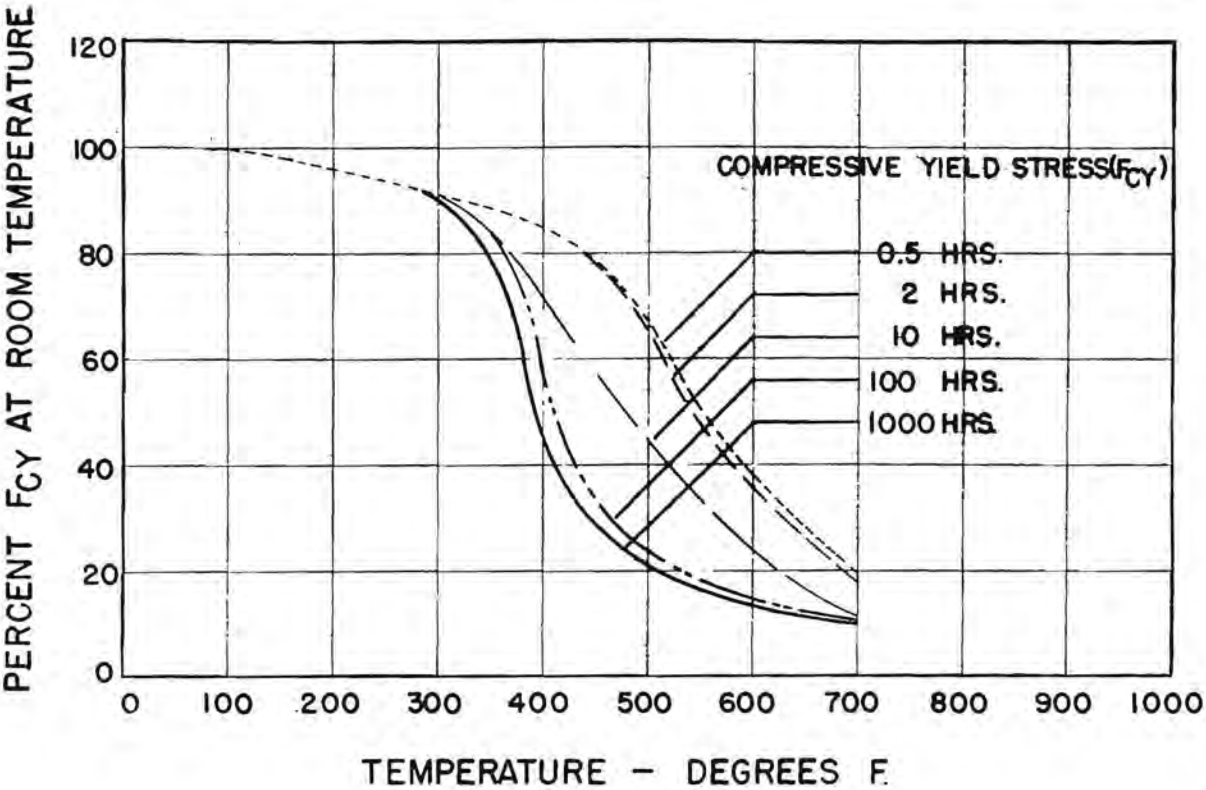


Figure 3.122 (b). Bearing properties of clad 24S–T3 aluminum alloy at elevated temperatures.



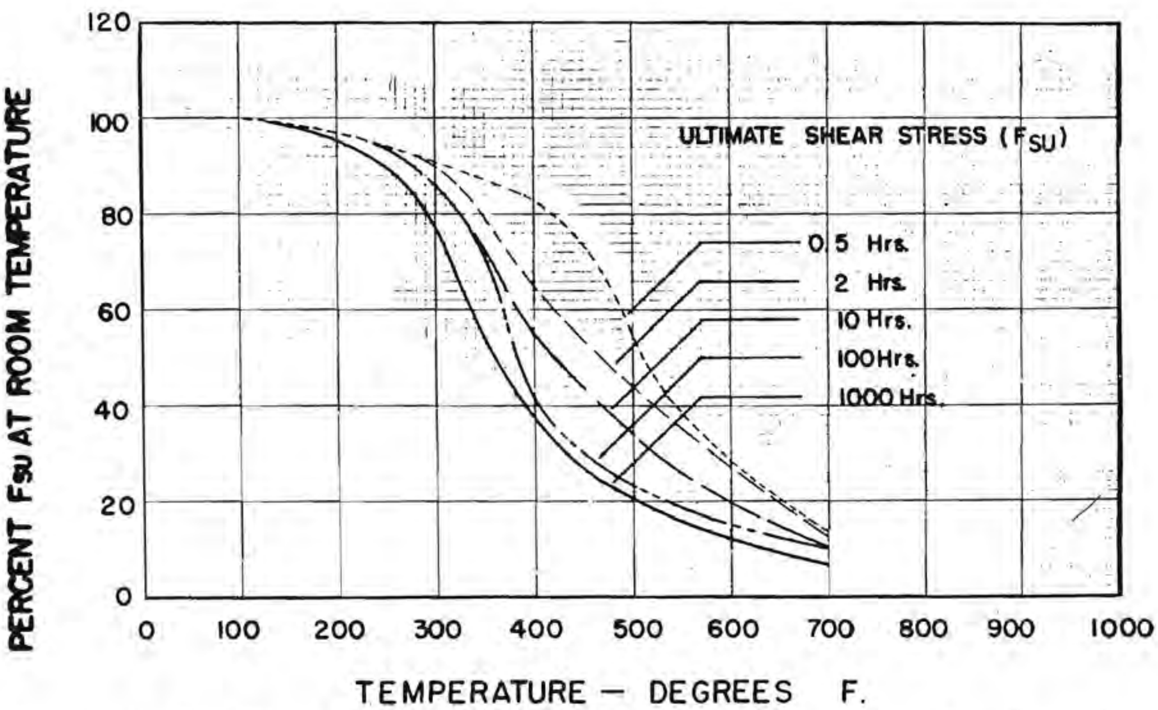
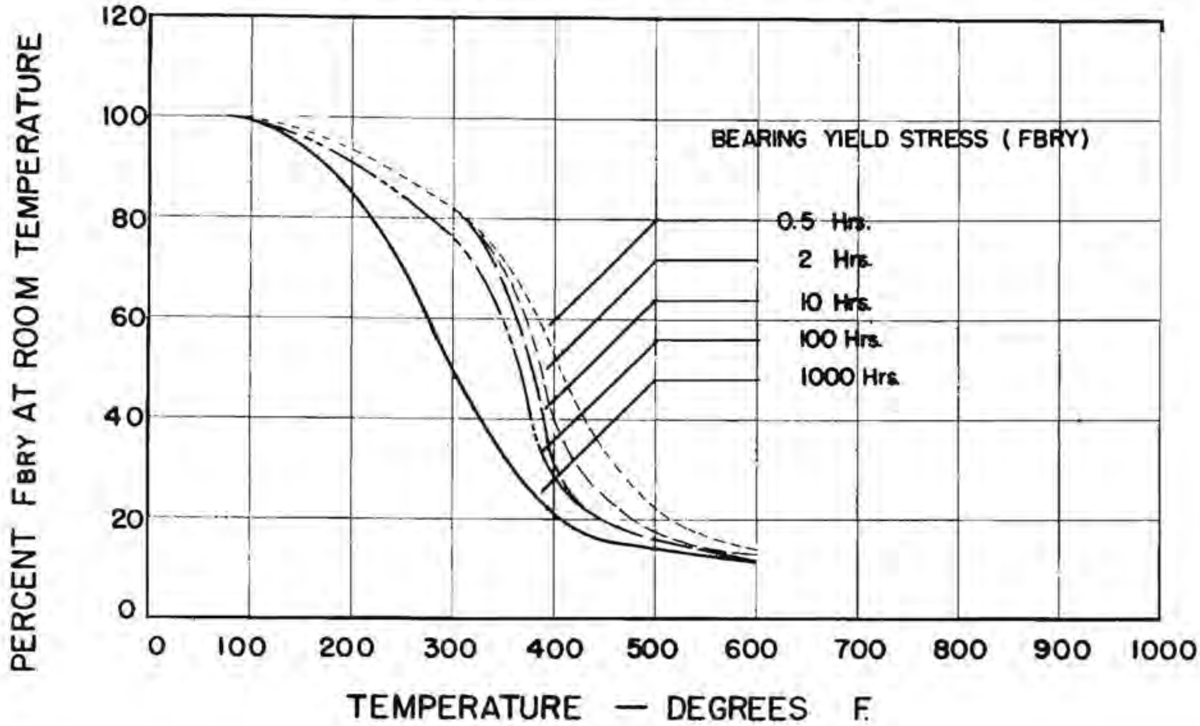


Figure 3.122 (c). Compressive yield and shear properties of clad 24S-T3 aluminum alloy at elevated temperatures.



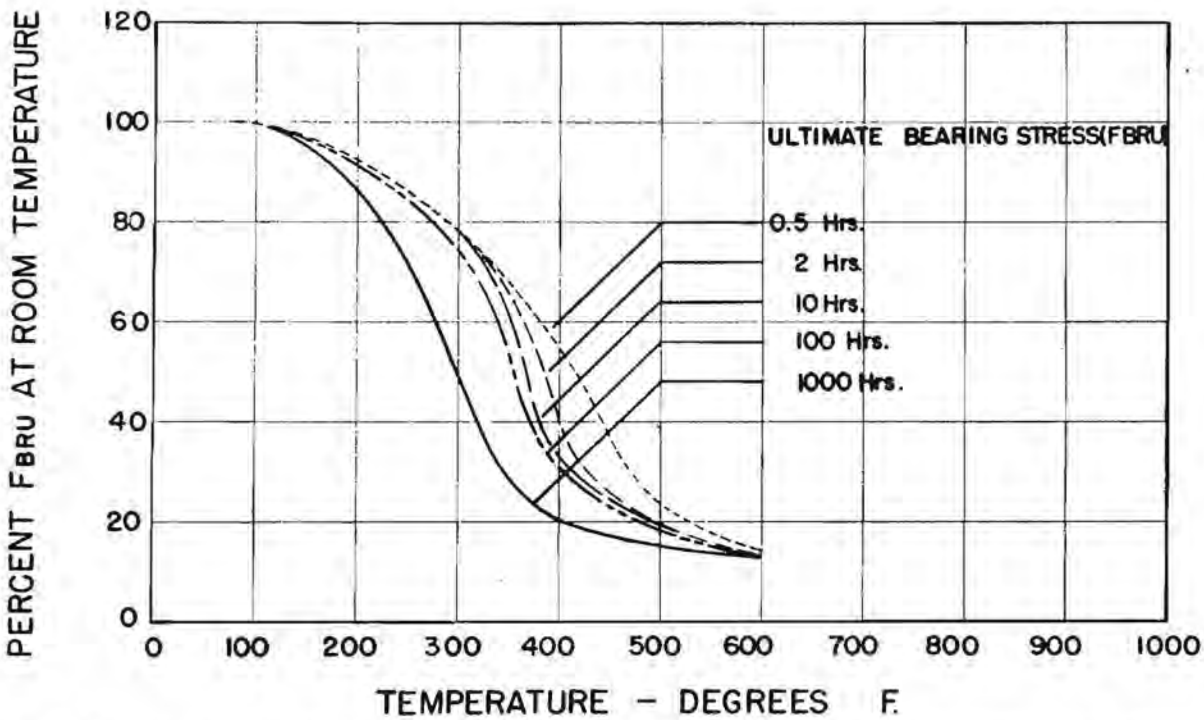
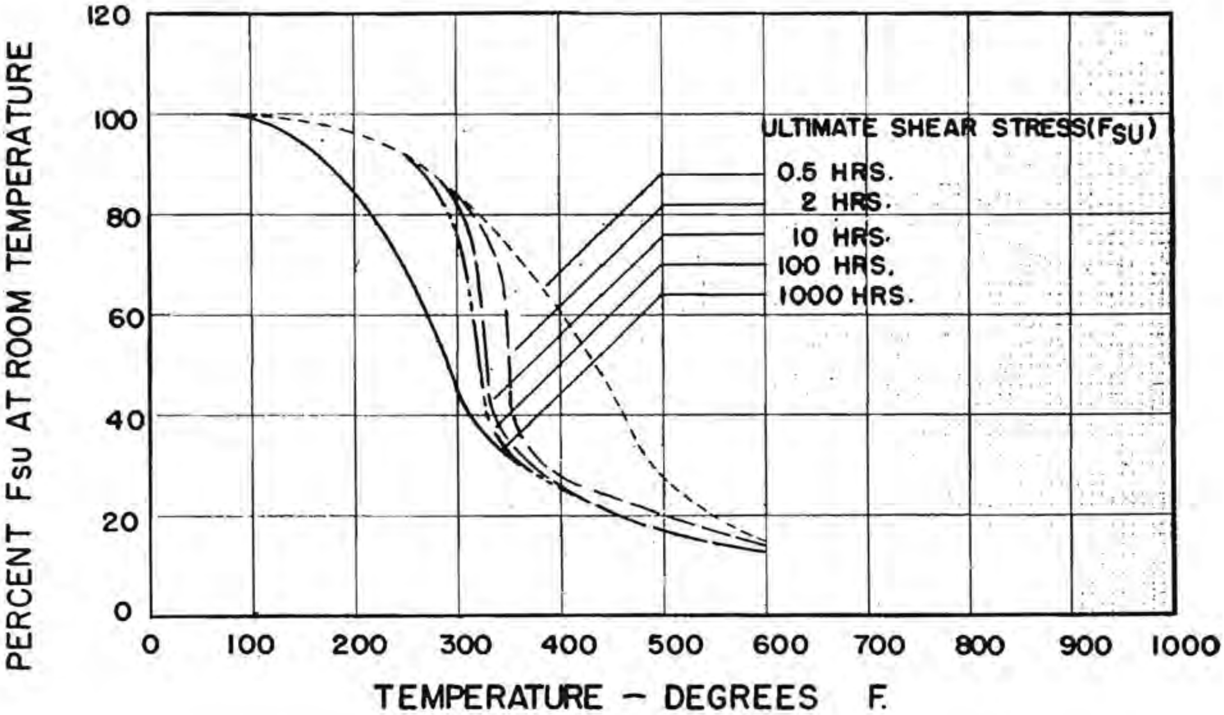
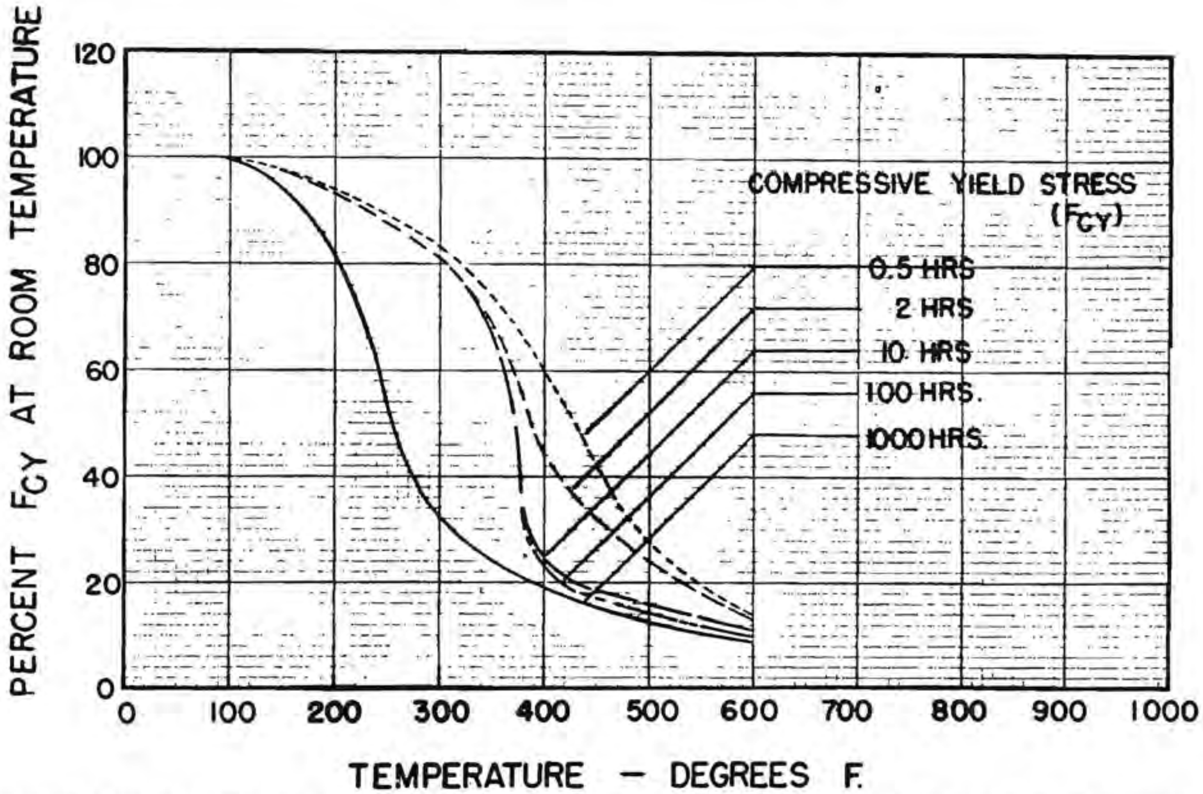


Figure 3.122 (d). Bearing, shear, and compressive yield properties of clad 75S–T6 aluminum alloy at elevated temperatures.





Figures 3.122 (d). Bearing, shear, and compressive yield properties of clad 75S–T6 aluminum alloy at elevated temperatures—Concluded.

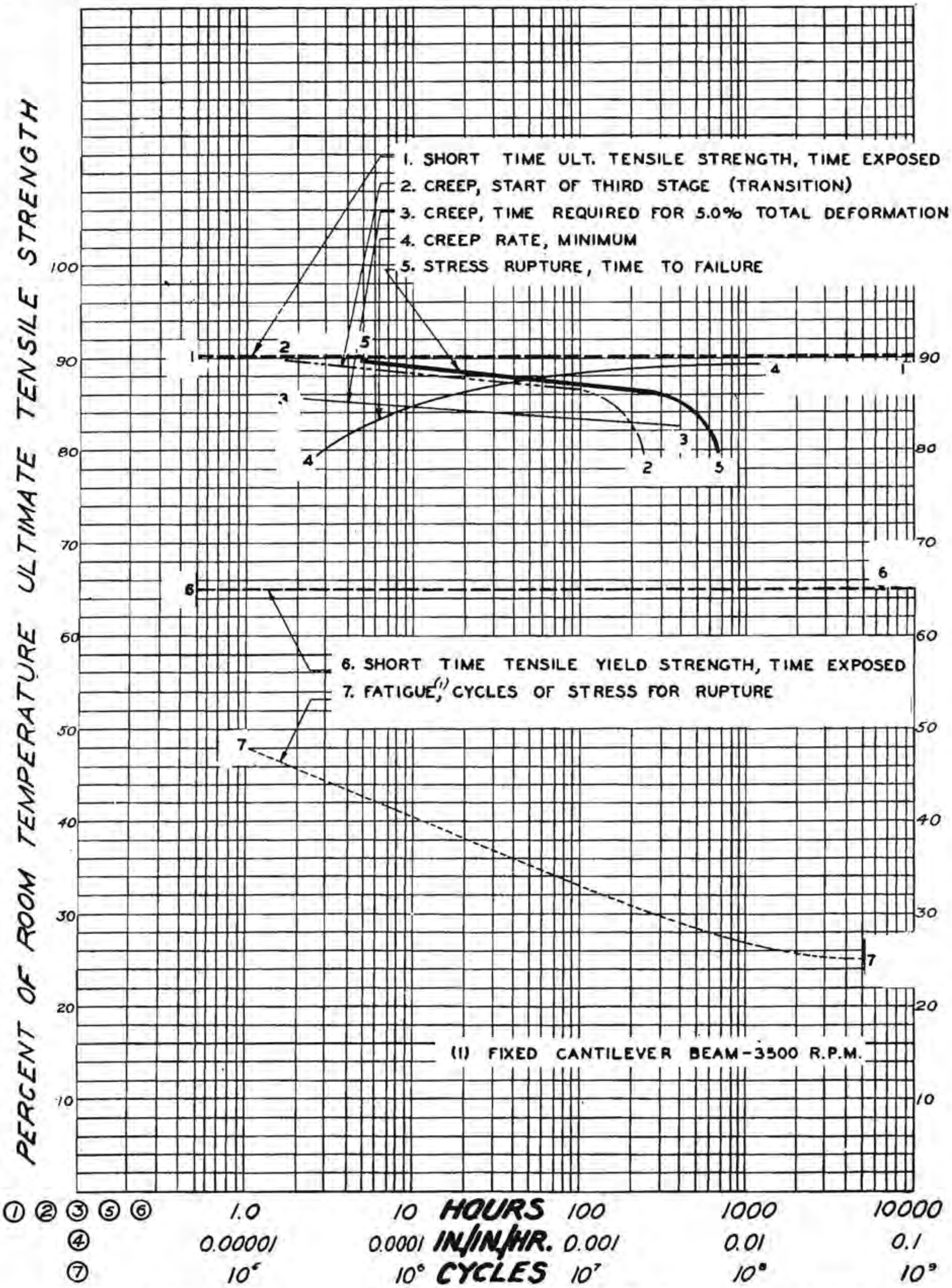


Figure 3.122 (e). Elevated temperature properties of wrought 24S–T3 aluminum alloy at 211° F.

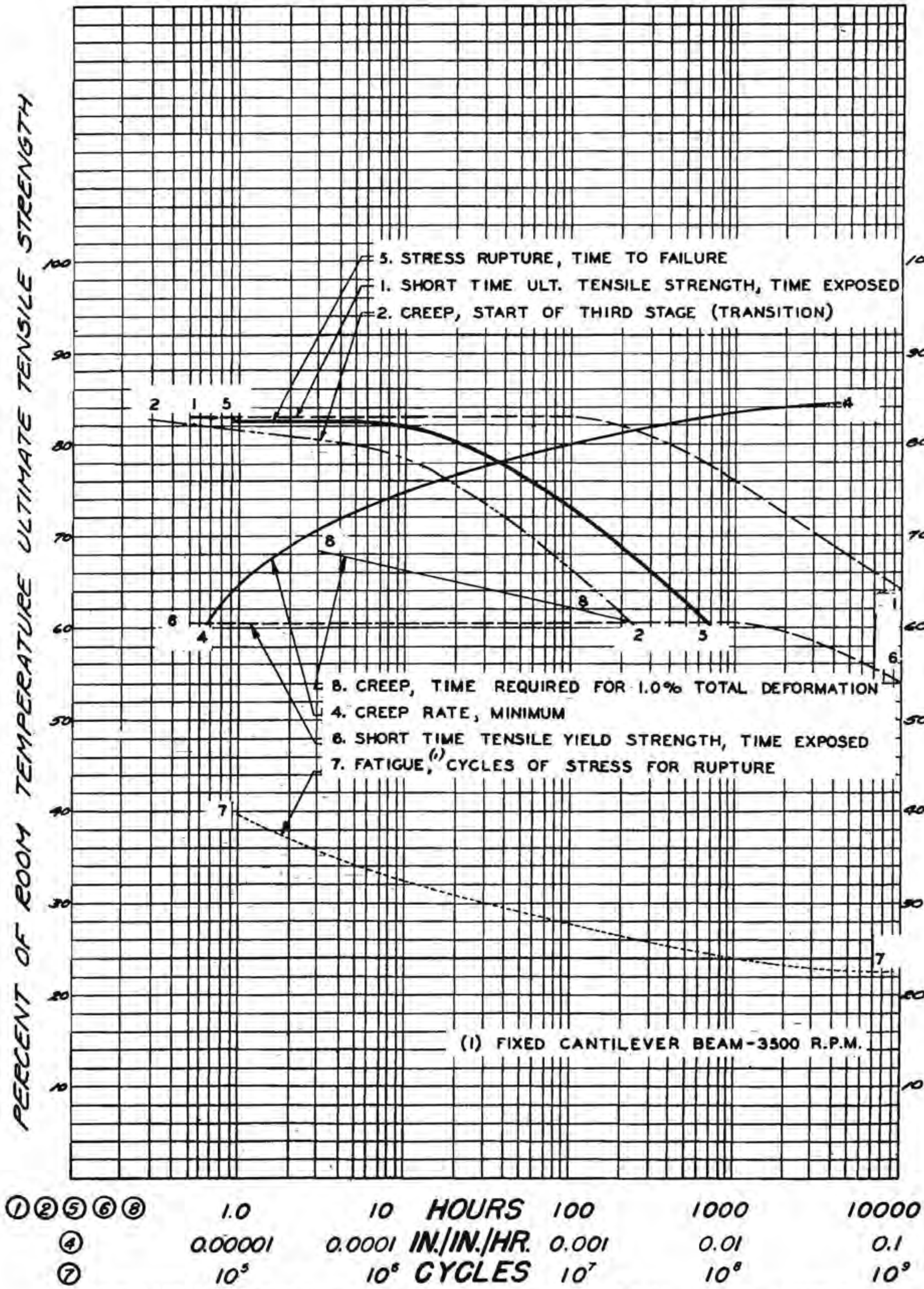


Figure 3.122 (f). Elevated temperature properties of wrought 24S–T3 aluminum alloy at 300° F.

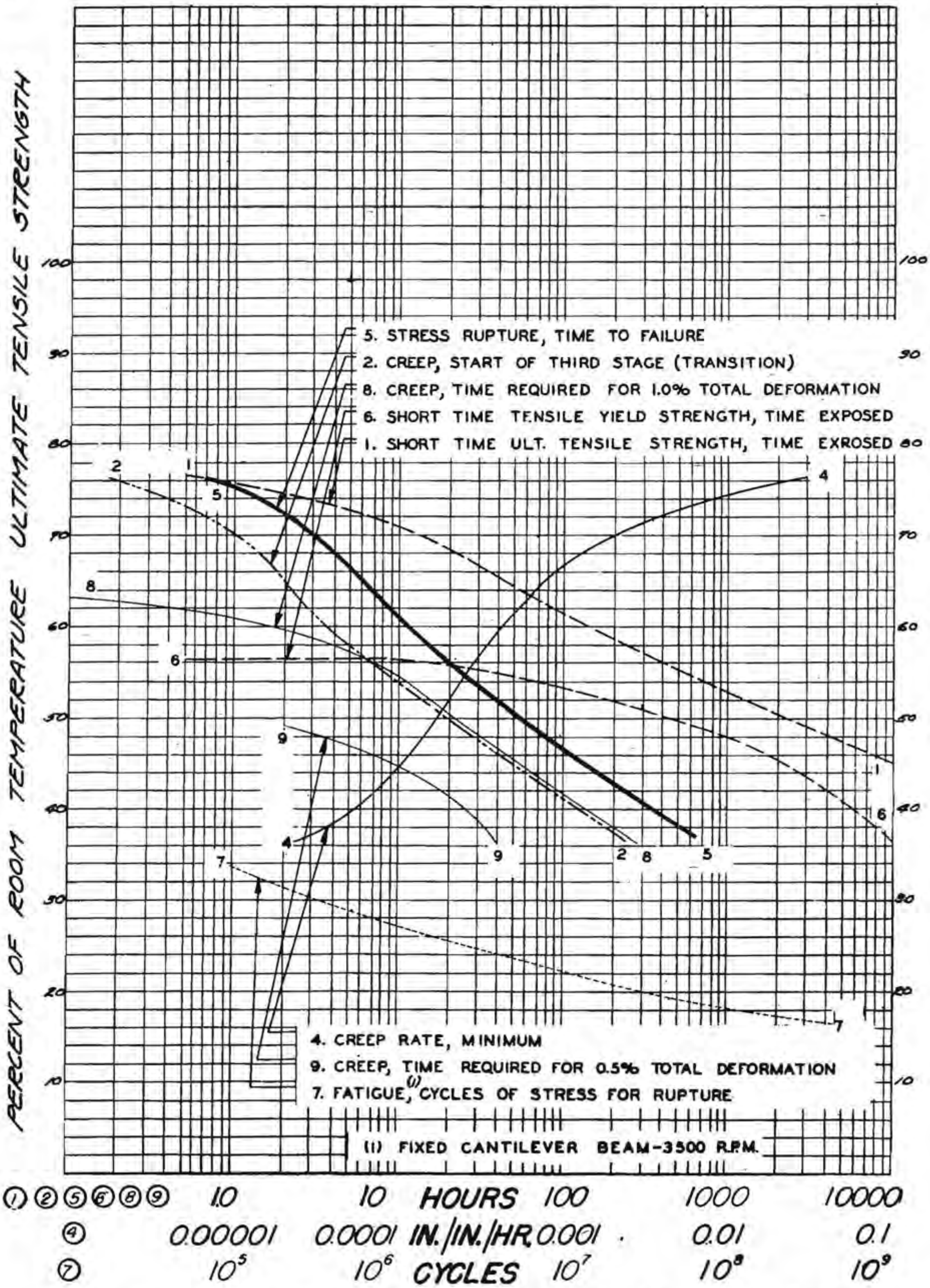


Figure 3.122 (g). Elevated temperature properties of wrought 24S–T3 aluminum alloy at 375° F.

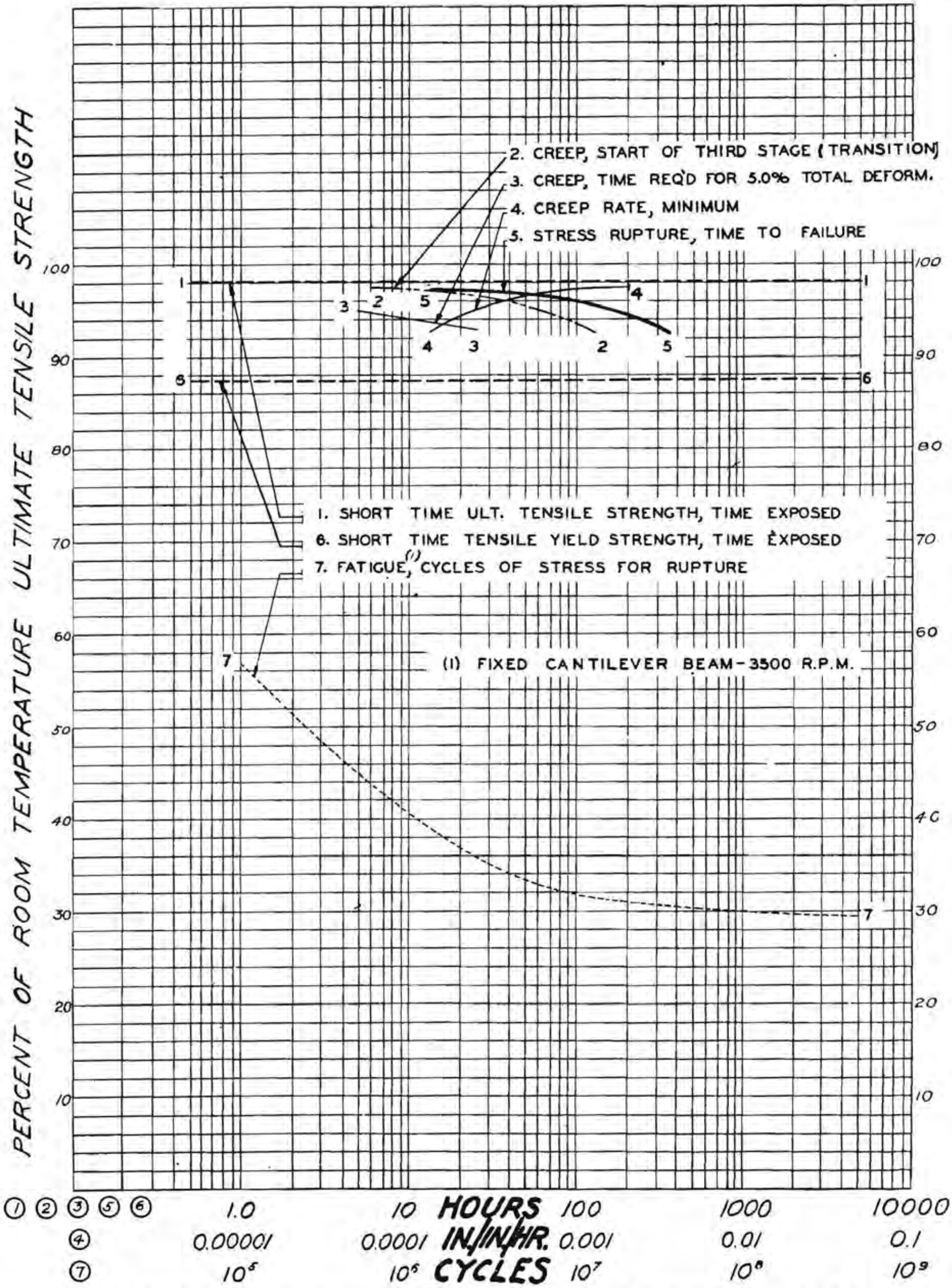


Figure 3.122 (h). Elevated temperature properties of wrought 75S–T6 aluminum alloy at 94° F.

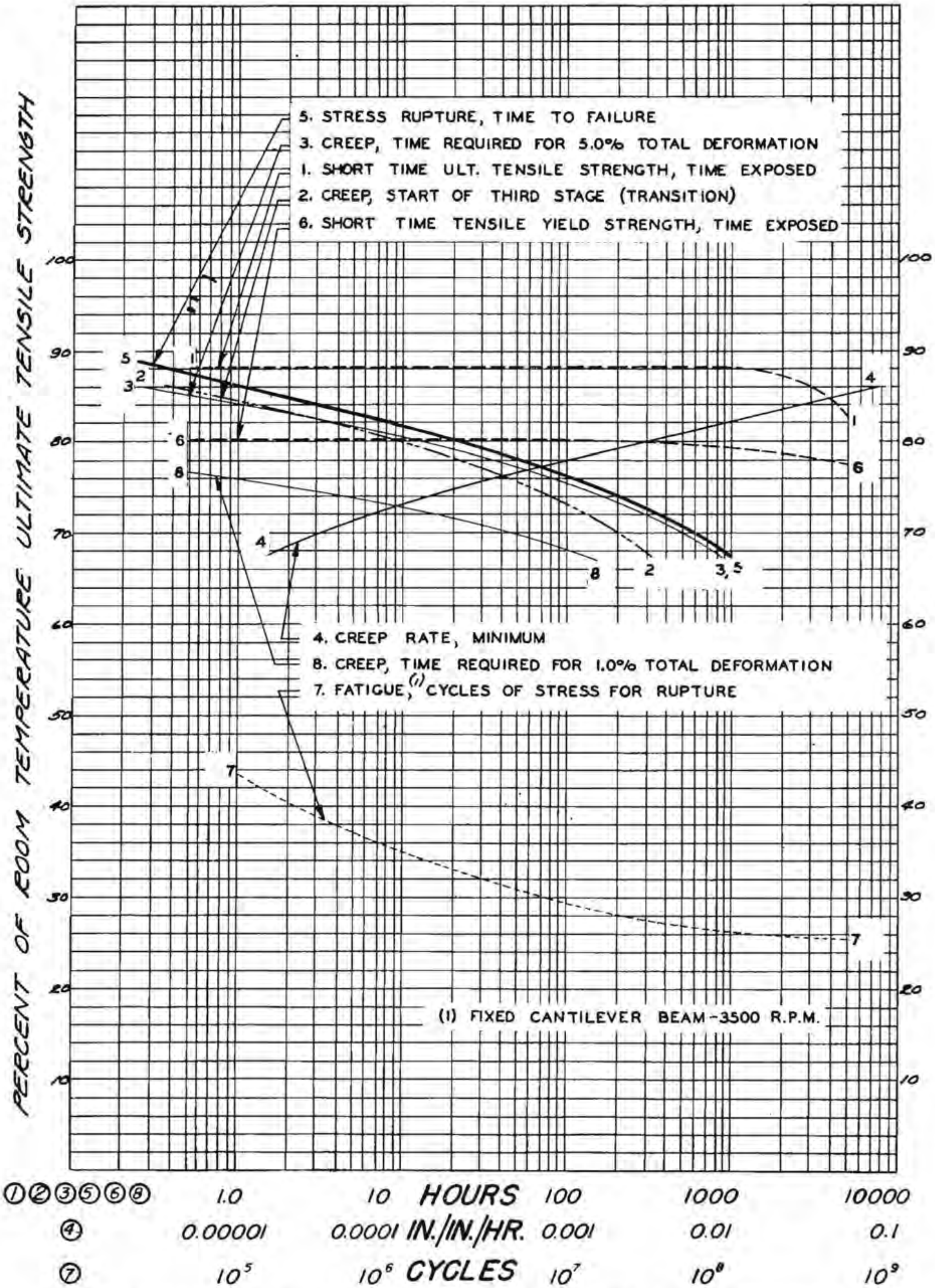


Figure 3.122 (i). Elevated temperature properties of wrought 75S–T6 aluminum alloy at 211° F.

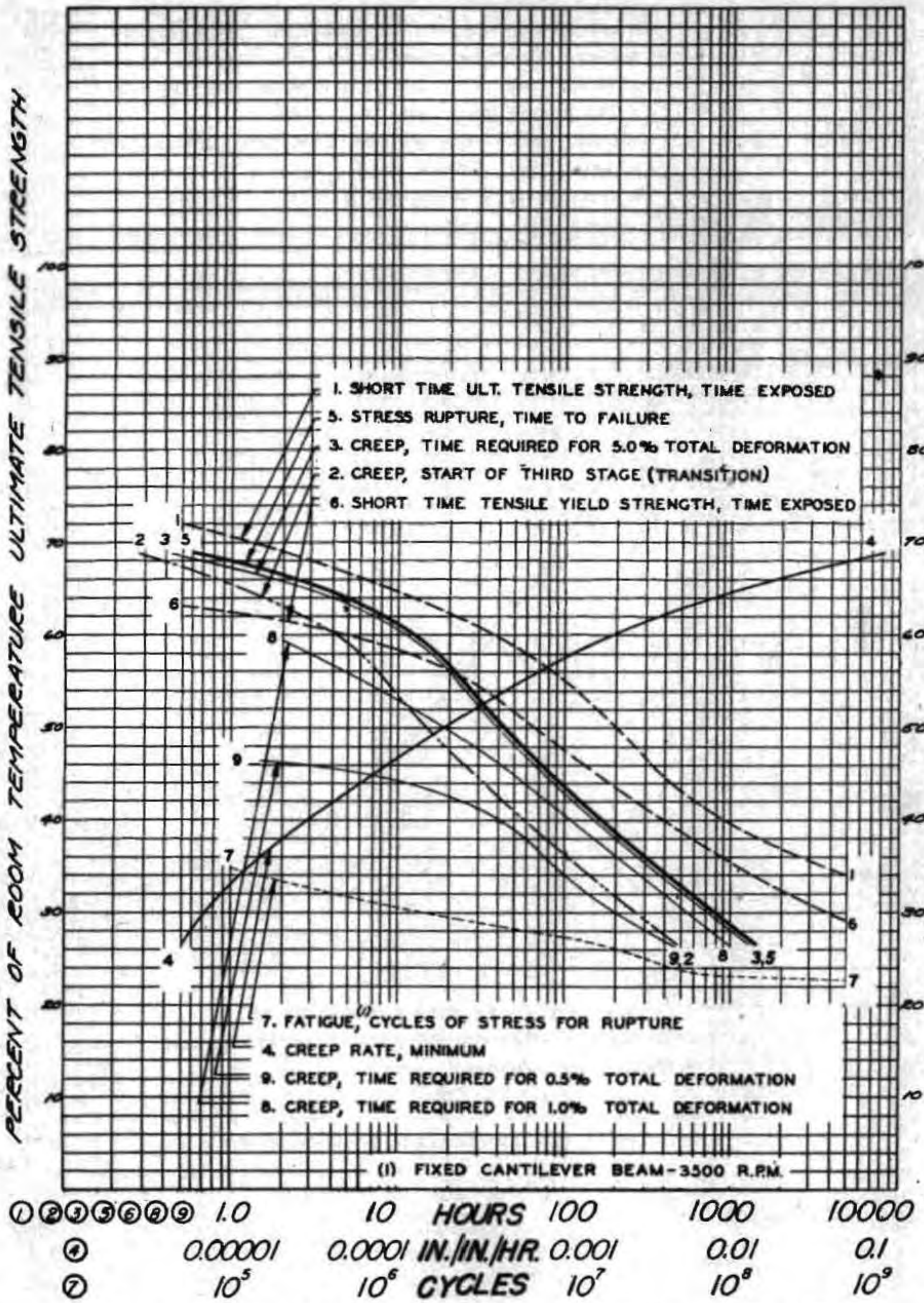


Figure 3.122 (j). Elevated temperature properties of wrought 75S–T6 aluminum alloy at 300° F.

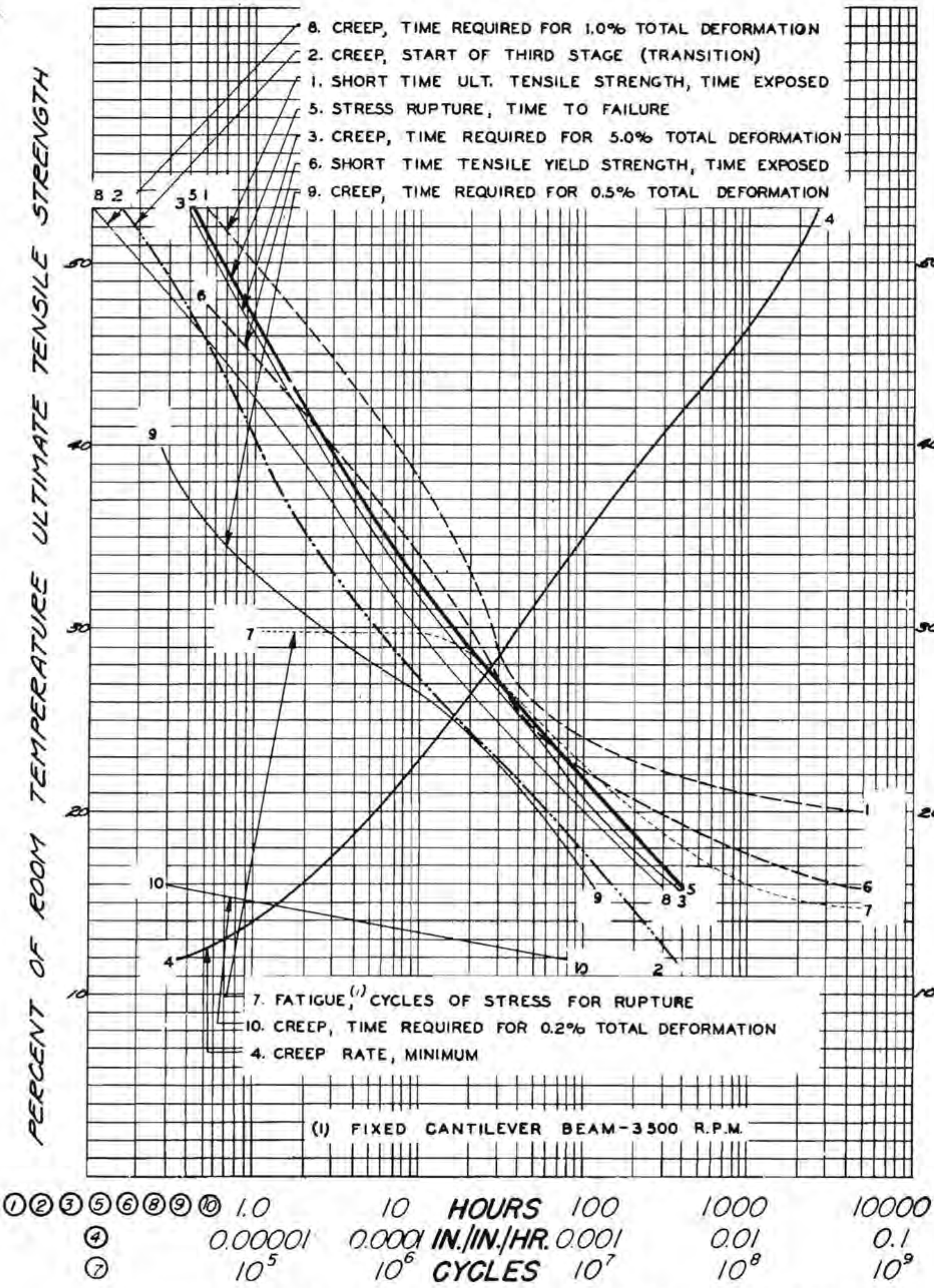


Figure 3.122 (k). Elevated temperature properties of wrought 75S–T6 aluminum alloy at 375° F.

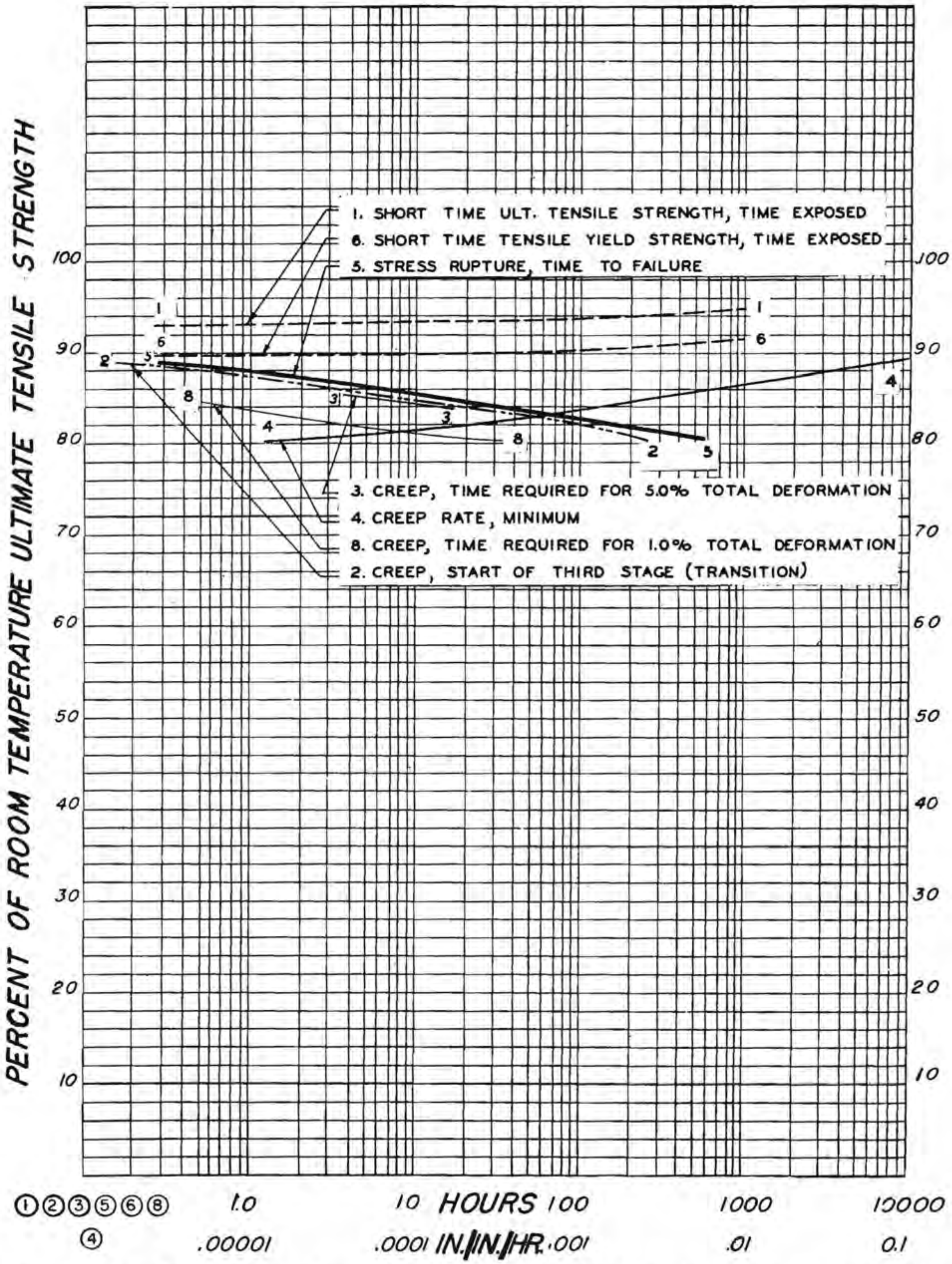


Figure 3.122 (l). Elevated temperature properties of clad 24S–T86 aluminum alloy (heat treated, cold worked, and aged) at 211° F.

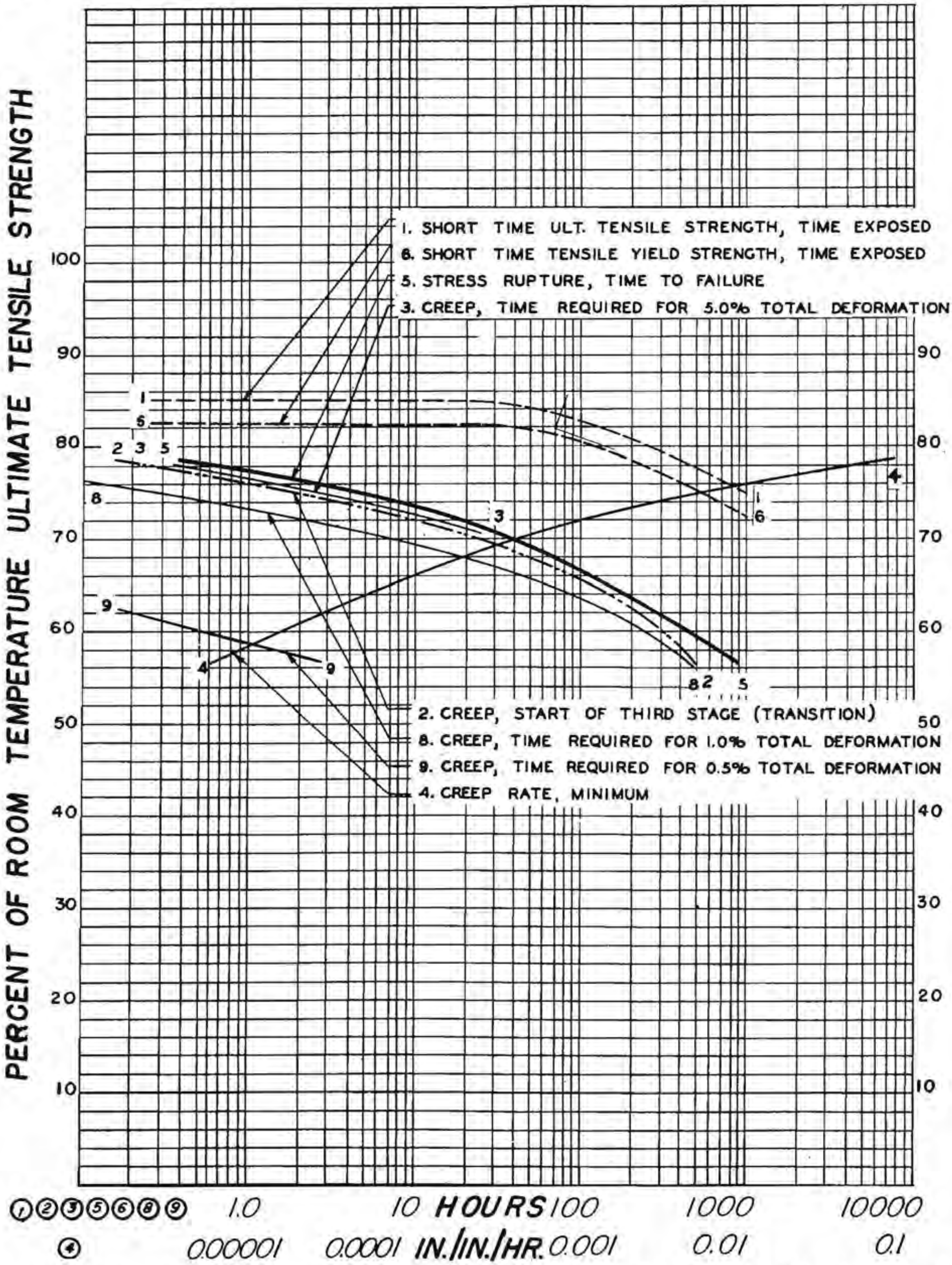


Figure 3.122 (m). Elevated temperature properties of clad 24S–T86 aluminum alloy (heat treated cold worked, and aged) at 300° F.

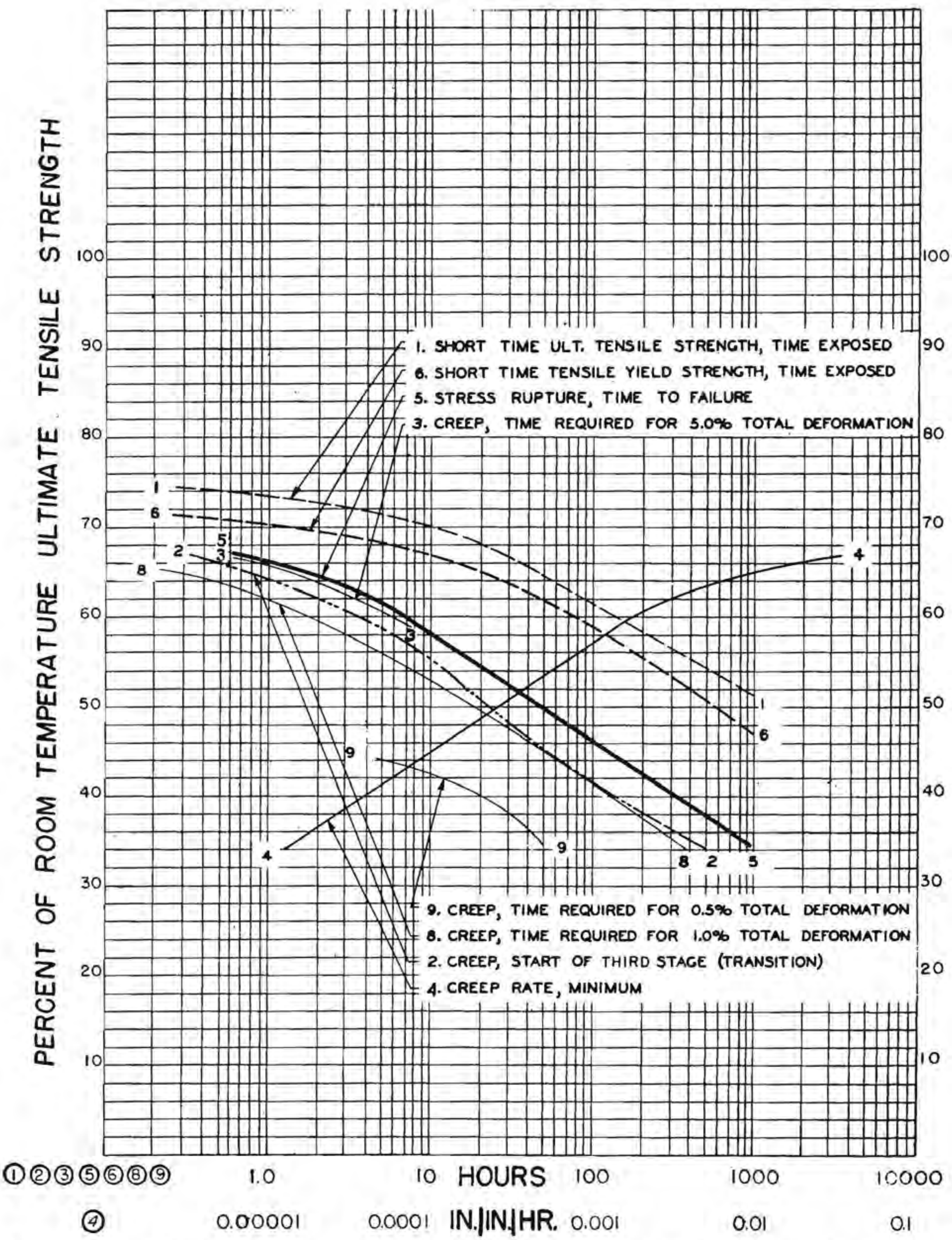


Figure 3.122 (n). Elevated temperature properties of clad 24S–T86 aluminum alloy (heat treated, cold worked, and aged) at 375° F.

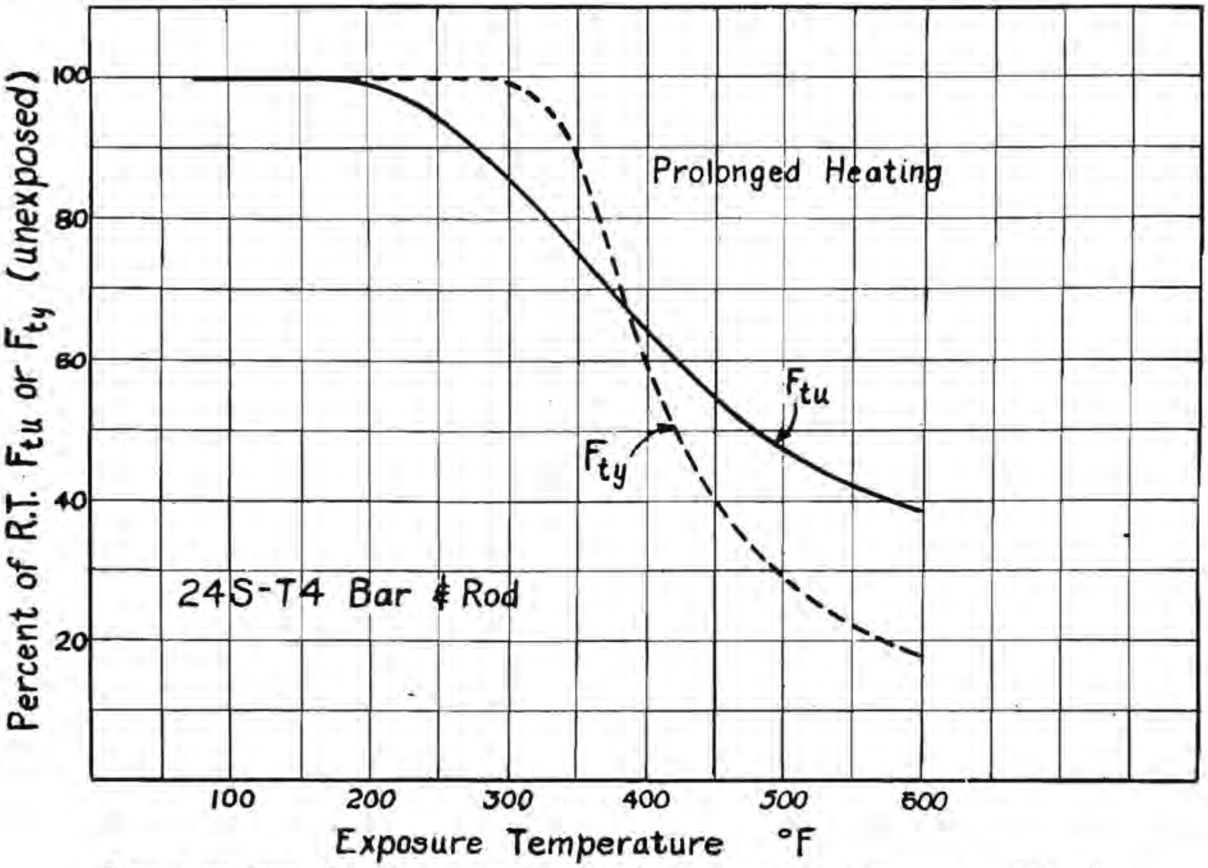


Figure 3.12212 (a). Room temperature properties after exposure to elevated temperature (24S–T4).

(*Continued from page 83.*)

for comparison with other high-temperature properties.

The information on tensile ultimate, tensile yield, and shear properties is based on tests which did not include any clad material. The percentages for nonclad material, however, are considered representative of what would be expected for the corresponding clad material. The data relating to the reduction in bearing and compressive properties were obtained from tests on clad material. These percentages may also be applied to the corresponding nonclad materials. The data concerning the effect of temperature on static properties are based on continuous heating, but may be applied to intermittent heating problems when the total time at temperature is the same.

The effect of temperature on the modulus of elasticity is given in table 3.121 for several aluminum alloys.

3.12212 *Effect of exposure.* The tensile ultimate and yield strength of aluminum alloys 24S-T4 and 75S–T6 at room temperature after exposure to elevated temperatures up to 600° F. for various periods of time are given in figures 3.12212 (*a*) and 3.12212 (*b*). These curves present the effect of exposure on tensile properties only. No data are available for the effect of elevated temperature exposure on room temperature compressive, bearing, and shear properties.

3.1222 *Fatigue properties.* Curves for computing approximate reductions in tensile-ultimate strengths for 24S heat-treated and 75S heat-treated and aged aluminum alloy materials subjected to reversed loading at elevated temperatures are shown in figures 3.122 (*e*) to (*n*) for temperatures up to 375° F. This information is based on tests on cantilever beam machines in which one end of the specimen is deflected in the path of a circle subjecting the specimen to completely reversed loading. These tests include only nonclad materials but are considered applicable to clad materials. For situations involving fatigue stresses in which the mean stresses are other than zero, consideration must be given to creep and creep-rupture properties in addition to fatigue properties.

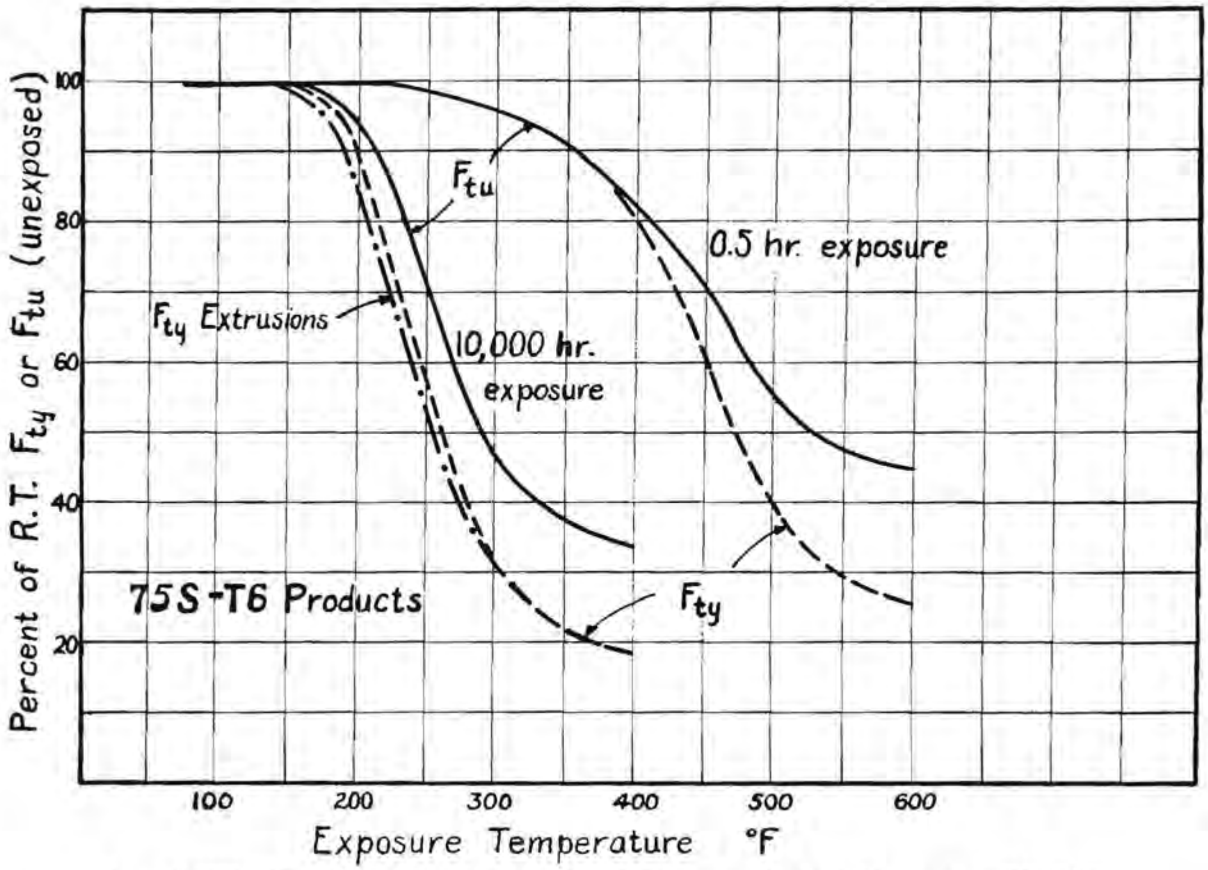


Figure 3.12212 (b). Room temperature properties after exposure to elevated temperature (75S–T6).

Table 3.1222. Cantilever-beam fatigue strengths of wrought aluminum alloys at elevated temperatures.

Alloy and temper	Testing temperature, °F.	Fatigue strength (reversed stress), *ksi*, at indicated number of cycles				
		100,000 cycles	1,000,000 cycles	10,000,000 cycles	100,000,000 cycles	500,000,000 cycles
14S–T6	75	39	30	24	19	18
	300	23	18	15	13	12
	400	14	12	10	8.5	8
	500	10	8.5	7	5.5	5
24S–T4	75	43	31	24	21	20
	300	24	20	17	15	14
	400	20	16	13	10	9.5
	500	14	11	8.5	7	6
A51S–T6	75	30	22	17	13	12
	300	21	16	11	9	8.5
	400	11	8	6	5	4.5
	500	6.5	5.5	4.5	4	3.5
61S–T6	75	31	23	17	15	14
	300	24	18	14	11	11
	400	19	15	11	8.5	7.5
	500	7.5	6	5.5	4.5	4.5
75S–T6	75	40	29	24	22	22
	300	18	15	13	12	12
	400	13	11	9.5	8.5	8.5
	500	12	9.5	8	7.5	7

Values of cantilever-beam fatigue strengths of wrought aluminum alloys at elevated temperatures are given in table 3.1222. These values were determined by testing 0.4-inch-diameter machined specimens in ARL fixed cantilever-beam fatigue machines and represent extreme fiber stresses that such specimens will withstand in completely reversed flexure. All specimens had been stabilized by prolonged heating at testing temperature before testing. Values at 75° F. are from rotating beam tests.

3.1223 *Creep and stress-rupture properties.* Curves for computing the approximate reduction in ultimate tensile strength under long-time loads and for predicting corresponding deformations for 24S (heat-treated), 24S (heat-treated, cold-worked, and aged), and 75S (heat-treated and aged) aluminum alloys are given in figures 3.122 (*e*) to (*n*), inclusive, for temperatures up to 375° F. This information is based on clad sheet material only, but the percentages are considered applicable to non-clad sheet and other wrought materials of 24S heat-treated and 75S heat-treated and aged. No data are currently available concerning the effect of elevated temperature on shear, bearing, and compression creep-rupture characteristics.

3.12231 *Short time creep.* Figures 3.12231 (*a*) through (*l*) present the effect of short times at temperature on the creep properties of aluminum alloys. These materials were tested by applying a dead load at room temperature, heating rapidly by using a welding transformer to apply a large electric current to the specimen, and then measuring the total deformation including the thermal expansion. Details of the procedure are given in reference 3.12231. These curves are intended to supplement the data given in figures 3.122 (*e*) to (*n*) by providing information concerning the effect of temperature on creep for times less than approximately 1 hour. The data shown in figures 3.12231 (*a*) to (*l*) are for clad aluminum alloys, but the percentage figures given can also be applied to non-clad products except extrusions.

3.13 CRITERIA FOR DESIGN MECHANICAL PROPERTIES. The test methods used to establish the design mechanical properties appearing in this chapter are discussed below, unless discussed in a note accompanying the table in which the allowables appear.

3.131 *Shear strengths.* The values of shear strengths of aluminum alloy sheet at room temperature were determined by measuring the load required to punch from the sheet a 2¾-inch-diameter disk, using a special punch and die. The values for other aluminum products were determined from double shear tests of cylindrical specimens in which a 1-inch length is sheared from the center of a specimen 3 inches long. In both cases, the shearing was done with hardened steel tools which have sharp smoothly finished cutting edges that are maintained in that condition. The shear strengths at elevated temperatures were also obtained

(*Continued on page 114.*)

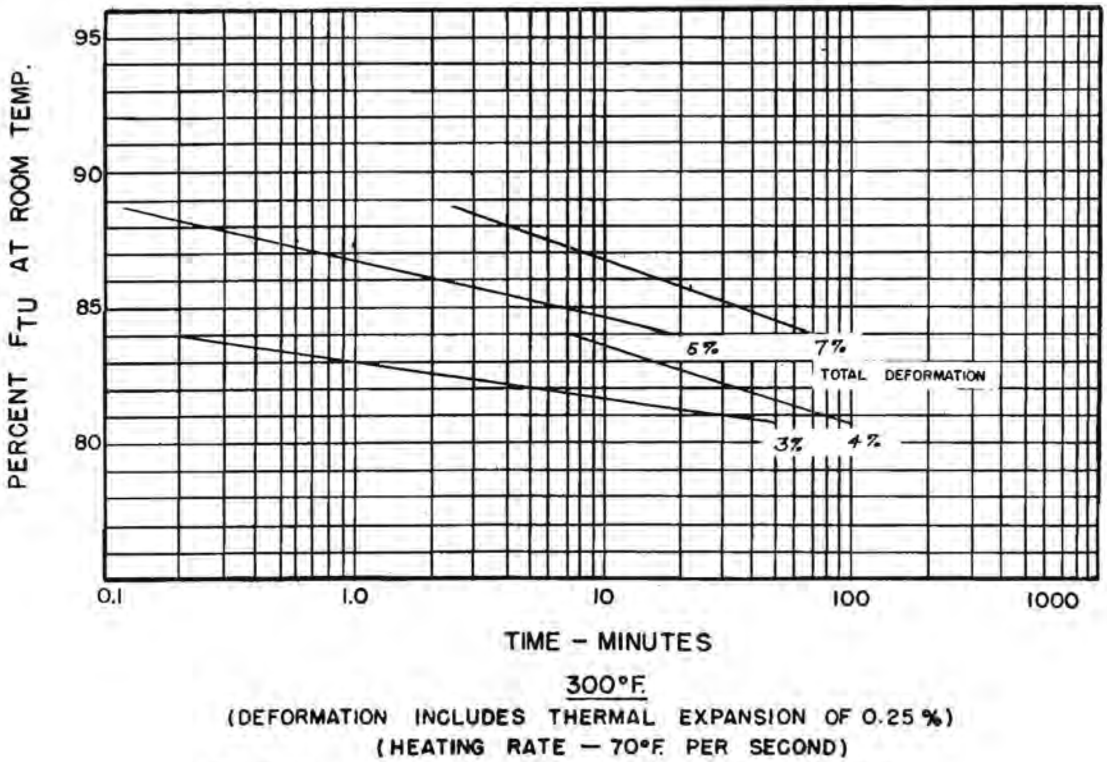


Figure 3.12231 (a). Short time creep curves for clad 24S–T3 sheet.

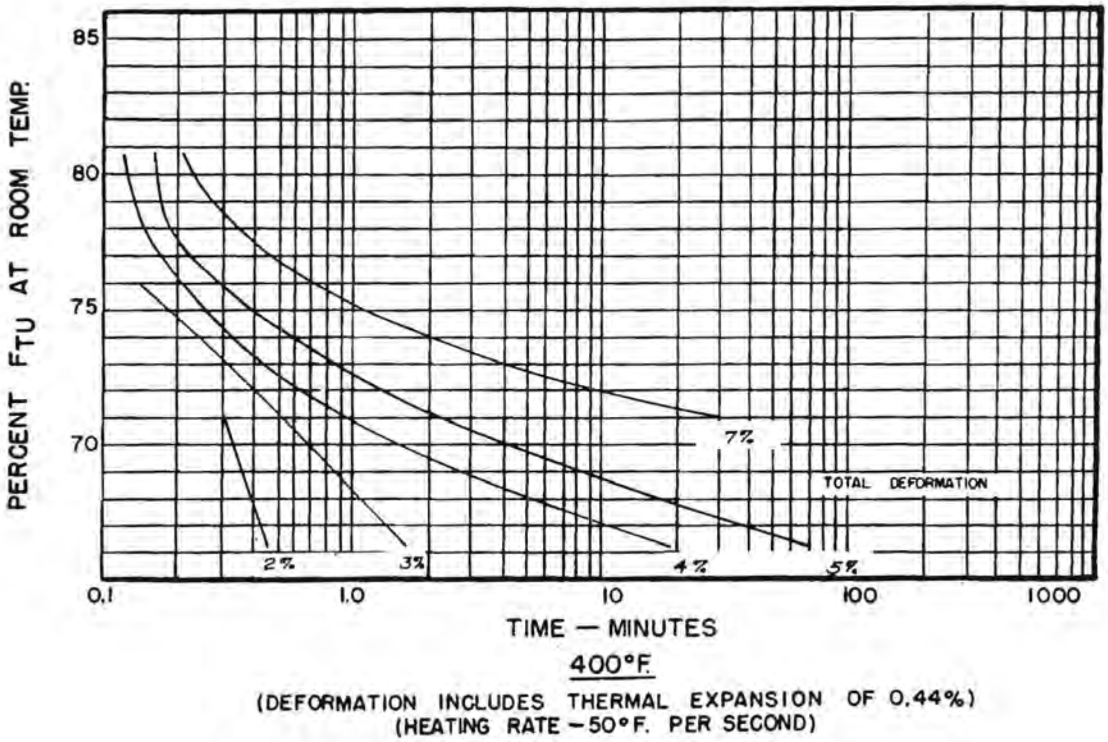


Figure 3.12231 (b). Short time creep curves for clad 24S–T3 sheet.

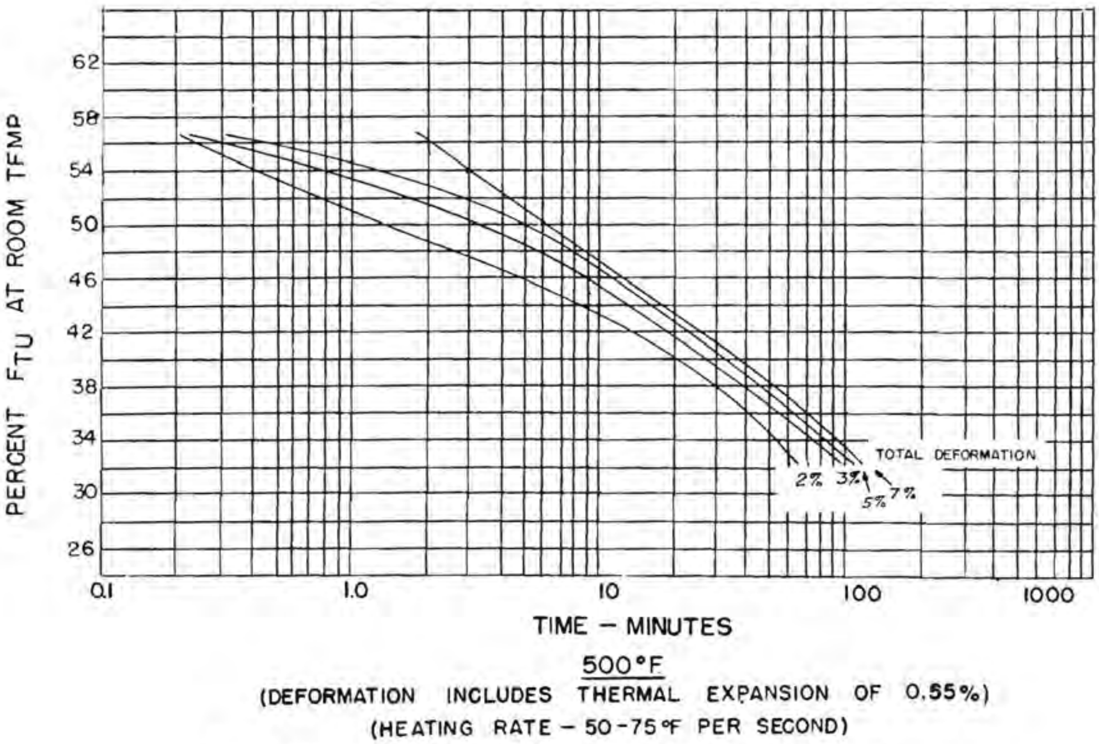


Figure 3.12231 (c). Short time creep curves for clad 24S–T3 sheet.

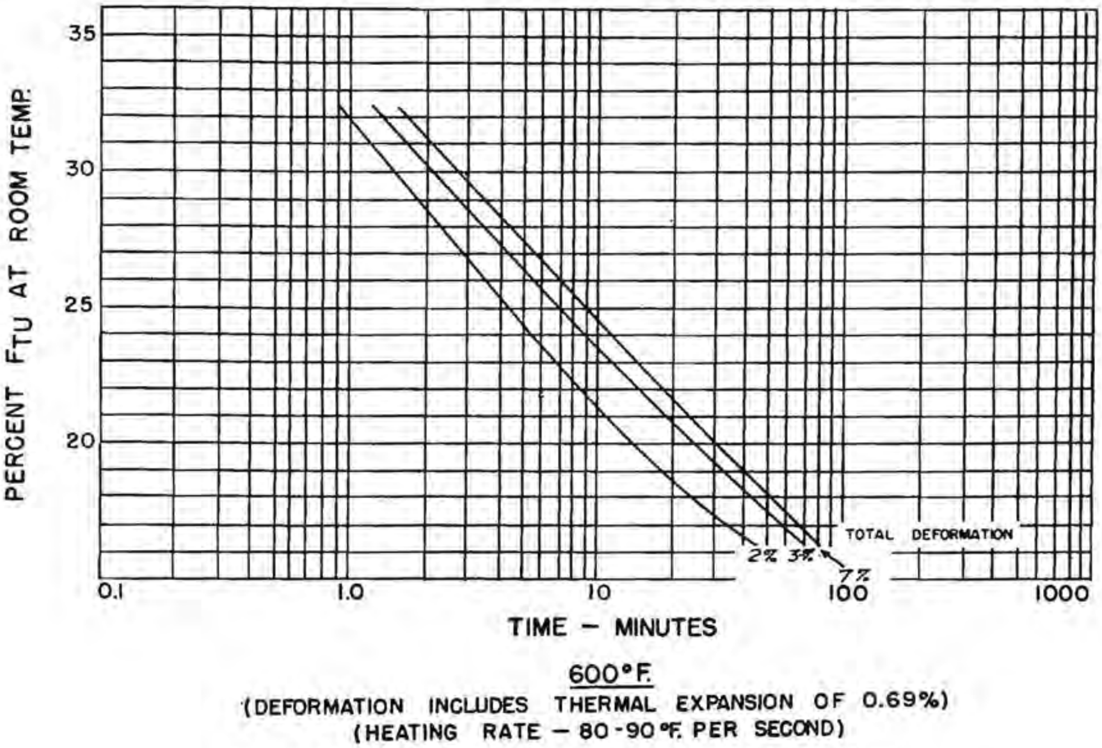


Figure 3.12231 (d). Short time creep curves for clad 24S–T3 sheet.

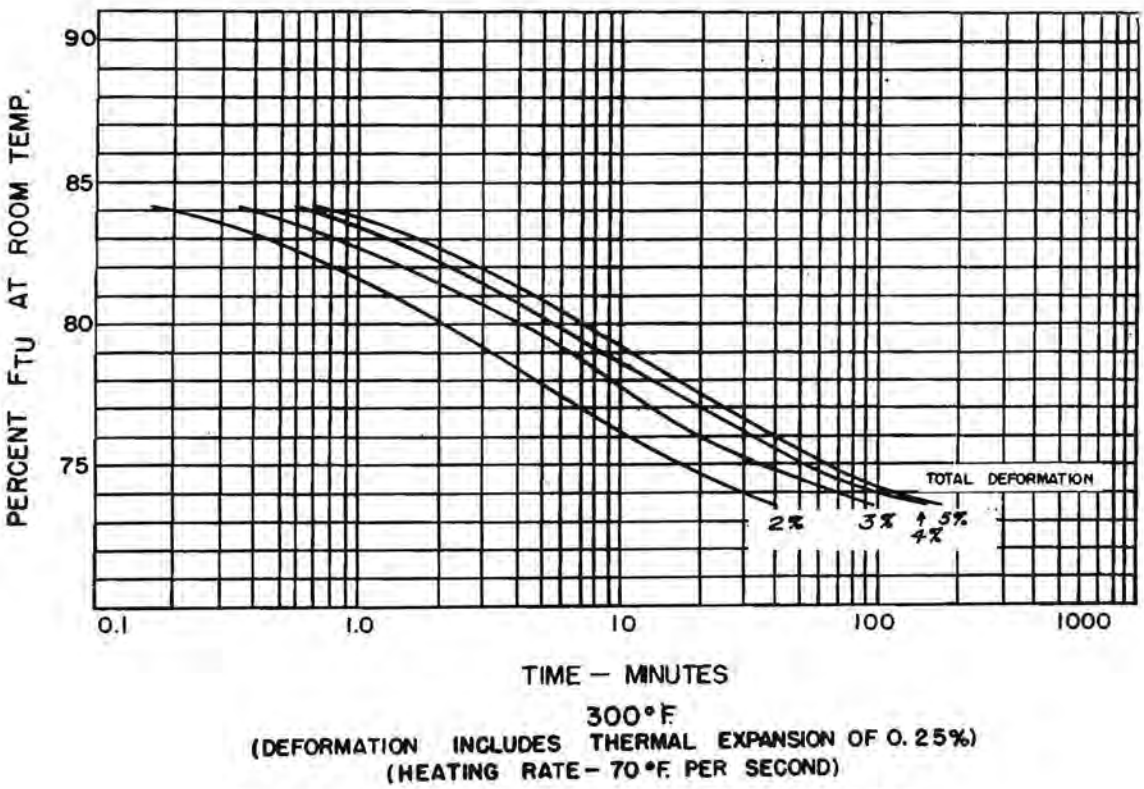


Figure 3.12231 (e). Short time creep curves for clad 24S–T86 sheet.

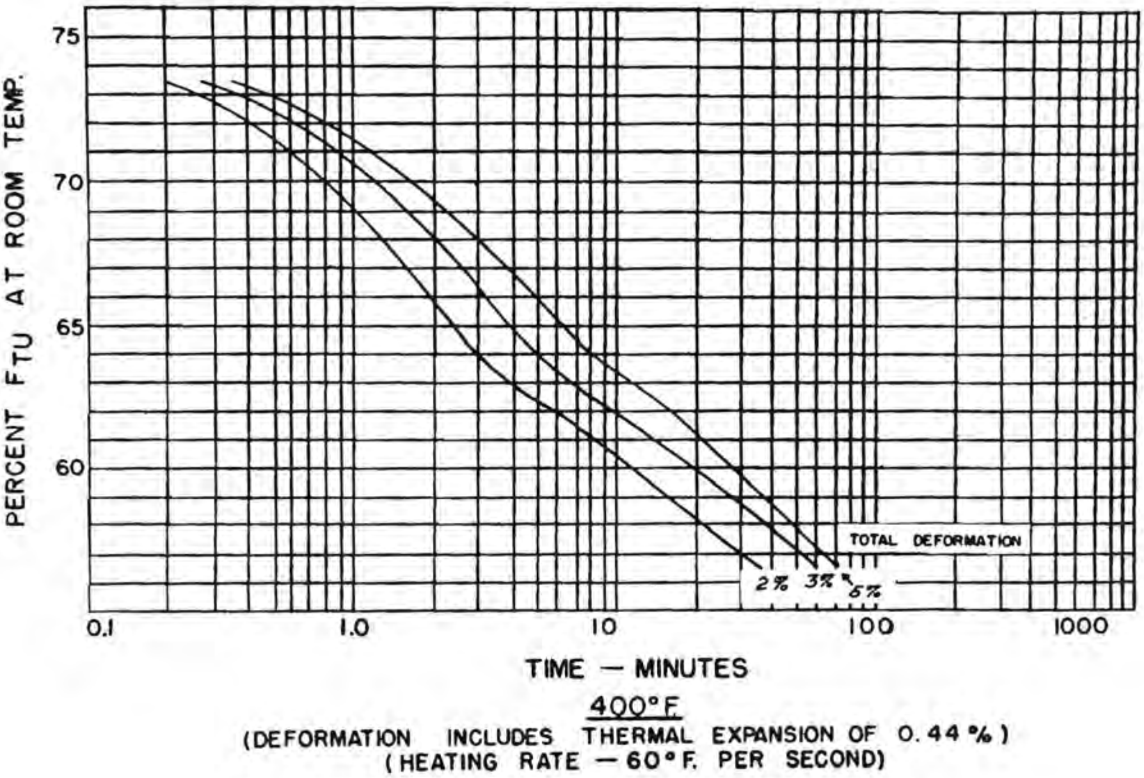


Figure 3.12231 (f). Short time creep curves for clad 24S–T86 sheet.

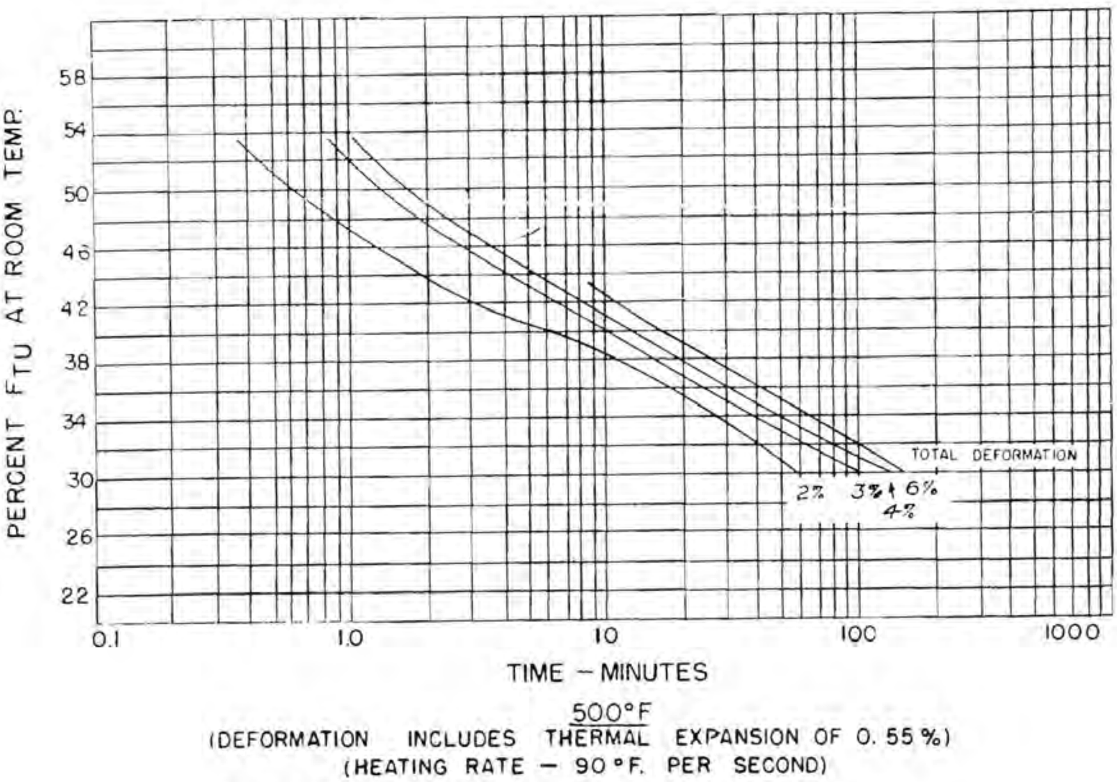


Figure 3.12231 (g). Short time creep curves for clad 24S–T86 sheet.

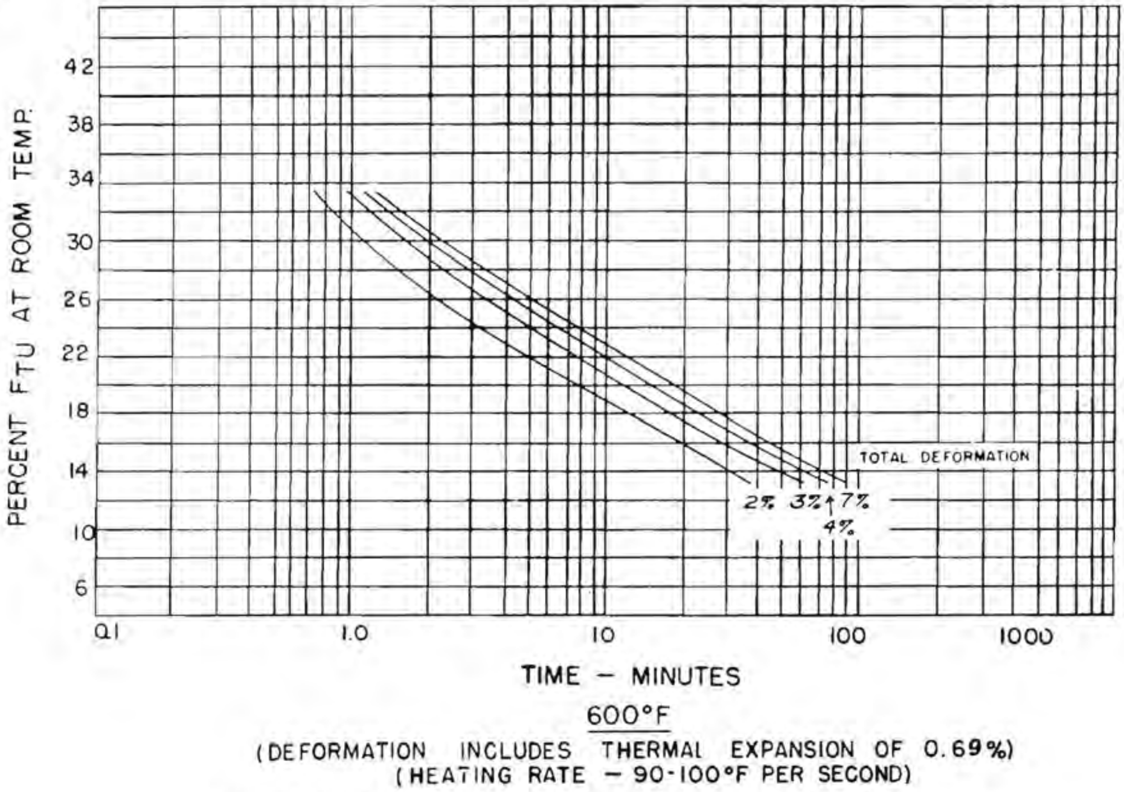


Figure 3.12231 (h). Short time creep curves for clad 24S–T86 sheet.

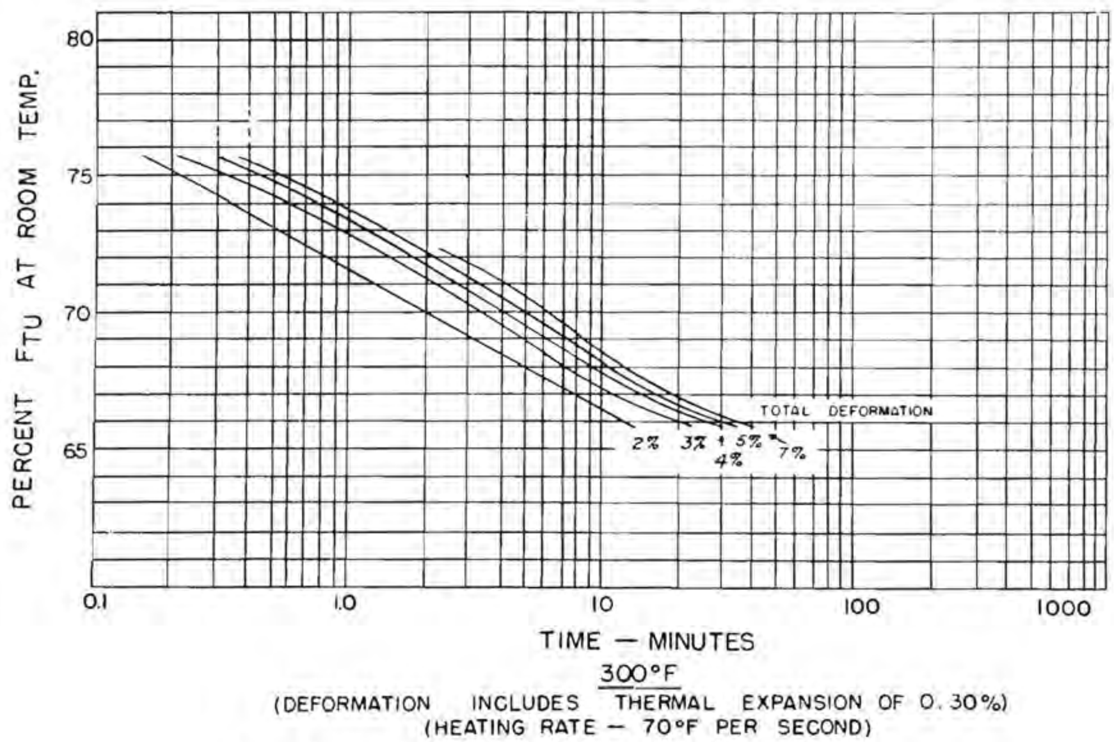
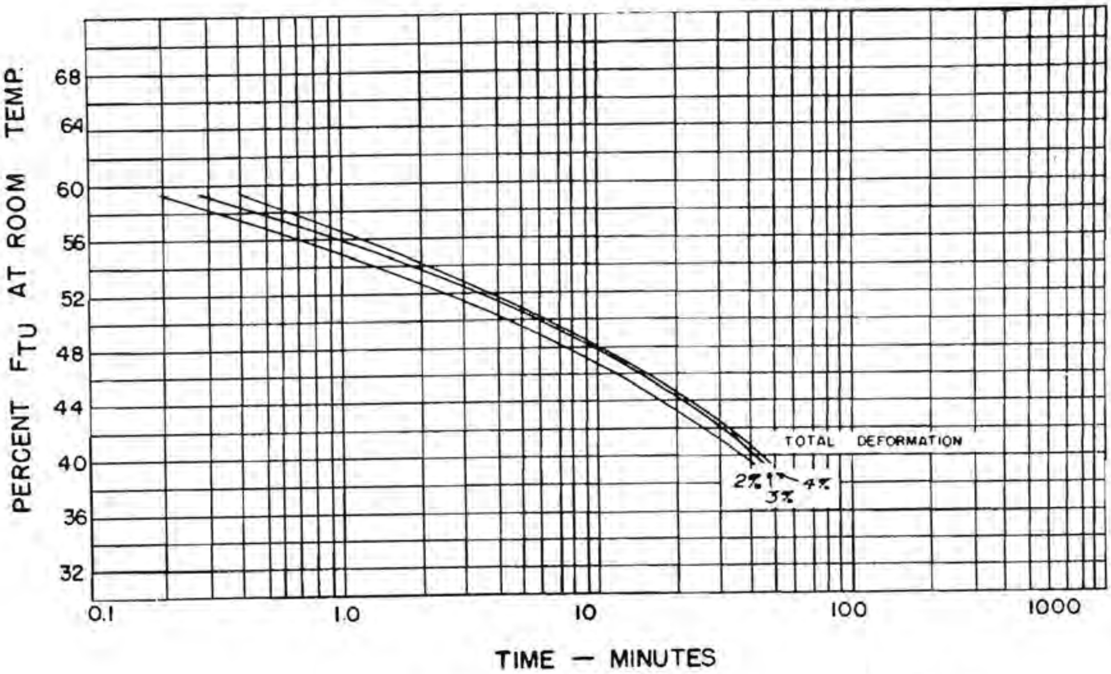
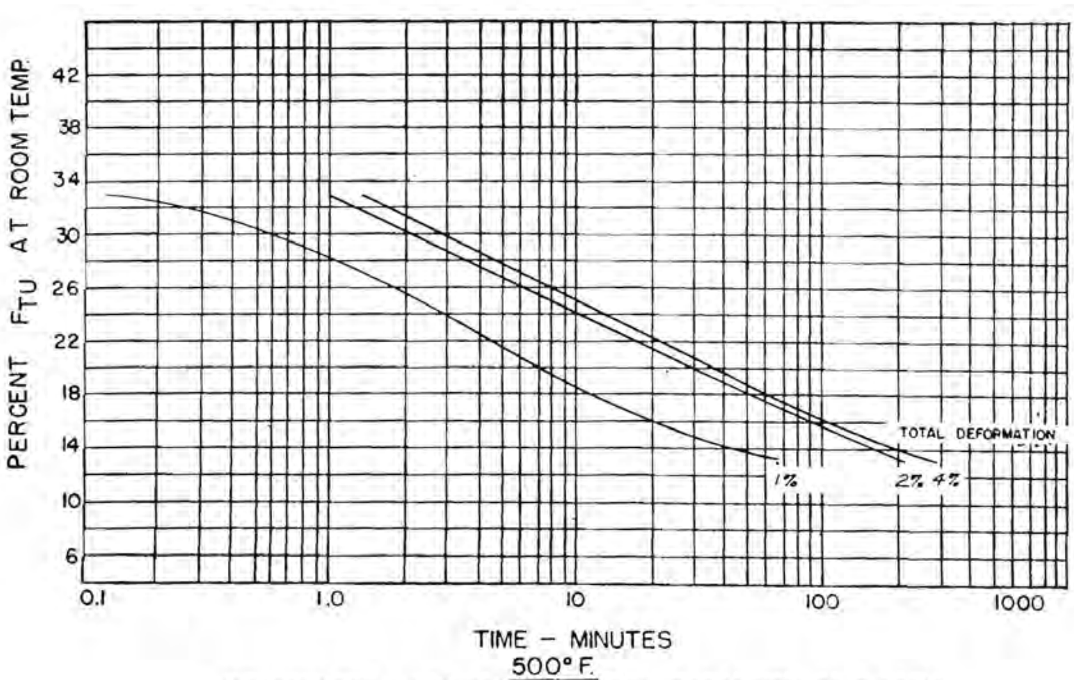


Figure 3 12231 (i). Short time creep curves for clad 75S–T6 sheet.



400°F.
(DEFORMATION INCLUDES THERMAL EXPANSION OF 0.43%)
(HEATING RATE — 75°F. PER SECOND)

Figure 3.12231 (j). Short time creep curves for clad 75S–T6 sheet.



500° F.
(DEFORMATION INCLUDES THERMAL EXPANSION OF 0.63%)
(HEATING RATE – 75–100°F. PER SECOND)

Figure 3.12231 (k). Short time creep curves for clad 75S–T6 sheet.

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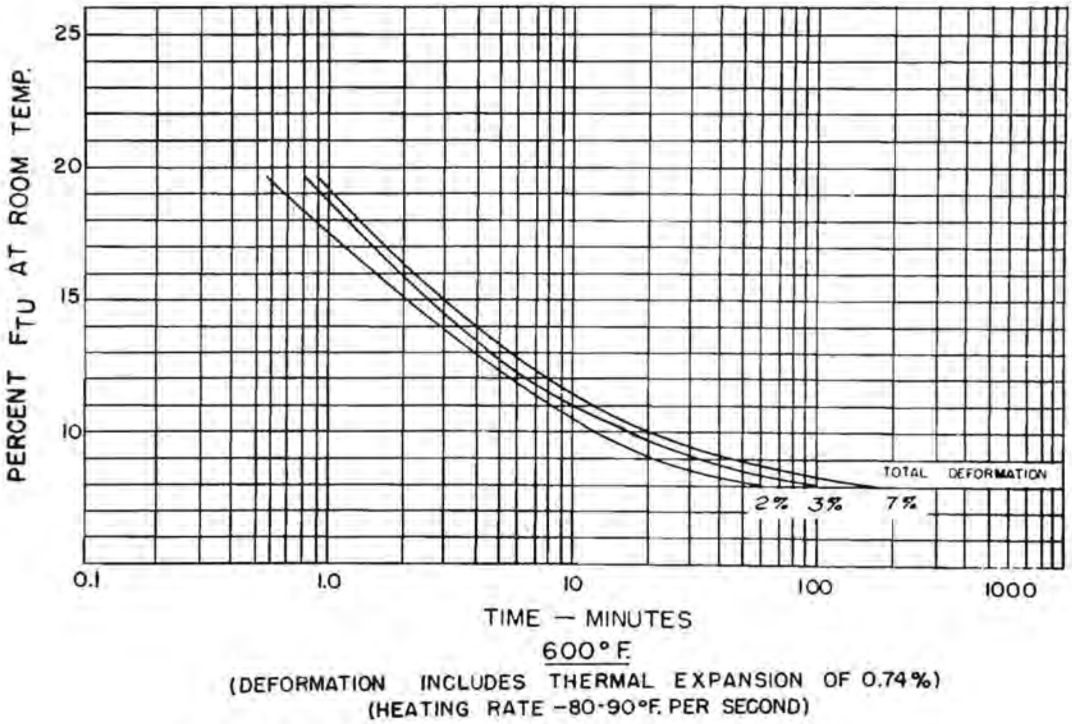


Figure 3.12231 (l). Short time creep curves for clad 75S–T6 sheet.

(Continued from page 108.)

from double shear tests of round pins. However, in these tests the pins were ⅜ inch in diameter and 1½ inches long. The center was sheared with ⅜-inch plate in a double shear fixture. The entire assembly was heated to the test temperature. See reference 3.131.

3.132 *Tensile strengths.* The values of room temperature and low temperature tensile strength of aluminum alloy materials were determined by the methods outlined in reference 1.441. Tests at elevated temperatures were also made generally as described in paragraph 1.441. However, paragraph 1.441 does not specify loading rate or time at temperature. These variables were controlled in the elevated temperature tests and the time at temperature is as noted on the figures or tables presenting the data. The loading rate was approximately 0.00005 inch per inch per second, although this value may vary somewhat depending on the source of the data. Specific effects of varying the rate of loading at elevated temperatures are not now available but are being investigated (see par. 3.14).

3.133 *Bearing strengths.* The values of bearing strength of aluminum alloy materials were determined by loading a steel pin inserted in a close-fitting hole in material test specimens having widths at least four times the pin diameter and thicknesses not less than one-fourth the pin diameter. Tests were made for edge distances, the distance from the edge of the specimen to the center of the hole in the direction of loading, of 1.5 and 2.0 times the pin diameter. The bearing yield-strength values were obtained from bearing stress versus hole elongation curves using an offset from the initial straight-line portion of the curves of 2 percent of the pin diameter. The elevated temperature bearing tests were made similarly to the room-temperature tests. However, only one edge distance—1.5D—was used. The hole diameter was ¼ inch in 0.064-inch sheet. The specimen was 1¾ by 4 inches. See references 3.133 (*a*) through (*j*).

3.14 RATE OF STRAINING EFFECTS. A knowledge of the effect of the rate of loading on the load-deformation characteristics of aluminum alloys is important since the aircraft structure in which the material is used is subjected to various loading rates depending on aircraft speed, gust sizes and velocities, maneuver conditions and alighting conditions. Sufficient information is available for the higher strength aluminum alloys to establish that the effect of rate of loading on their load-deformation characteristics at room temperature is insignificant. However, no data are available from this investigation for the lower strength material such as 2S and 3S or for any of the alloys at low and elevated temperatures. However, there is some evidence from impact tests as described in NACA TN 2082 and from other sources that at low temperatures rate of stressing is no more critical than at room temperature.

3.2 Columns

3.21 PRIMARY FAILURE. The general formulas for primary instability are given in section 1.38. For convenience, these formulas are repeated in table 3.21 in simplified form applicable to round aluminum alloy tubes. These formulas can also be used for columns having cross sections other than those of round tubes when local instability is not critical.

3.22 LOCAL FAILURE. Table 3.21 also contains notes and references concerning the local instability of round tubes.

3.23 COLUMN STRESS CURVES. Curves of the allowable column stresses for round and streamline tubing are given in figure 3.23. The allowable stress is plotted against the effective slenderness ratio defined by the formula:

$$\frac{L'}{\rho}=\frac{L}{\rho\sqrt{c}} \qquad (3.231)$$

3.3 Beams

3.31 GENERAL. See equation 1.323, section 1.525, and reference 1.71 for general information on stress analysis of beams.

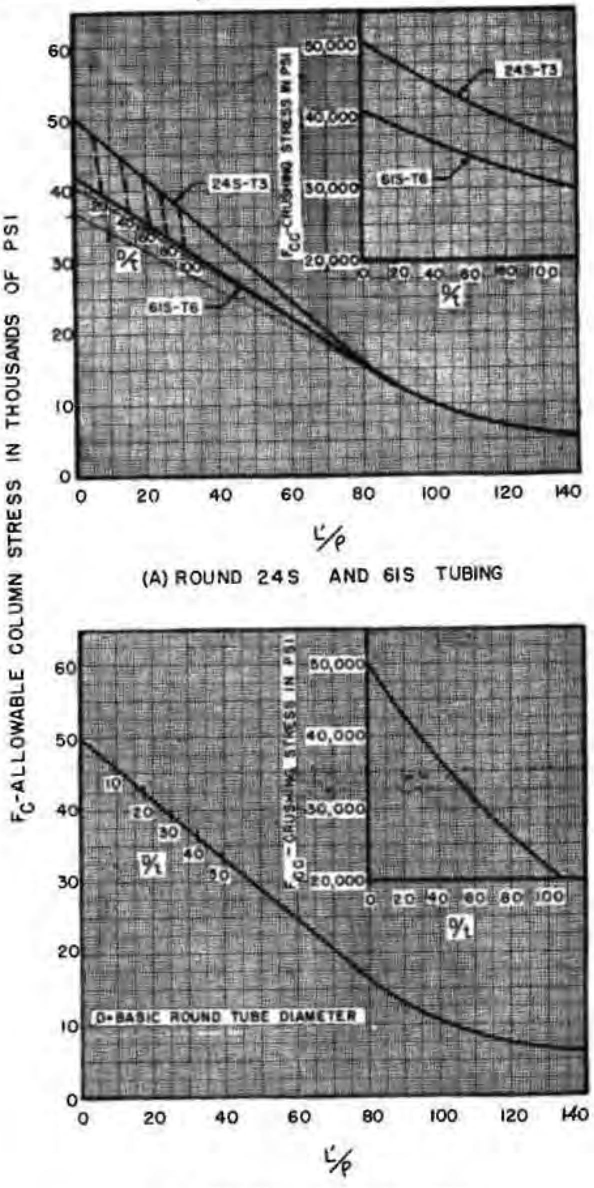


Figure 3.23. Allowable column and crushing stresses 24S and 61S aluminum alloy tubing.

Table 3.21. Column Formulas for Aluminum Alloy Tubing and/or Shapes

Material	F_{co}	Short columns	Transitional L'/ρ	Long columns	Local failure
24S–T3 and T4, 14S–T4, and 61S–T6.	$F_{cy}\left[1+\frac{F_{cy}}{200,000}\right]$	Equation 1.385	$1.732\pi\sqrt{E/F_{co}}$	Equation 1.381	(*).
75S–T6	$1.075\ F_{cy}$	Equation 1.383	$1.414\pi\sqrt{E/F_{co}}$	Equation 1.381	(*).

*Must be determined by test unless conservatively assumed.

$\frac{L'}{\rho}=\frac{L}{\rho\sqrt{c}}$; L'/ρ shall not exceed 150 without specific authority from the procuring or certificating agency.

Transitional L'/ρ is that above which the columns are "long" and below which they are "short."

Equation 1.381 (a) may be used in the short column range if E' is replaced by E_t obtained from the compressive stress-strain curve for the material.

3.32 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). For solid sections it can usually be safely assumed F_b equals the ultimate tensile stress.

3.321 *Round tubes.* For round tubes the value of F_b will depend on the D/t ratio as well as the ultimate tensile stress. The bending modulus of rupture of 24S and 61S round tubes is given in figure 3.321. It should be noted that these values apply only when the tubes are restrained against local buckling at the loading points.

3.322 *Unconventional cross sections.* Sections other than solid or tubular should be tested to determine the allowable bending stress.

3.33 BUILT-UP BEAMS. Built-up beams will usually fail due to local failures of the component parts. In aluminum alloy construction the strength of fittings and joints is an important feature. (See reference 3.333.)

3.34 THIN-WEB BEAMS. The allowable stresses for thin-web beams will depend on the nature of the failure and are determined from the allowable stresses of the web in tension and of the flanges or stiffeners in compression.

3.4 Torsion

3.41 GENERAL. The torsional failure of aluminum-alloy tubes may be due to plastic failure of the metal, elastic instability of the walls, or to an intermediate condition. Pure shear failure will not usually occur within the range of wall thicknesses commonly used for aircraft tubing.

3.42 ALLOWABLE TORSIONAL SHEAR STRESSES. In the range of low values of D/t, no theoretical formula is directly applicable. The results of tests have been used to determine the empirical curves of figure 3.42.

3.5 Combined loadings

3.51 ROUND TUBES IN BENDING AND COMPRESSION. The general theory of failure under combined loadings is given in section 1.535. In the case of combined bending and compression it is necessary to consider the effects of secondary bending, that is, bending produced by the axial load acting in conjunction with the lateral deflection of the column. In general, equation 1.5353, can be used in the following forms for safe values:

$$(f_b'/F_b)+(f_c/F_{cy})=1.0 \quad (3.511)$$

$$\text{M. S.}=\frac{1}{(R_b'+R_c)}-1 \quad (3.511a)$$

where

f_b'=maximum bending stress including effects of secondary bending.
F_b=Bending modulus of rupture.
f_c=Axial compressive stress.
F_{cy}=Compressive yield stress.

In no case shall the axial compressive stress f_c, exceed the allowable stress, F_c, for a simple column.

3.52 TUBES IN BENDING AND TORSION. Equation 1.5353, can be used in the following forms for safe values:

$$(f_b/F_b)^2+(f_s/F_{st})^2=1.0 \quad (3.521)$$

Round tubes:

$$R_b^2+R_s^2=1.0 \quad (3.521a)$$

$$\text{M. S.}=\frac{1}{\sqrt{(R_b)^2+(R_s)^2}}-1 \quad (3.521b)$$

Streamline tubes:

$$R_b+R_s=1.0 \quad (3.522)$$

$$\text{M. S.}=\frac{1}{R_b+R_s}-1 \quad (3.522a)$$

f_s=Shear stress.
F_{st}=Torsional modulus of rupture.

Higher values can be used if substantiated by adequate test data.

3.53 TUBES IN BENDING, COMPRESSION AND TORSION. The bending stresses should include the effects of secondary bending due to compression. The following empirical equation will serve as a working basis, pending a more thorough investigation of the subject:

$$[f_b'/F_b]^2+[f_s/F_{st}]^2=[1-f_c/F_{cy}]^2 \quad (3.531)$$

$$\text{M. S.}=\frac{1}{R_c+\sqrt{(R_b')^2+(R_s)^2}}-1 \quad (3.531a)$$

In no case shall the axial compressive stress, f_c, exceed the allowable stress, F_c, for a simple column.

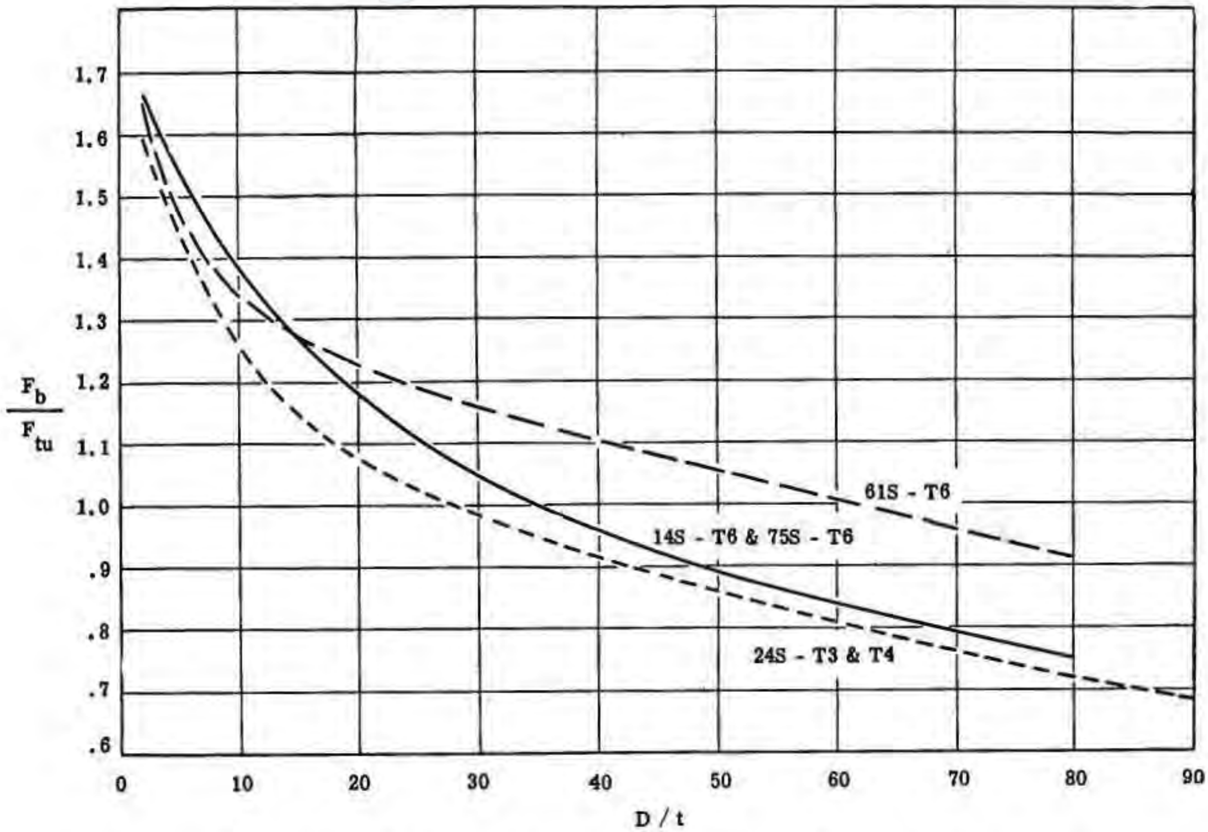


Figure 3.321. Bending modulus of rupture—aluminum-alloy round tubing.

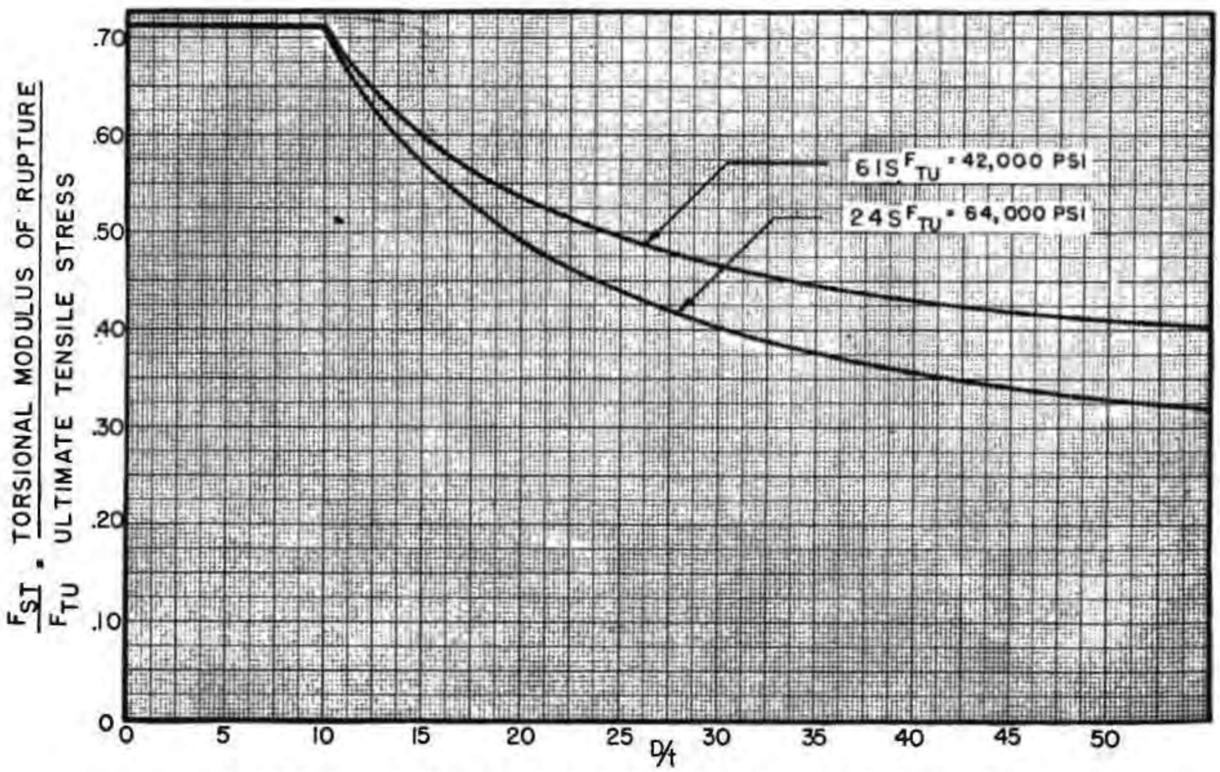


Figure 3.42. Torsional modulus of rupture—aluminum alloy round tubing.

3.6 Joints and parts

3.61 JOINTS

3.611 *Riveted and bolted joints.* In order to determine the strength of such joints it is necessary to know the strength of the individual rivets or bolts. In most cases, such joint failures occur by shearing the connecting element, or by bearing and/or tearing the sheet or plate. Information on strength of joints is contained in references 3.611 (*a*) through (*s*)

3.6111 *Protruding head rivets and bolts.* The load per rivet or bolt at which the shear or bearing type of failure occurs is separately calculated and the lower of the two governs the design. The basic shear strengths for protruding head aluminum alloy rivets are given in table 3.6111 (*a*). In computing aluminum rivet design shear strengths, the correction factors given in table 3.6111 (*a*) should be used to compensate for the reductions in rivet shear strength resulting from high bearing stresses on the rivet at D/t ratios in excess of 3.0 for single shear joints, and 1.5 for double shear joints. The design bearing stresses for aluminum alloys given in tables 3.111 (*a*) through (*o*) are applicable to riveted or bolted joints wherein cylindrical holes are used and where $D/t<5.5$; where $D/t>5.5$, tests to substantiate yield and ultimate bearing strengths must be made. Yield strengths of rivets or bolts may be computed in a manner similar to ultimate strengths except that the factors of table 3.6111 (*a*) need not be applied. For 24S bolts the design allowable F_{su}=38,000 p. s. i. The bearing yield stresses correspond to a permanent set in the hole (in a single sheet) equal to two percent of the hole diameter. These bearing stresses are applicable only for the design of rigid joints where there is no possibility of relative movement of the parts joined without deformation of such parts. For other types of joints the design bearing stresses are to be reduced by dividing by the factors of safety specified in table 2.61122 (*a*). For convenience, "unit" sheet bearing strengths on rivets based on a stress of 100 *ksi* and nominal hole diameters are given in table 3.6111 (*d*). Factors representing the ratio of actual sheet bearing strengths to 100 *ksi* are given in table 3.6111 (*b*). Table 2.61121 contains "unit" sheet bearing strengths on bolts.

Table 3.6111 (a). Shear Strengths of Protruding and Flush Head Aluminum Alloy Rivets (Pounds)

Diameter of rivet	1/16	3/32	1/8	5/32	3/16	1/4	5/16	3/8
56S—F_{su}=28 *ksi*	99	203	363	556	802	1, 450	2, 290	3, 280
A17S-T3—F_{su}=30 *ksi*	106	217	388	596	862	1, 550	2, 460	3, 510
17S-T31—F_{su}=34 *ksi*	120	247	442	675	977	1, 760	2, 790	3, 970
17S-T3—F_{su}=38 *ksi*	135	275	494	755	1, 090	1, 970	3, 110	4, 450
24S-T31—F_{su}=41 *ksi*	145	296	531	815	1, 180	2, 120	3, 360	4, 800
SINGLE SHEAR RIVET STRENGTH FACTORS								
Sheet thickness:								
0.014								
0.016	0. 964							
0.018	. 984							
0.020	. 996							
0.025	1. 000	0. 972						
0.032		1. 000	0. 964					
0.036			. 980					
0.040			. 996	0. 964				
0.045			1. 000	. 980				
0.051				. 996	0. 972			
0.064				1. 000	1. 000	0. 964		
0.072						. 980	0. 964	
0.081						. 996	. 974	
0.091						1. 000	. 984	
0.102							. 996	0. 972
0.128							1. 000	1. 000
0.156								
0.188								
0.250								
DOUBLE SHEAR RIVET STRENGTH FACTORS								
Sheet thickness:								
0.014								
0.016	0. 688							
0.018	. 753							
0.020	. 792							
0.025	. 870	0. 714						
0.032	. 935	. 818	0. 688					
0.036	. 974	. 857	. 740					
0.040	. 987	. 896	. 792	0. 688				
0.045	1. 000	. 922	. 831	. 740				
0.051		. 961	. 870	. 792	0. 714			
0.064		1. 000	. 935	. 883	. 818	0. 688		
0.072			. 974	. 919	. 857	. 740		
0.081			1. 000	. 948	. 896	. 792	0. 688	
0.091				. 974	. 922	. 831	. 753	
0.102				1. 000	. 961	. 870	. 792	0. 714
0.128					1. 000	. 935	. 883	. 818
0.156						. 987	. 935	. 883
0.188						1. 000	. 974	. 935
0.250							1. 000	1. 000

NOTE

Values of shear strength should be multiplied by the factors given herein whenever the *D/t* ratio is large enough to require such a correction.

Shear values are based on areas corresponding to the nominal hole diameters specified in table 3.6111 (*c*) note e.

Shear stresses in table 3.6111 (*c*) corresponding to 90 percent probability data are used wherever available.

Sheet thickness is that of the thinnest sheet in single shear joints and the middle sheet in double shear joints.

Table 3.6111 (b). Aluminum Alloy Sheet and Plate—Bearing Factors [a]

[K=ratio of actual bearing strength to 100 *ksi*]

Material	Thickness	A values				B values			
		K ultimate		K yield		K ultimate		K yield	
		e/D=2.0	e/D=1.5	e/D=2.0	e/D=1.5	e/D=2.0	e/D=1.5	e/D=2.0	e/D=1.5
24S–T4 (heat-treated by user)	<0.250	1.18	0.93	0.64	0.56	------	------	------	------
24S–T42 (heat-treated by user)	0.250–0.500	1.22	.96	.61	.53	------	------	------	------
	.501–1.000	1.18	.93	.61	.53	------	------	------	------
24S–T3	<.250	1.24	.98	.79	.69	1.29	1.02	0.82	0.71
24S–T4	.250– .500	1.24	.98	.74	.64	1.27	1.01	.78	.69
	.501–1.000	1.20	.95	.70	.62	1.29	1.02	.77	.67
24S–T36	≦.500	1.33	1.05	.96	.84	1.37	1.08	1.00	.88
24S–T4 (coiled)	<.250	1.18	.93	.64	.56	1.26	.99	.66	.57
Clad 24S–T4 (heat-treated by user)	<.064	1.10	.87	.59	.52	------	------	------	------
	.064– .249	1.16	.92	.61	.53	------	------	------	------
Clad 24S–T4 (heat-treated by user)	.250– .499	1.18	.93	.61	.53	------	------	------	------
	.500–1.000	1.14	.90	.58	.50	------	------	------	------
Clad 24S–T3	.010– .063	1.14	.90	.73	.64	1.18	.93	.76	.67
	.064– .249	1.20	.95	.74	.64	1.24	.98	.78	.69
Clad 24S–T4	.250– .499	1.20	.95	.74	.64	1.24	.98	.78	.69
	.500–1.000	1.16	.92	.67	.59	1.24	.98	.74	.64
Clad 24S–T36	.019– .063	1.20	.95	.88	.77	1.25	.99	.93	.81
	.064– .500	1.27	1.01	.93	.81	1.31	1.04	.96	.84
Clad 24S–T4 (coiled)	.012– .063	1.10	.87	.59	.52	1.16	.92	.61	.53
	.064	1.16	.92	.61	.53	1.20	.95	.64	.56
Clad 24S–T6	<.064	1.14	.90	.75	.66	------	------	------	------
	≧.064	1.18	.93	.78	.69	------	------	------	------
Clad 24S–T81	<.064	1.22	.96	.90	.78	------	------	------	------
	≧.064	1.27	1.00	.94	.83	------	------	------	------
Clad 24S–T84	<.064	1.27	1.00	1.01	.88	------	------	------	------
	≧.064	1.33	1.05	1.06	.92	------	------	------	------
Clad 24S–T86	<.064	1.33	1.05	1.04	.91	------	------	------	------
	≧.064	1.35	1.06	1.09	.95	------	------	------	------
75S–T6	.016– .039	1.44	1.14	1.06	.92	1.48	1.17	1.10	.97
	.040– .249	1.46	1.16	1.07	.94	1.50	1.19	1.12	.98
	.250– .500	1.39	1.08	1.00	.87	1.42	1.10	1.04	.90
	.501–1.000	1.42	1.10	1.04	.90	1.47	1.15	1.08	.94
Clad 75S–T6	.016– .039	1.33	1.05	.98	.85	1.39	1.10	1.02	.90
	.040– .249	1.37	1.08	1.01	.88	1.41	1.11	1.04	.91
	.250– .499	1.30	1.01	.94	.82	1.33	1.04	.98	.82
	.500–1.000	1.33	1.04	.98	.84	1.37	1.06	1.00	.87
R301–T6 and Alclad 14S–T6	≦.039	1.22	.96	.90	.78	1.22	.96	.90	.78
	.040–0.499	1.24	.98	.93	.81	1.27	1.01	.96	.84
	.500–1.000	1.24	.98	.93	.81	1.27	1.01	.96	.84
14S–T6	.040–0.499	1.29	1.02	.96	.84	1.33	1.05	.99	.87
	.500–1.000	1.29	1.02	.96	.84	1.33	1.05	.99	.87
52S–H32 (¼H)	------	.65	.50	.34	.29	------	------	------	------
52S–H34 (½H)	------	.71	.54	.38	.34	------	------	------	------
52S–H36 (¾H)	------	.78	.59	.46	.41	------	------	------	------
52S–H38(H)	------	.82	.62	.53	.46	------	------	------	------
61S–T4	------	.63	.48	.26	.22	------	------	------	------
61S–T6	------	.88	.67	.58	.50	------	------	------	------

[a] For e/D values between 1.5 and 2.0 bearing factors may be obtained by linear interpolation (e=edge distance, D=hole diameter).

Table 3.6111 (c). Design Mechanical Properties for Aluminum Alloy Rivets (Kips Per Square Inch)

Type	Protruding head rivets [e]									
Alloy	A17S		17S				24S		56S	
Specification	MIL-R-5674									
Condition	(T3)		(T31) [b]		(T3) [c]		(T31)		(H-321)	
Basis [d]	A	B	A	B	A	B	A	B	A	B
F_{su} [e] (for driven rivets)	28	30	33	34	35	38	37	41	27	28
F_{su} (for undriven rivets and rivet wire)	26	29	------	------	33	37	37	38	24	27

[a] The driven head diameter shall be at least 1.3 times the nominal shank diameter of the rivet.

[b] The 17S-T31 designation refers to rivets that have been heat treated and then maintained in the heat treated condition until driving.

[c] The 17S-T3 designation refers to 17S rivets which are fully aged at room temperature for at least 4 days after quenching, and then driven. (The higher strength properties of the 17S-T3 rivets result from the cold-working effects obtained when the rivets are driven in the aged condition.)

[d] A is the mechanical property column based upon the minimum guaranteed tensile properties; B is the mechanical property column based upon probability data. (See par. 3.111.)

[e] Shear and bearing strength values 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 listed values listed below. If the nominal hole diameter is larger than the listed values the listed value shall be used.

Standard rivet hole drill sizes and nominal hole diameters

Rivet size	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	0.067	0.096	0.1285	0.159	0.191	0.257	0.323	0.386

Table 3.6111 (d). Unit Bearing Strength of Sheet on Rivets, F_{br}=100,000 p. s. i. (Pounds) [a]

Diameter of rivet	1/16	3/32	1/8	5/32	3/16	1/4	5/16	3/8
Sheet thickness:								
0.014	44	------	------	------	------	------	------	------
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	463	572	688	------	------	------
0.040	268	384	514	636	764	------	------	------
0.045	302	432	578	716	860	------	------	------
0.051	342	490	655	811	974	1,310	------	------
0.064	429	614	822	1,020	1,220	1,640	2,070	------
0.072	482	691	925	1,140	1,370	1,850	2,330	2,780
0.081	543	778	1,040	1,290	1,550	2,080	2,620	3,130
0.091	610	874	1,170	1,450	1,740	2,340	2,940	3,510
0.102	683	979	1,310	1,620	1,910	2,620	3,290	3,940
0.128	858	1,230	1,640	2,030	2,410	3,290	4,130	4,940
0.156	1,050	1,500	2,010	2,480	2,980	4,010	5,040	6,030
0.188	1,250	1,800	2,410	2,980	3,580	4,820	6,060	7,240
0.250	1,670	2,400	3,210	3,970	4,770	6,420	8,070	------

[a] Bearing values are based on areas corresponding to the nominal hole diameters specified in table 3.6111 (c).

3.6112 *Flush rivets*. Tables 3.6112 (*a*) through (*d*) contain ultimate and yield allowable single-shear strength values for both machine countersunk and dimpled flush riveted joints employing solid rivets with a head angle of 100°. These strength values are applicable when the edge distance is equal to or greater than two times the nominal rivet diameter. Other strength values and edge distances may be used if substantiated by tests.

The allowable ultimate loads were established from test data using the average failing load divided by a factor of 1.15. The yield loads were established from test data wherein the yield load was defined as the average test load at which the following permanent set across the joint is developed.

(*a*) 0.005 inch up to and including 3/16-inch-diameter rivets.

(*b*) 2.5 percent of the rivet diameter for rivet sizes larger than 3/16-inch diameter.

Test data from which the yield and ultimate strengths listed were derived are to be found in reference 3.6112.

Table 3.6112 (a). Ultimate Strength of Solid 100° Machine Countersunk Rivets (Pounds)

Rivet material	A17S-T3				17S-T3			24S-T31	
Clad sheet material	24S-T3, 24S-T4, 24S-T6, 24S-T81, 24S-T86, and 75S-T6								
Rivet diameter	3/32	1/8	5/32	3/16	5/32	3/16	1/4	3/16	1/4
Sheet thickness: [a]									
0.020	132								
0.025	156								
0.032	178	272							
0.040	193	309	*418		*476				
0.051	206	340	*479	*628	*580	*726		758	
0.064	216	363	523	705	*657	*859		886	*1, 290
0.072		373	542	739	690	*917	*1, 338	942	*1, 424
0.081			560	769	720	*969	*1, 452	992	*1, 543
0.091			575	795	746	1, 015	*1, 552	1, 035	*1, 647
0.102				818		1, 054	*1, 640	1, 073	*1, 738
0.125				853		1, 090	1, 773	1, 131	1, 877
0.156							1, 891		2, 000
0.188							1, 970		2, 084
0.250									

[a] Sheet gage is that of the countersunk sheet.

In cases where the lower sheet is thinner than the upper the shear-bearing allowable for the lower sheet-rivet combination should be computed.

The values in this table are based on "good" manufacturing practice, and any deviation from this will produce significantly reduced values.

Yield values of the sheet-rivet combinations marked thus (*) are less than 3/4 of the indicated ultimate values.

Table 3.6112 (b). Yield Strength of Solid 100° Machine Countersunk Rivets (Pounds)

Rivet material	A17S-T3				17S-T3			24S-T31	
Clad sheet material	24S-T3, 24S-T4, 24S-T6, 24S-T81, 24S-T86, and 75S-T6								
Rivet diameter	3/32	1/8	5/32	3/16	5/32	3/16	1/4	3/16	1/4
Sheet thickness: [a]									
0.020	91								
0.025	113								
0.032	132	198							
0.040	153	231	265		270				
0.051	188	261	321	389	345	419		538	
0.064	213	321	402	471	401	515		614	811
0.072		348	453	538	481	557	706	669	902
0.081			498	616	562	623	788	761	982
0.091			537	685	633	746	861	842	1,053
0.102				745		854	1,017	913	1,115
0.125				836		1,018	1,313	1,021	1,357
0.156							1,574		1,694
0.188							1,753		1,925
0.250									

[a] Sheet gage is that of the countersunk sheet.

In cases where the lower sheet is thinner than the upper the shear-bearing allowable for the lower sheet-rivet combination should be computed.

The values in this table are based on "good" manufacturing practice and any deviation from this will produce significantly reduced values

Table 3.6112 (c). Ultimate Strength of Solid 100° Dimpled Rivets (Pounds)

Rivet material	A17S-T3							17S-T3						24S-T31			
Clad sheet material	24S-T3, 24S-T4, 24S-T6, and 24S-T81		24S-T86	24S-T3, and 24S-T4		24S-T6, 24S-T81, 24S-T86, 75S-T6		24S-T3, 24S-T4, 24S-T6, and 24S-T81		24S-T86 and 75S-T6		24S-T3 and 24S-T4	24S-T6, 24S-T81, 24S-T86, and 75S-T6	24S-T3, and 24S-T4		24S-T6, 24S-T81, 24S-T86, and 75S-T6	
Rivet diameter	3/32	1/8	1/8	5/32	3/16	5/32	3/16	5/32	3/16	5/32	3/16	1/4	1/4	3/16	1/4	3/16	1/4
Sheet thickness: [a]																	
0.016	177																
0.020	209	299	302														
0.025	235	360	383	474		462		419		530							
0.032	257	413	454	568	722	599	725	600	681	672	822			744		786	
0.040	273	451	505	635	839	695	891	728	905	775	1,000	845	1,108	941	879	982	1,300
0.051		484	548	693	940	778	1,036	840	1,097	864	1,153	1,332	1,508	1,110	1,359	1,152	1,705
0.064				736	1,012	840	1,142	922	1,240	930	1,267	1,695	1,803	1,236	1,727	1,277	2,010
0.072				755	1,045	867	1,190	958	1,301	957	1,315	1,853	1,930	1,291	1,883	1,332	2,150
0.081					1,074		1,230		1,357		1,358	1,995	2,044	1,340	2,025	1,380	2,260
0.091					1,098		1,267		1,405		1,398	2,115	2,145	1,382	2,150	1,424	2,365
0.102												2,220	2,232		2,255		2,455

[a] The above 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 dimple sheet for dimpled-machine countersunk joints. The thickness of the machine countersunk sheet must be at least 1 tabulated gage thicker than the upper sheet.

In no case shall allowables be obtained by extrapolation for skin gages other than those shown.

The values in this table are based on "good" manufacturing practice and any deviation from this will produce significantly reduced values.

Table 3.6112 (d). Yield Strength of Solid 100° Dimpled Rivets (Pounds)

Rivet material	A17S-T3						17S-T3						24S-T31					
Clad sheet material	24S-T3, 24S-T4, 24S-T6, and 24S-T81	24S-T3, 24S-T4, 24S-T6, 24S-T81, and 24S-T86	24S-T3, 24S-T4, 24S-T6, and 24S-T81		24S-T86 and 75S-T6		24S-T3, 24S-T4, 24S-T6, and 24S-T81			24S-T86 and 75S-T6			24S-T3, and 24S-T4		24S-T6 and 24S-T81		24S-T86 and 75S-T6	
Rivet diameter	5/32	1/8	5/32	3/16	5/32	3/16	5/32	3/16	1/4	5/32	3/16	1/4	3/16	1/4	3/16	1/4	3/16	1/4
Sheet thickness: [a]																		
0.016	154	------	---	---	---	-----	---	-----	-----	---	-----	-----	-----	-----	-----	-----	-----	-----
0.020	184	257	---	---	---	-----	---	-----	-----	---	-----	-----	-----	-----	-----	-----	-----	-----
0.025	209	315	324	---	410	-----	336	-----	-----	450	-----	-----	-----	-----	-----	-----	-----	-----
0.032	231	367	430	512	525	640	483	546	-----	581	705	-----	582	-----	649	-----	786	-----
0.040	246	404	506	644	606	782	589	730	845	675	867	978	666	879	816	962	982	978
0.051	------	436	571	757	677	905	681	888	1, 187	756	1, 007	1, 508	738	1, 308	961	1, 308	1, 152	1, 543
0.064	------	------	619	841	729	995	748	1, 006	1, 415	816	1, 111	1, 803	925	1, 564	1, 068	1, 564	1, 277	1, 958
0.072	------	------	641	878	752	1, 034	778	1, 056	1, 656	842	1, 156	1, 930	1, 045	1, 711	1, 115	1, 711	1, 332	2, 140
0.081	------	------	---	910	---	1, 070	---	1, 102	1, 870	---	1, 196	2, 044	1, 152	1, 928	1, 177	1, 928	1, 380	2, 260
0.091	------	------	---	939	---	1, 100	---	1, 142	2, 057	---	1, 231	2, 145	1, 246	2, 121	1, 324	2, 121	1, 424	2, 365
0.102	------	------	---	---	---	-----	---	-----	2, 220	---	-----	2, 232	-----	2, 255	-----	2, 268	-----	2, 455

[a] The above 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 the machine countersunk sheet must be at least 1 tabulated gage thicker than the upper sheet.

In no case shall allowables be obtained by extrapolation for skin gages other than those shown.

The values in this table are based on "good" manufacturing practice and any deviation from this will produce significantly reduced values

3.6113 *Blind rivets.* Tables 3.6113 (*a*) and (*b*) contain ultimate and yield allowable single-shear strengths for Military Standard (MS) protruding head and 100° countersunk head aluminum alloy blind rivets in aluminum alloy sheet. These strengths are applicable only when the grip lengths and rivet hole tolerances are as recommended by the respective manufacturers. These strengths may be substantially reduced if oversize holes or improper grip lengths are used.

Test data on which these strength values were based were obtained at room temperature using standard degreased clad 24S–T4 specimens having an edge distance e/D equal to 2.0. In the preparation of the test specimen, both the hole diameter and the gage thickness were determined. Test loads were converted to P/D^2 (where P=actual test load and D=actual hole diameter) and plotted against the appropriate t/D values (where t=actual sheet thickness and D=actual hole diameter). Ultimate strength values of protruding and 100° countersunk-head blind rivets recommended for design were then obtained from the analysis by dividing the average failing load curve by 1.15.

Yield strength values were similarly plotted on a nondimensional analysis wherein the yield load is defined as the load at which the following permanent set across the joint is developed:

(*a*) 0.005 inches up to and including 3/16-inch-diameter rivets.

(*b*) 2.5 percent of the rivet diameter for rivet sizes larger than 3/16-inch diameter.

For both protruding and 100° countersunk-head blind rivets, the ultimate rivet shear strength was based on the comparable rivet shear strength of A17S solid rivets, as noted in table 3.6111 (*a*).

For applications involving e/D values less than 2.0, tests to substantiate yield and ultimate bearing strengths must be made.

In view of the wide variance in dimpling methods and tolerances, no standard or uniform load allowables are recommended. Allowables for ultimate and shear strengths of blind rivets in double-dimpled or dimpled-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 rivets in machine countersunk sheet, noted in table 3.6113 (*b*), may be used.

Since blind rivets are primarily shear-type fasteners, they should not be used in applications where appreciable tensile loads on the rivets will exist. Reference should be made to the requirements of the applicable procuring or certifying agency relative to the use of blind rivets, such as the limitations of usage on drawing MS33522.

Table 3.6113 (a). Ultimate and Yield Strengths for Protruding Head (MS20600 and MS20602) Aluminum-Alloy Blind Rivets (Pounds) [a] [b]

ULTIMATE STRENGTH

Rivet type	Universal MS20600 AD (A17ST) or and Brazier head MS20602 AD (17ST)			
Sheet material	For 24S-T4 clad and higher strength aluminum sheet materials.			
Rivet diameter	1/8	5/32	3/16	1/4
Sheet thickness: [c]				
0.020	186	------	------	------
0.025	233	286	------	------
0.032	277	368	445	601
0.040	321	425	544	750
0.051	386	506	643	961
0.064	388	596	753	1, 110
0.072	388	596	823	1, 200
0.081	------	------	862	1, 305
0.091	------	------	862	1, 415
0.102	------	------	------	1, 548
0.125	------	------	------	1, 550

YIELD STRENGTH

Sheet thickness: [c]	1/8	5/32	3/16	1/4
0.020	180	------	------	------
0.025	226	271	------	------
0.032	264	356	431	572
0.040	304	406	523	720
0.051	362	475	610	925
0.064	388	560	709	1, 058
0.072	388	596	771	1, 135
0.081	------	------	862	1, 230
0.091	------	------	862	1, 330
0.102	------	------	------	1, 450
0.125	------	------	------	1, 550

[a] Protruding head blind rivet yield values are included for information purposes as they are not critical for piloted aircraft design per CAA, Air Force, or Navy design yield criteria.

[b] Design allowables for alloys in other physical conditions, joint configurations other than that indicated in paragraph 3.6113, or for section thicknesses outside the range for which values are indicated, shall be substantiated by test data and shall be subject to specific approval by the procuring or certifying agency.

[c] Thickness of thinnest sheet.

Table 3.6113 (b). Ultimate and Yield Strengths for 100° Countersunk Head (MS20601 and MS20603) Aluminum Alloy Blind Rivets (Pounds) [a] [b]

ULTIMATE STRENGTH

Rivet type	100° Countersunk head MS20601 AD (A17ST) and MS20603 AD (17ST)			
Sheet material	For 24S-T4 clad and higher strength aluminum sheet materials.			
Rivet diameter	1/8	5/32	3/16	1/4
Sheet thickness: [c]				
0.040	159	------	------	------
0.051	236	258	------	------
0.064	327	369	398	------
0.072	360	439	485	------
0.081	388	511	577	654
0.091	388	561	684	795
0.102	------	596	768	945
0.125	------	596	862	1, 270

YIELD STRENGTH [d]

Sheet thickness: [c]	1/8	5/32	3/16	1/4
0.040	*110	------	------	------
0.051	198	*185	------	------
0.064	300	308	*296	------
0.072	336	384	391	------
0.081	377	468	497	*456
0.091	388	524	614	621
0.102	------	592	709	793
0.125	------	596	862	1, 150

[a] Design allowables for sheet thicknesses above or below the range for which values are indicated, shall not be determined by extrapolation.

[b] Design allowables for alloys in other physical conditions, for joint configurations other than that indicated in paragraph 3.6113, or for section thicknesses outside the range for which values are indicated, shall be substantiated by test data and shall be subject to specific approval by the procuring or certifying agency.

[c] Sheet thickness of countersunk sheet.

[d] Yield values of the sheet-rivet combinations marked thus (*) are less than 77 percent (i. e., $\frac{\text{Average yield}}{1.5} \times 1.15$) of the indicated ultimate values, and are thus critical per Navy design yield criteria. The remaining countersunk-head blind rivet values are included for information purposes as they are not critical for piloted aircraft design per CAA, Air Force, or Navy design yield criteria.

3.6114 *Hollow-end rivets.* If hollow-end rivets with solid cross sections for a portion of the length (AN450) are used, the strength of these rivets may be taken equal to the strength of solid rivets of the same material, provided that the bottom of the cavity is at least 25 percent of the rivet diameter from the plane of shear, as measured toward the hollow end, and further provided that they are used in locations where they will not be subjected to appreciable tensile stresses.

3.6115 *High-shear rivets.* Allowable loads for high-shear steel rivets are given in section 2.6114. These rivets may be used in aluminum alloy materials.

3.6116 *Lockbolts.* Lockbolts and lockbolt stumps shall be installed in conformance with the lockbolt manufacturer's recommended practices, and shall be inspected in accordance with procedures recommended by the manufacturer or by an equivalent method. The ultimate allowable shear and tensile strengths for protruding and flush head Huck lockbolts and lockbolt stumps are contained in table 3.6116. These strength values were established from test data and are minimum values guaranteed by the manufacturer. Yield shear and tensile strengths and ultimate and yield bearing strengths will be added when available.

3.6117 *Flush screws.* Tables 3.6117 (*a*) and (*b*) contain ultimate and yield allowable strength values for 100° flush-head screws with recessed heads installed in machine countersunk clad 24ST and 75ST sheet. These strength values are applicable when the edge distance is equal to or greater than two times the nominal screw diameter. Other strength values and edge distances may be used if substantiated by tests.

These strength values may be used for design of dimpled joints. Higher values may be used for dimpled joints if based on test results subjected to approval by the procuring or certificating agency.

Table 3.6116. Ultimate Single Shear and Tensile Strengths of Protruding and Flush Head Huck Lockbolts[a] and Lockbolt Stumps (Pounds)

Lockbolt pin material	Heat treated alloy steel		75S-T6	
Lockbolt collar material	24S-T4		61S-T6	
Diameter (in.) \ Loading	Single shear	Tension	Single shear	Tension
3/16[b]	2,620	2,210	1,330	1,375
1/4[b]	4,650	4,080	2,280	2,535
5/16	7,300	6,500	3,620	4,025
3/8	10,500	10,100	5,270	6,275

[a] Lockbolts are pull gun driven, lockbolt stumps are hammer or squeeze driven.

[b] Heat treated alloy steel Huck pull type lockbolts are available only in 3/16- and 1/4-inch diameters. Heat treated alloy steel Huck lockbolt stumps are available in 3/16-, 1/4-, 5/16-, and 3/8-inch diameters.

Table 3.6117(a). Ultimate Strength of 100° Machine Countersunk Screw Joints (Pounds)[a b]

Type fastener	AN 509 steel screw with AN 365 steel nut[d e]									
Sheet material	Clad 24S-T3					Clad 75S-T6				
Rivet diameter	3/16	1/4	5/16	3/8	1/2	3/16	1/4	5/16	3/8	1/2
Sheet thickness:[c]										
0.032	493					569				
0.040	657	761				791	905			
0.051	903	1,074	1,224			*1,080	1,277	1,454		
0.064	*1,211	1,439	1,690	1,887		*1,365	1,748	1,995	2,211	
0.072	*1,392	*1,693	1,955	2,235		*1,501	*2,006	*2,386	2,608	
0.081	*1,567	*1,965	*2,288	2,600		*1,632	*2,252	*2,777	*3,105	
0.091	*1,726	*2,263	*2,679	3,022	3,690	*1,762	*2,488	*3,162	*3,693	4,263
0.102	*1,877	*2,576	*3,105	*3,519	4,292	*1,892	*2,723	*3,536	*4,222	5,100
0.125	*2,126	*3,054	*3,922	*4,579	5,586	2,126	*3,109	*4,180	*5,216	6,791
0.156	2,126	*3,536	*4,772	*5,878	7,482	2,126	*3,551	*4,858	*6,193	8,673
0.188		3,680	*5,405	*6,872	*9,408		3,680	*5,433	*6,996	10,202
0.250			*5,750	*8,280	*12,201			5,750	*8,280	*12,421
0.312				*8,280	*14,141				8,280	14,185
0.375					14,700					14,700

[a] This table refers to recessed head screws only. Design allowables for sheet thicknesses above or below the range for which values are indicated, shall not be determined by extrapolation.

[b] Design allowables for alloys in other physical conditions, for joint configurations other than that indicated in par. 3.6113, or for section thicknesses outside the range for which values are indicated, shall be substantiated by test data and shall be subject to specific approval by the procuring or certifying agency.

[c] Sheet thickness of countersunk sheet.

[d] Yield values of the sheet screw combinations marked thus (*) are less than 2/3 of the indicated ultimate values.

[e] The values in this table are based on "good" manufacturing practice, and any deviation from this will produce significantly reduced values.

Table 3.6117 (b). Yield Strength of 100° Machine Countersunk Screw Joints (Pounds) [a] [b]

Type fastener	AN 509 steel screw with AN 365 steel nut									
Sheet material	Clad 24S-T3					Clad 75S-T6				
Rivet diameter	3/16	1/4	5/16	3/8	1/2	3/16	1/4	5/16	3/8	1/2
Sheet thickness: [c]										
0.032	436					559				
0.040	508	732				616	931			
0.051	617	854	1,035			710	1,041	1,156		
0.064	744	1,012	1,248	1,531		819	1,181	1,374	1,722	
0.072	818	1,122	1,380	1,697		884	1,269	1,495	1,887	
0.081	903	1,232	1,512	1,871		965	1,369	1,610	2,045	
0.091	989	1,354	1,633	2,070	3,395	1,063	1,479	1,731	2,219	3,925
0.102	1,084	1,490	1,765	2,244	3,719	1,179	1,600	1,857	2,401	4,292
0.125	1,296	1,748	2,001	2,559	4,336	1,462	1,895	2,098	2,699	5,145
0.156	1,615	2,116	2,334	2,939	5,189	1,913	2,363	2,501	3,088	6,085
0.188		2,484	2,702	3,361	6,012		2,926	3,018	3,601	6,835
0.250			3,404	4,197	7,306			4,312	4,868	8,041
0.312				5,092	8,452				6,624	9,437
0.375					9,996					11,686

[a] This table refers to recessed head screws only.
[b] Design allowables for sheet thickness above or below the range of values tabulated shall not be determined by extrapolation.
[c] Sheet thickness is that of both sheets.

The allowable ultimate loads were established from test data using the average failing load divided by a factor of 1.15. The yield loads were established from test data, wherein the yield load was defined as the average test load at which the following permanent set across the joint is developed.

(*a*) 0.012 inch up to and including 1/4-inch-diameter screws.

(*b*) 4.0 percent of the screw diameter for screw sizes larger than 1/4-inch diameter.

The test specimens used were made up of two equal gage sheets lap jointed and machine countersunk with washers to build up thickness to minimum grip. All joints had 2D nominal edge distance in the direction of the load and were either of the three screws across, or the two screws in tandem, type. For the latter type the flush heads were placed on opposite sides of the joint to assure 2D edge distances.

Test data from which the yield and ultimate strengths listed were derived are to be found in reference 3.6117.

3.612 *Welded joints*

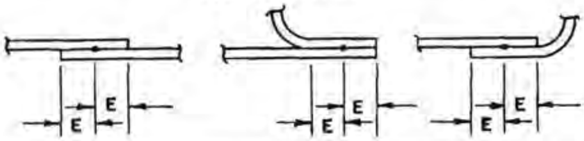
3.6121 *Fusion welds.* Since fusion welding is not generally used in the joining of major structural parts made of aluminum alloy, no values for allowable stresses for such joints will

Table 3.6122 (a). Spotweld Maximum Design Shear Strength Standards for Bare and Clad Aluminum Alloys [a]

Nominal thickness of thinner sheet	Material ultimate tensile strength above 56 *ksi* [b]	Material ultimate tensile strength 28 *ksi* to 56 *ksi* [c]	Material ultimate tensile strength 20 *ksi* to 27.5 *ksi* [d]	Material ultimate tensile strength 19.5 *ksi* and below [e]
Inch	*Pounds*	*Pounds*	*Pounds*	*Pounds*
0.012	60	52	24	16
0.016	86	78	56	40
0.020	112	106	80	62
0.025	148	140	116	88
0.032	208	188	168	132
0.040	276	248	240	180
0.051	384	354	329	240
0.064	552	500	451	320
0.072	678	589	524	364
0.081	842	691	620	424
0.091	1,020	810	703	484
0.102	1,230	960	760	548
0.114	1,465	1,085	803	591
0.125	1,698	1,300	840	629
0.156	2,400			

[a] Spotwelding of aluminum alloy combinations conforming to QQ-A-277, QQ-A-355, and QQ-A-255 may be accomplished providing specific approval is obtained from the procuring or certificating agency.
[b] Heat-treated and aged 14S, heat-treated 17S and 24S, heat-treated and rolled 24S, heat treated and aged 75S and R-301, R-303.
[c] 52S-H34, 52S-H38, heat-treated and aged 53S and 61S.
[d] 2S-H18, 3S-H14, 61S annealed, 61S-T4, 52S annealed.
[e] 2S annealed, 2S-H14, 3S annealed.

Table 3.6122 (b). Minimum Edge Distances for Spotweld Joints [a] [b]



Thickness thinner sheet	Edge distance *E*	Thickness thinner sheet	Edge distance *E*
Inch	*Inch*	*Inch*	*Inch*
0.016	3/16	0.060	11/32
0.020	3/16	0.070	3/8
0.025	7/32	0.080	13/32
0.030	1/4	0.090	7/16
0.035	1/4	0.100	7/16
0.040	9/32	0.120	1/2
0.045	5/16	0.125	9/16
0.050	5/16	0.157	5/8

[a] Intermediate gages will conform to the requirement for the next thinner gage shown.

[b] For edge distances less than those specified above, appropriate reductions in the spotweld allowable loads shall be made. These reductions shall be subject to approval by the procuring or certificating agency.

be given. Fusion welding, however, is used on certain parts; e. g., fuel and oil tanks. The design of these parts is substantiated in part by special tests specified or deemed suitable by the procuring or certificating agency.

3.6122 *Spot welding.* The permissibility of the use of spot welding on structural parts is governed by the requirements of the procuring or certificating agency. Design shear strength allowables for spotwelds in various aluminum alloys are given in table 3.6122 (*a*). Table 3.6122 (*b*) gives the minimum allowable edge distance for the spotwelds in aluminum alloys; these values may be reduced for nonstructural applications, or for applications not depended upon to develop the full tabulated weld strength. Combinations of alloys suitable for spot welding are given in table 3.6122 (*c*). The thickness ratio of the thickest sheet to the thinnest outer sheet in the combination should not exceed 3.1.

Table 3.6122 (c). Acceptable Aluminum and Aluminum Alloy Combinations [a] *for Spotwelding*

Specification No.	Material	QQ-A-315 (52S)	QQ-A-318 (52S)	QQ-A-327 (61S)	QQ-A-354 (Bare 24S) [b]	QQ-A-355 (Bare 24S) [b]	QQ-A-359 (3S)	QQ-A-362 (Clad 24S)	QQ-A-411 (2S)	QQ-A-561 (2S)	QQ-A-287 (Clad 75S) [c]	QQ-A-277 (Bare 75S) [b]	QQ-A-355 (Bare 24S) [b]	QQ-A-362a (Clad 24S)	QQ-A-255 (R301, Clad 14S)	QQ-A-261 and QQ-A-266 (Bare 14S) [b]
QQ-A-315	(52S)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
QQ-A-318	(52S)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
QQ-A-327	(61S)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
QQ-A-354	(Bare 24S) [b]	---	---	---	(*)	(*)	---	---	---	---	---	(*)	(*)	---	(*)	(*)
QQ-A-355	(Bare 24S) [b]	---	---	---	(*)	(*)	---	---	---	---	---	(*)	(*)	---	(*)	(*)
QQ-A-359	(3S)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
QQ-A-362	(Clad 24S)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
QQ-A-411	(2S)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
QQ-A-561	(2S)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
QQ-A-287	(Clad 75S) [c]	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
QQ-A-277	(Bare 75S) [b]	---	---	---	(*)	(*)	---	---	---	---	---	(*)	(*)	---	(*)	(*)
QQ-A-355	(Bare 24S) [b]	---	---	---	(*)	(*)	---	---	---	---	---	(*)	(*)	---	(*)	(*)
QQ-A-362a	(Clad 24S)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
QQ-A-255	(R301, Clad 14S)	---	---	---	(*)	(*)	---	---	---	---	---	(*)	(*)	---	---	(*)
QQ-A-261 and QQ-A-266	(Bare 14S) [b]	---	---	---	(*)	(*)	---	---	---	---	---	(*)	(*)	---	(*)	(*)

[a] *Aluminum alloys.* The various aluminum and aluminum alloy materials referred to in this table may be spotwelded in any combinations except the combinations indicated by the asterisk (*) in the table. The combinations, indicated by the asterisk (*), may be spotwelded only with the specific approval of the procuring or certificating agency.

[b] The above 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 certificating agency.

[c] Clad heat-treated and aged 75S material in thicknesses less than 0.020 inch shall not be welded without specific approval of the procuring or certificating agency.

3.61221 *Reduction in tensile strength of parent metal due to spot welding.* In applications of spot welding where ribs, intercostals, or doublers are attached to sheet, either at splices or at other points on the sheet panels, the allowable ultimate tensile strength of spot-welded sheet shall be determined by multiplying the "A" value for ultimate tensile sheet strength obtained from tables 3.111 (*a*) through (*o*) by the appropriate efficiency factor shown on figure 3.61221. The minimum values of the basic sheet efficiency in tension should not be considered applicable to cases of seam welds. Allowable ultimate tensile strengths for spot-welded sheet gages of less than 0.020 inch shall be established on the basis of tests acceptable to the procuring or certificating agency.

3.6123 *Aluminum brazing.* No values for allowable stresses in shear are given for joints made with this process. Allowables used in the design of parts made by this process are subject to substantiation by special tests in accordance with the requirements of the procuring or certificating agency.

3.613 *Adhesive bonded joints.* Joints may in some instances be made to advantage by the use of an adhesive suitable for the structural bonding of metals. This subject is discussed in reference 2.613.

3.62 PARTS

3.621 *Bursting strength of tubes.* The bursting strength of aluminum-alloy tubing may be calculated for room-temperature conditions from the formula found in specification MIL-T-7081.

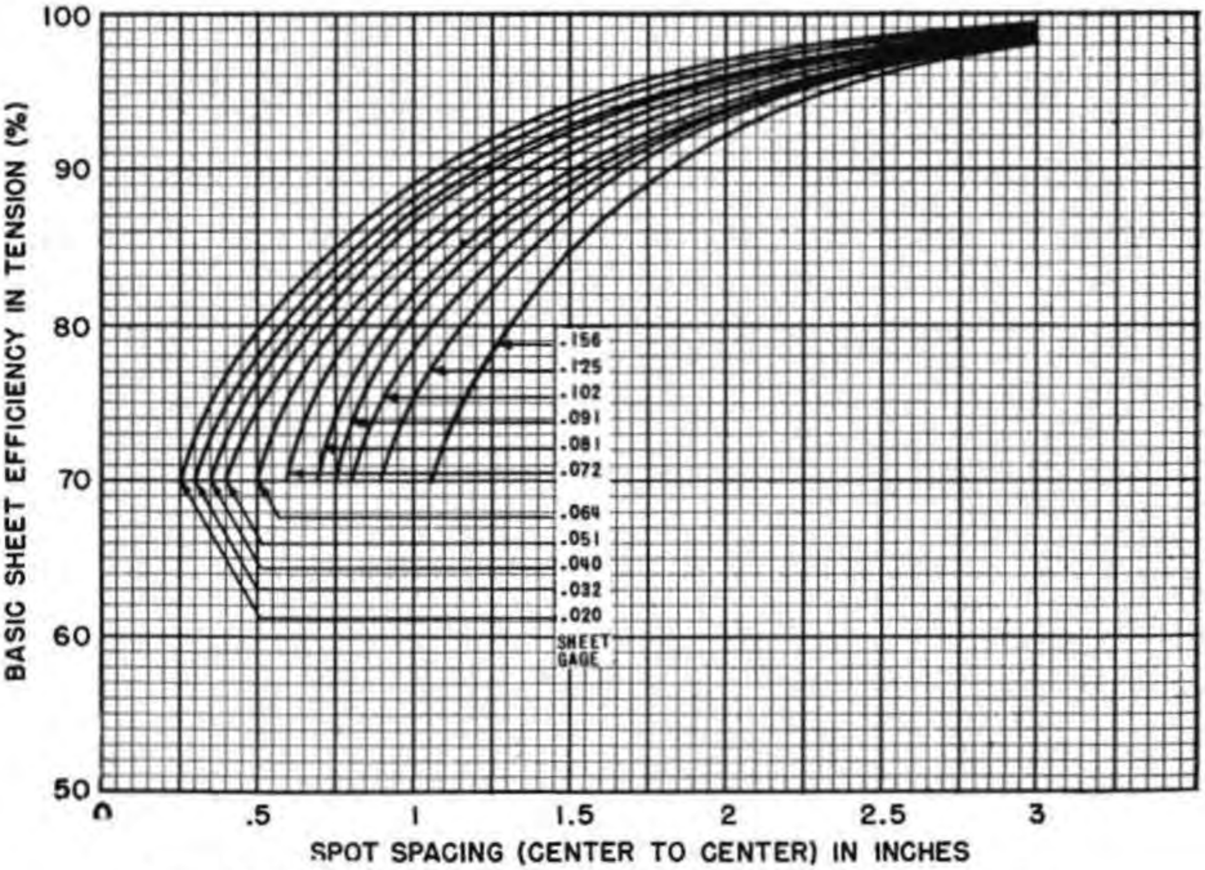


Figure 3.61221. Efficiency of the parent metal in tension for spotwelded aluminum alloys.

CHAPTER 4
MAGNESIUM ALLOYS

4.1 General Properties

4.11 NORMAL (ROOM) TEMPERATURE PROPERTIES

4.111 *Design mechanical properties.* The design mechanical properties at normal (room) temperature for various magnesium alloys are listed in tables 4.111 (*a*) through (*d*). The values in tables 4.111 (*a*) through (*d*) have been derived from test data and are the minimum values expected but are not necessarily covered by procurement specifications.

The effects of notches, holes, and stress raisers on the static properties of magnesium alloys (see sec. 1.526) are given in references 4.111 (*a*) through (*c*).

In the definition of bearing values, D is equal to the hole diameter and e is equal to the edge distance measured from the hole center to the edge of the material in the direction of applied stress. Values of $e/D=2.0$ shall be used for larger values of edge distance; values of e/D less than 1.5 shall be substantiated by adequate tests subject to the approval of the procuring or certificating agency. For values of edge distance between $e/D=2.0$ and $e/D=1.5$, linear interpolation may be employed.

Table 4.111 (a). Design Mechanical Properties of Magnesium Alloy Sheet, Bars, Rods and Shapes (Kips per Square Inch) [a]

Type	Sheet				Bars, rods, and solid shapes					
Alloy (ASTM designation)	AZ31A		M1A		M1A			AZ31B		
Specification	QQ-M-44		QQ-M-54		QQ-M-31					
Condition	Annealed	Hard rolled	Annealed	Hard rolled	As extruded					
Thickness	0.020–0.250				0.249 or less	0.250 to 1.499	1.500 to 2.499	0.249 or less	0.250 to 1.499	1.500 to 2.499
F_{tu}	32	39	28	32	30	32	32	33	32	32
F_{ty}	15	29	12	22	17	17	17	20	20	20
F_{cy}	12	24	11	17	8	8	8	12	12	10
F_{su}	17	18	17	18	14	14	14	18	18	18
F_{bru} $(e/D=1.5)$	50	58	45	48	36	36	36	36	36	36
F_{bru} $(e/D=2.0)$	60	68	50	51	45	45	45	45	45	45
F_{bry} $(e/D=1.5)$	29	43	23	33	23	23	23	23	23	23
F_{bry} $(e/D=2.0)$	29	43	23	35	23	23	23	23	23	23
e	12	4	12	3	2	3	2	7	7	7
w	0.0645		0.0635		0.0635			0.0645		
E, E_c	6,500				6,500					
G	2,400				2,400					
Commercial designations	AMC51S–0 FS1–0	AMC52S–H24 FS1–H24	AM3S–0 M–0	AM3S–H24 M–H24	AM3S–F M–F			AMC52S–F FS1–F		

[a] Properties for sheet, bars, rods, and shapes are taken parallel to the direction of rolling, drawing, or extrusion or maximum metal flow during fabrication.

Table 4.111 (b). Design Mechanical Properties of Magnesium Alloy Bars, Rods and Shapes (Kips per Square Inch) [a]

Type	Bars, rods, and solid shapes								Hollow shapes		
Alloy (ASTM designation)	AZ61A		AZ80A						M1A	AZ31B	AZ61A
Specification	QQ-M-31										
Condition	As extruded					Extruded and aged			As extruded		
Thickness	0.249 or less	0.250 to 2.499	0.249 or less	0.250 to 1.499	1.500 to 2.499	0.249 or less	0.250 to 1.499	1.500 to 2.499	0.050–0.250		
F_{tu}	38	39	43	43	43	47	47	47	28	32	36
F_{ty}	20	24	28	28	28	30	32	32	----------	16	16
F_{cy}	14	14	----------	17	17	----------	28	27	----------	10	11
F_{su}	19	19	19	19	19	20	20	20	----------	----------	----------
F_{bru} $(e/D=1.5)$	45	45	48	48	48	----------	----------	----------	----------	----------	----------
F_{bru} $(e/D=2.0)$	55	55	56	56	56	----------	----------	----------	----------	----------	----------
F_{bry} $(e/D=1.5)$	28	28	36	36	36	----------	----------	----------	----------	----------	----------
F_{bry} $(e/D=2.0)$	32	32	40	40	40	----------	----------	----------	----------	----------	----------
e	8	9	9	8	6	4	3	2	2	8	7
w	0.0649		0.0653						0. 0635	0. 0645	0. 0649
E, E_c	6,500		6,500								
G	2,400		2,400								
Commercial designations	AMC57S-F J1-F		AMC58S-F O1-F			AMC58S-T51 O1-T5			AM3S-F M-F	AMC52S-F FS1-F	AMC57S-F J1-F

[a] Properties for bars, rods, and shapes are taken parallel to the direction of rolling, drawing, or extrusion or maximum metal flow during fabrication.

Table 4.111 (c). Design Mechanical Properties of Magnesium Alloy Tubes, Die Castings, Sand Castings, and Forgings (Kips per Square Inch) [a]

Type	Round tubing			Die castings	Sand castings [b]										Forgings				
Alloy (ASTM designation)	M1A	AZ31B	AZ61A	AZ91A	AZ63A			M1A	AZ91C			AZ92A			AZ61A	AZ80A		M1A	TA54A
Specification	WW-T-825			QQ-M-38	QQ-M-56										QQ-M-40				
Condition	As extruded			As cast	As cast	Heat treated	Heat treated and aged	As cast	As cast	Heat treated	Heat treated and aged	As cast	Heat treated	Heat treated and aged	As forged	As forged	Forged and aged	As forged	As forged
Thickness	0.050–0.250																		
F_{tu}	28	32	36	30	24	34	34	12	18	32	34	20	34	34	38	42	42	30	36
F_{ty}	16	16	16	20	10	10	16	4	10	10	16	10	10	18	22	26	28	18	22
F_{cy}	....	10	11	20	10	10	16	4	10	10	16	10	10	18	14	18	25	....	16
F_{su}	....	....	....	18	16	17	19	10	....	17	19	16	17	20	19	20	20	14	15
F_{bru} $(e/D=1.5)$	....	....	....	....	36	36	50	14	....	36	50	32	48	52	50	....	50	46	....
F_{bru} $(e/D=2.0)$	....	....	....	....	50	50	65	19	....	50	65	42	58	70	60	....	70	50	....
F_{bry} $(e/D=1.5)$	....	....	....	....	28	32	36	8	....	32	36	30	32	45	28	....	42	23	....
F_{bry} $(e/D=2.0)$	....	....	....	....	30	36	45	10	....	36	45	40	40	55	32	....	....	23	....
e	2	8	7	2	4	7	3	3	....	7	3	....	6	....	6	5	2	3	7
w	0.0635	0.0645	0.0649	0.0653		0.0664		0.0635		0.0653			0.0667		0.0649	0.0353		0.0635	0.0674
Commercial designations	AM 3S-F M-F	AMC 52S-F FS1-F	AMC 57S-F J1-F	AM 263-F R-F	AM 265-F H-F	AM 265-T4 H-T4	AM 265-T6 H-T6	AM 403-F M-F	AMA 263-F AZ91C-F	AMA 263-T4 AZ91C-T4	AMA 263-T6 AZ91C-T6	AM 260-F O-F	AM 260-T4 O-T4	AM 260-T6 O-T6	AMC 57S-F J1-F	AMC 58S-F O1-F	AMC 58S-T5 O1-T5	AM 35-F M-F	AM 65S-F D-F
E, E_c	6,500			6,500	6,500										6,500				
G	2,400			2,400	2,400										2,400				

[a] Properties for tubing, castings and forgings are taken parallel to the direction of rolling, drawing, or extrusion or maximum metal flow during fabrication.

[b] The sand casting properties are minimum values obtained from cast test bars. Reference should be made to the specific requirements of the procuring or certificating agency with regard to the use of the above values in the design of castings.

Table 4.111 (d). Design Mechanical Properties of Magnesium Alloy ZK60A Extrusions (Kips per Square Inch)

Specification and alloy designation		QQ-M-31(ZK60A)							
Type		Rods, bars, and solid shapes						Tubes and hollow shapes	
Condition		As extruded	Extruded and aged	As extruded	Extruded and aged	As extruded	Extruded and aged	As extruded	Extruded and aged
Least cross-sectional dimension, inches		Less than 2.0		2.0 to 2.99		3.0 to 4.99			
F_{tu}	L	43	45	43	45	43	45	40	60
	T								
	ST								
F_{ty}	L	31	36	31	36	31	36	28	38
	T								
	ST								
F_{cy}	L	27	30	26	28	25	25	20	26
	T								
	ST								
F_{su}		22	22	22	22	22	22		
F_{bru} $(e/D=1.5)$									
F_{bru} $(e/D=2.0)$		70	71	70	71	70	71		
F_{bry} $(e/D=1.5)$									
F_{bry} $(e/D=2.0)$		45	47	45	47	45	47		
e		5	4	5	4	5	4	5	4
E		6,500							
E_c		6,500							
G		2,400							
w		.0661							
Commercial designations		ZK60A-F	ZK60A-T5	ZK60A-F	ZK60A-T5	ZK60A-F	ZK60A-T5	ZK60A-F	ZK60A-T5

4.112 *Fatigue properties.* Rotating beam, repeated flexure, and direct tension and compression strength data, for several magnesium alloy materials are given in tables 4.112 (*a*) through (*c*). In using these data it should be remembered that they have been obtained from specimens in which stress concentrations are purposely minimized, and that suitable allowance should be made for reentrant corners, notches, holes, joints, and all other conditions which may produce localized high stresses. These localized high stresses, which have almost no effect on the static strength of the members, are of great importance in studying the effect of repeated stresses.

The values given in table 4.112 (*a*) were determined by testing 0.3-inch diameter machined and polished specimens (die cast were cast to shape) in R. R. Moore rotating beam fatigue machines and represent extreme fiber stresses which such specimens will withstand.

The values given in table 4.112 (*b*) were determined by testing 0.25-inch thick cast and forged specimens and 0.064-inch thick sheet specimens in Krouse plate bending fatigue machines and represent the completely reversed stresses that such specimens will withstand. Sand-cast specimens were machined; all other specimens received no special surface treatment. The values given in table 4.112 (*c*) were determined by testing 0.064-inch by 1-inch sheet specimens and 0.3-inch diameter machined and polished specimens in Krouse direct tension-compression fatigue machines, and represent uniformly distributed stresses which such specimens will withstand under repeated axial loads. The data presented in this table show a mean stress with a superimposed alternating stress, instead of maximum and minimum values. It also indicates the magnitude of the alternating stress that is expected to cause failure in conjunction with various mean stresses for various numbers of cycles.

Table 4.112 (a). Rotating-Beam Fatigue Strength

Alloy and temper	Fatigue strength (reversed stress), *ksi*, at indicated number of cycles			
	100,000 cycles	1,000,000 cycles	10,000,000 cycles	100,000,000 cycles
Sand cast:				
C–AC, AM260C	18. 5	16. 5	14. 5	13. 0
C–HT	20. 0	18. 0	16. 5	16. 0
C–HTS	20. 5	17. 5	15. 0	13. 0
C–HTA	19. 5	17. 5	16. 0	15. 0
H–AC, AM265C	18. 0	14. 0	10. 5	10. 5
H–ACS	23. 0	19. 0	15. 0	12. 0
H–HT	21. 5	19. 0	16. 5	16. 5
H–HTS	21. 0	18. 5	16. 0	15. 0
H–HTA	18. 0	17. 0	16. 0	15. 0
Die cast: R, AM263C	17. 5	16. 0	15. 0	15. 0
Extruded:				
M, AM3S	15. 5	13. 0	10. 5	10. 5
FS–1	27. 0	24. 0	21. 0	19. 0
J–1, AMC57S	24. 5	22. 5	20. 5	20. 0
O–1, AMC58S	27. 0	24. 5	22. 5	20. 5
O–1HTA and AMC58ST51	27. 0	24. 5	22. 5	20. 5
Forged:				
J–1	27. 5	24. 5	21. 5	19. 5
O–1	28. 0	25. 0	22. 0	19. 5
O–1A	25. 0	22. 5	20. 0	18. 0
O–1HTA	26. 0	21. 0	16. 0	16. 0

Table 4.112 (b). Repeated-Flexure Fatigue Strength

Alloy and temper	Mean stress ksi	Fatigue strength (reversed stress), ksi, at indicated number of cylces		
		100,000 cycles	1,000,000 cycles	10,000,000 cycles
Sand cast and machined H-AC, H-HTS, H-HT, H-HTA, C-AC, C-HT, and C-HTA [a]	0	±13.0 to ±19.5	±11.0 to ±16.0	±11.0 to ±13.5
	+5	±10.0 to ±16.3	±8.0 to ±15.5	±8.5 to ±13.0
	+10	±8.0 to ±13.5	±6.0 to ±12.5	±6.0 to ±11.0
	+15	±6.0 to ±11.0	±5.0 to ±8.5	±3.5 to ±6.5
Die cast R	0	±10.5	±9.0	±8.0
Extruded:				
M	0	±14.0	±11.0	±10.0
O-1A	0	±20.0	±15.0	±12.5
O-1HTA	0	±19.5	±16.0	±13.0
J-1	0	±17.5	±12.0	±11.5
Ma sheet	0	±15.5	±12.0	±10.0
	+5	±13.5	±11.0	±8.5
	+10	±11.0	±9.0	±7.5
	+15	±9.5	±7.0	±6.5
	+20	±8.0	±5.0	±5.0
M-H24 sheet	0	±18.5	±14.0	±11.0
	+5	±18.0	±13.0	±11.0
	+10	±16.0	±12.5	±11.0
	+15	±14.5	±11.0	±10.0
	+20	±13.0	±10.0	±9.0
FS-1a, sheet	0	±15.5	±15.0	±14.5
	+5	±15.0	±13.5	±13.5
	+10	±14.5	±12.5	±12.5
	+15	±13.0	±11.5	±11.5
	+20	±10.5	±9.5	±8.5
FS1-H24, sheet	0	±18	±16	±15.5
	+5	±18	±15	±14.5
	+10	±18	±14	±14
	+15	±16	±13	±13
	+20	±15.5	±11.5	±11.5
Forged:				
M	0	±13.0	±9.0	±6.0
O-1HTA	0	±18.0	±14.5	±14.0
J-1	0	±16.5	±12.5	±12.0

[a] Stress scatterbands for sand cast and machined alloys are applicable to all alloys listed, but the range of scatter for any particular alloy is not necessarily as broad as the bands listed.

Table 4.112 (c). Direct Tension-Compression Fatigue Strength[a]

Alloy and temper	Mean (steady) stress, ksi	Reversed (alternating) stress, ksi, at indicated number of cycles		
		100,000 cycles	1,000,000 cycles	10,000,000 cycles
Sand cast and machined H-AC, H-HTS, H-HT, H-HTA, C-AC, and C-HT[a]	0	±17.5 to ±21.5	±15.0 to ±19.0	±12.0 to ±17.5
	+5	±14.0 to ±17.5	±12.0 to ±17.0	±10.0 to ±16.0
	+10	±11.5 to ±15.0	±9.5 to ±14.5	±8.0 to ±14.0
	+15	±9.0 to ±13.0	±7.5 to ±10.0	±6.0 to ±12.0
Ma, sheet	0	±9.0	±6.0	±6.0
	+5	±8.5	±6.0	±6.0
	+10	±8.0	±5.5	±5.0
	+15	±7.0	±5.0	±5.0
	+20	±6.5	±4.5	±4.5
M-H24, sheet	0	±17.0	±14.0	±14.0
	+5	±15.0	±12.0	±12.0
	+10	±13.0	±10.0	±10.0
	+15	±11.5	±8.0	±8.0
	+20	±9.5	±6.0	±6.0
FS-1a, sheet	0	±10.5	±8.5	±8.0
	+5	±9.5	±8.0	±7.5
	+10	±9.5	±7.5	±7.0
	+15	±8.0	±7.0	±7.0
	+20	±7.0	±6.5	±6.5
FS1-H24, sheet	0	±14.5	±14.0	±14.0
	+5	±12.5	±12.0	±12.0
	+10	±11.0	±10.0	±10.0
	+15	±9.0	±8.0	±8.0
	+20	±7.0	±6.0	±6.0
O-1 HTA, extrusions	0	±38.0	±31.5	±25.5
	+5	±33.0	±27.5	±22.5
	+10	±28.0	±23.5	±19.5
	+15	±23.0	±20.0	±16.5
	+20	±18.0	±16.0	±13.5
J-1, extrusions	0	±17.5	±13.5	±13.5
	+5	±15.0	±11.5	±11.5
	+10	±13.0	±9.0	±9.0
	+15	±11.0	±7.0	±7.0
	+20	±9.0	±5.0	±5.0
ZK-60A-T5[b]	0	±23.0	±22.0	±22.0
	+5	±21.5	±20.0	±20.0
	+10	±20.0	±18.0	±17.5
	+15	±17.5	±16.0	±15.5
	+20	±16.0	±14.0	±13.0

[a] NOTE.—See note *a* on table 4.112 (*b*).
[b] Data on ZK-60A-T5 based on 0.400-inch diameter polished specimens loaded in the constant axial-load test machine.

4.113 *Typical stress-strain and tangent modulus data.* Typical stress-strain diagrams and tangent modulus values at various stresses are given in figures 4.113 (*a*) and (*b*) for several magnesium alloy products. The stress-strain curve in the region of low strains can be predicted accurately from the formula 1.342 where an appropriate value of E is selected from tables 4.111 (*a*) through (*d*).

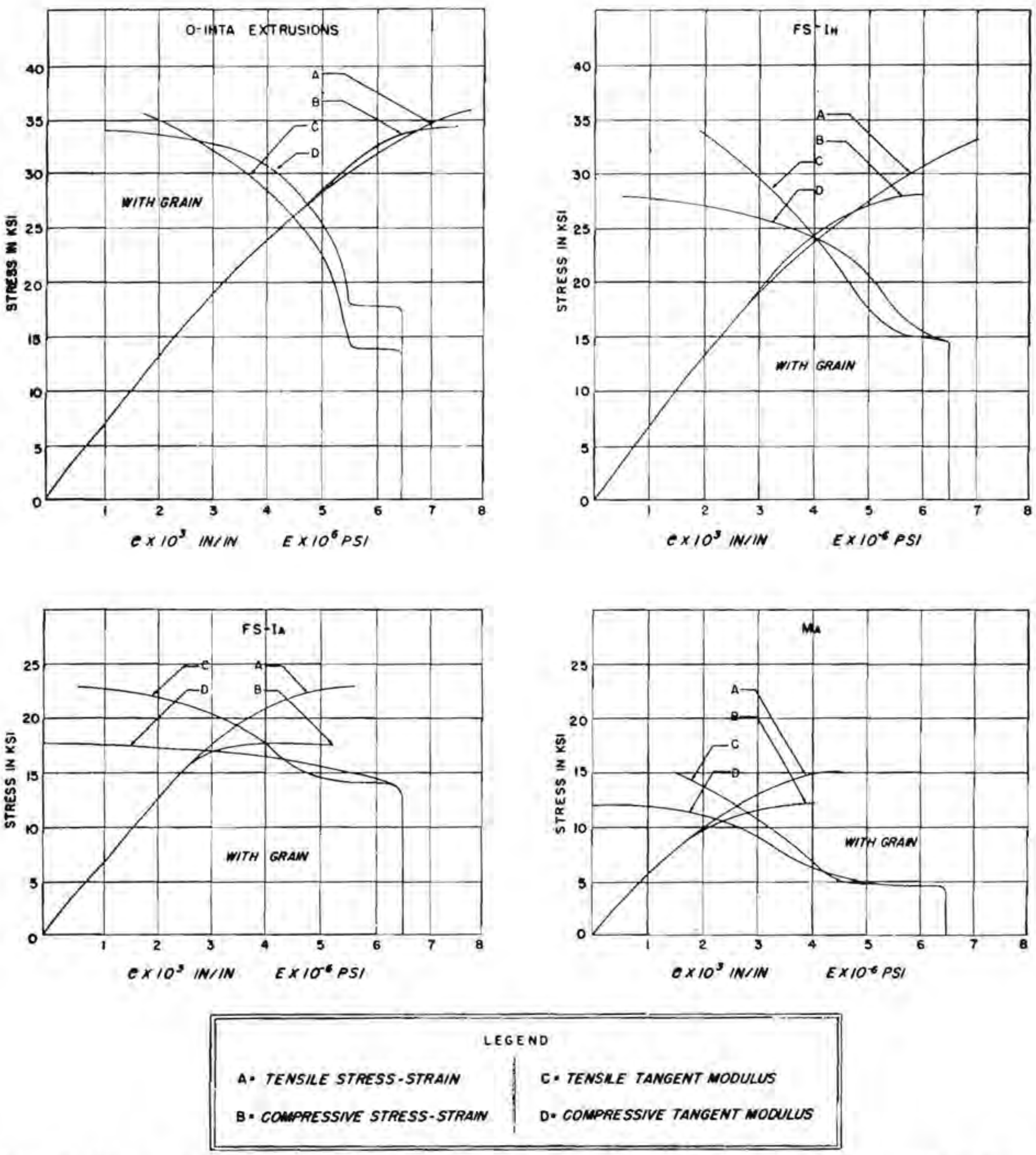


Figure 4.113 (a). Typical stress-strain and tangent modulus curves for magnesium alloy sheet and extruded shapes.

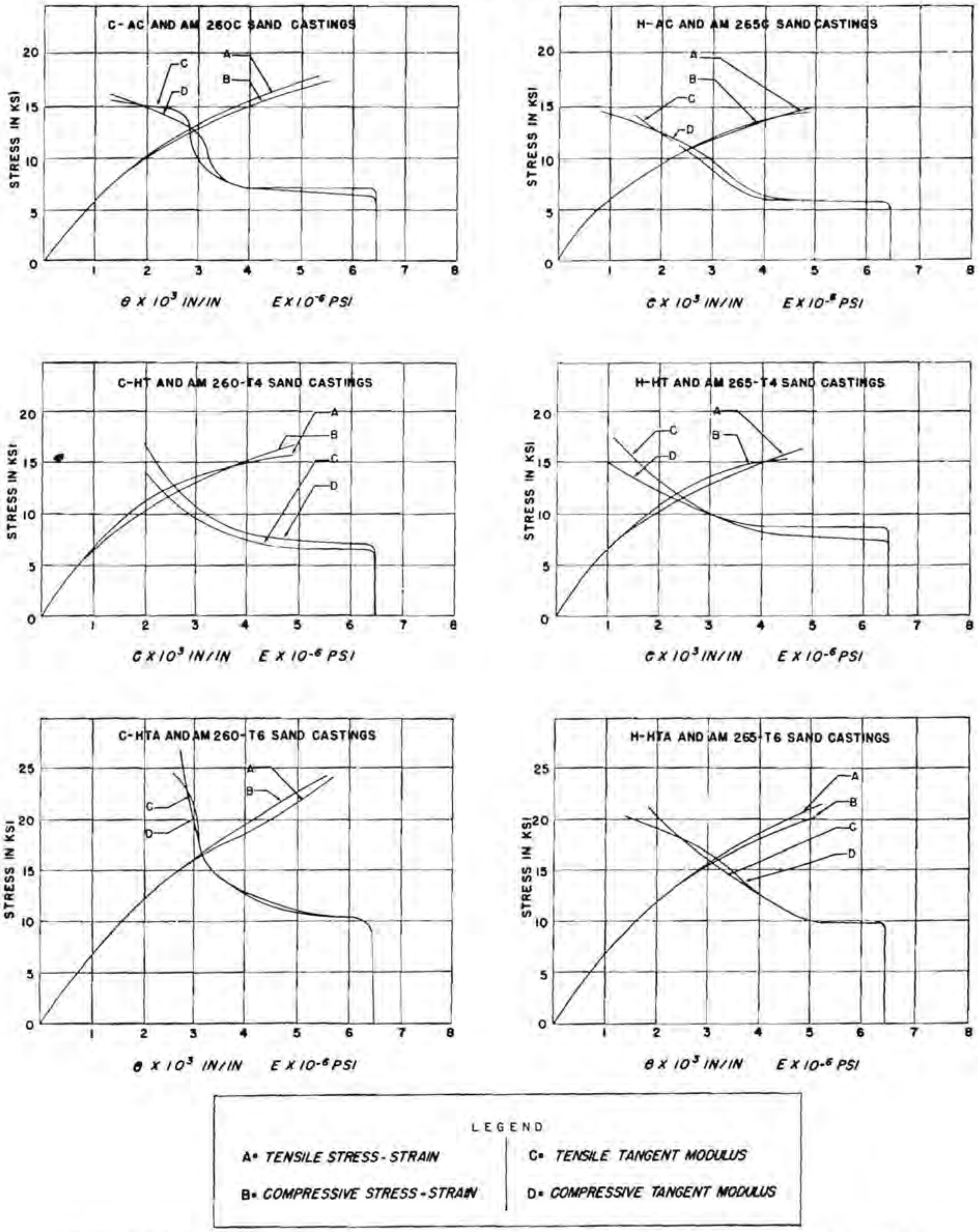


Figure 4.113 (b). Typical stress-strain and tangent modulus curves for magnesium alloy sand castings.

4.12 TEMPERATURE EFFECTS

4.121 *Low temperature.* Low temperatures have an effect on AZ-31 magnesium alloy similar to the effects on aluminum alloys. Strength properties are increased, ductility is decreased somewhat, and impact characteristics remain relatively unchanged. However, these properties were determined for uniaxial stressing conditions, and multiaxial stressing conditions may cause more trouble with magnesium than with aluminum alloys at low temperatures. No data are available for such conditions.

4.122 *Elevated temperature.*

4.1221 *Static properties.*

4.12211 *Strength at temperature.* Curves for computing the approximate reduction in the strength of some magnesium alloys at elevated temperatures are shown in figures 4.12211 (*a*) through (*m*) in one form and in 4.12211 (*n*) and (*o*) in another form. Those materials in 4.12211 (*a*) through (*m*) are for the forged or cast condition (as noted) and those in figures 4.12211 (*n*) and (*o*) are for sheet materials. The materials were held unstressed for various times at temperatures up to 600° F. and then tested statically at temperature. The effect of temperature on the tensile, compressive, bearing, and shear properties of the materials are shown in the various figures.

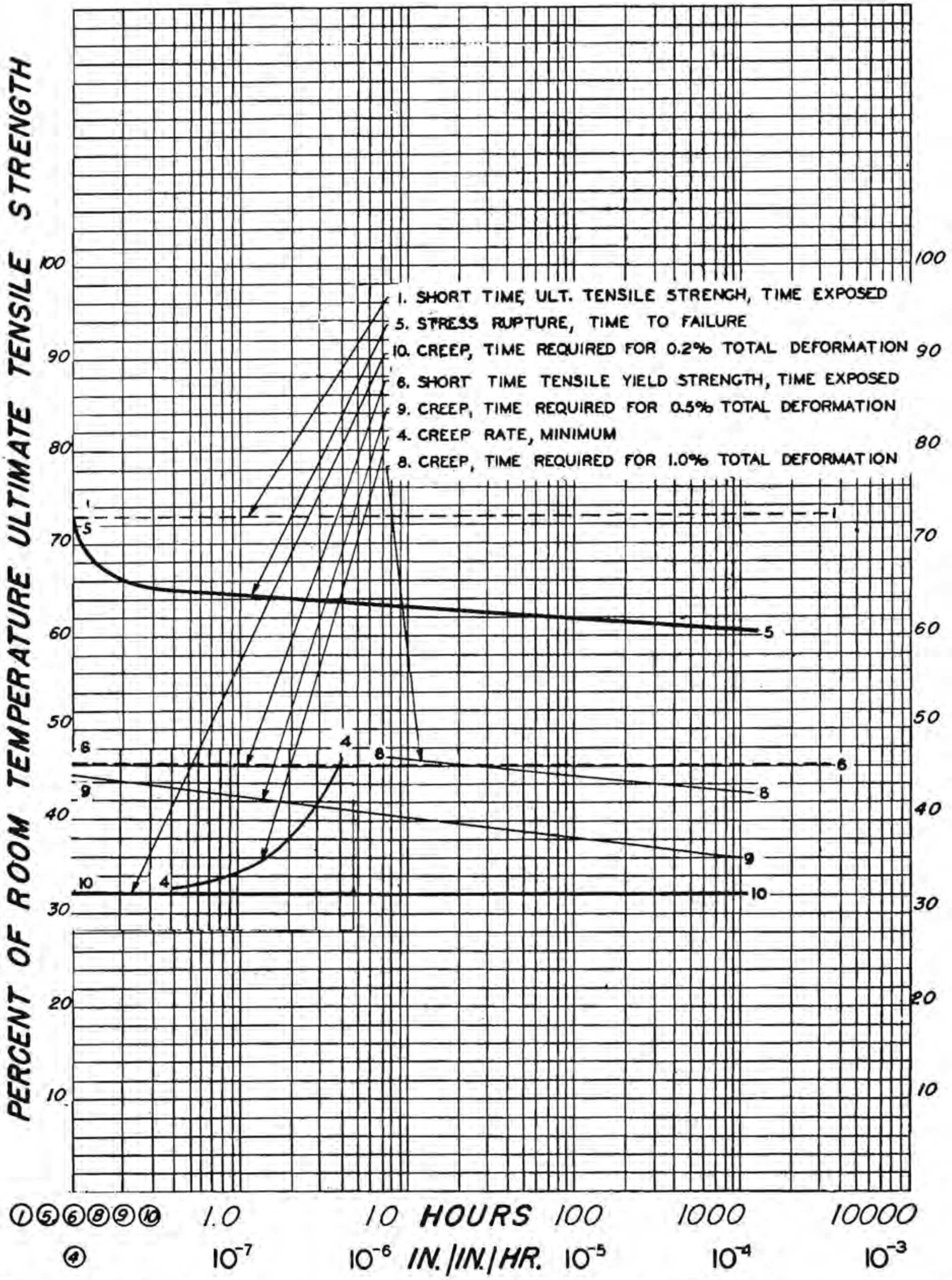


Figure 4.12211 (a). Elevated temperature properties of forged M (annealed 1 hour at 700° F.) magnesium alloy at 200° F. (tensile); (R. T. F_{tu}=33,500 p. s. i.).

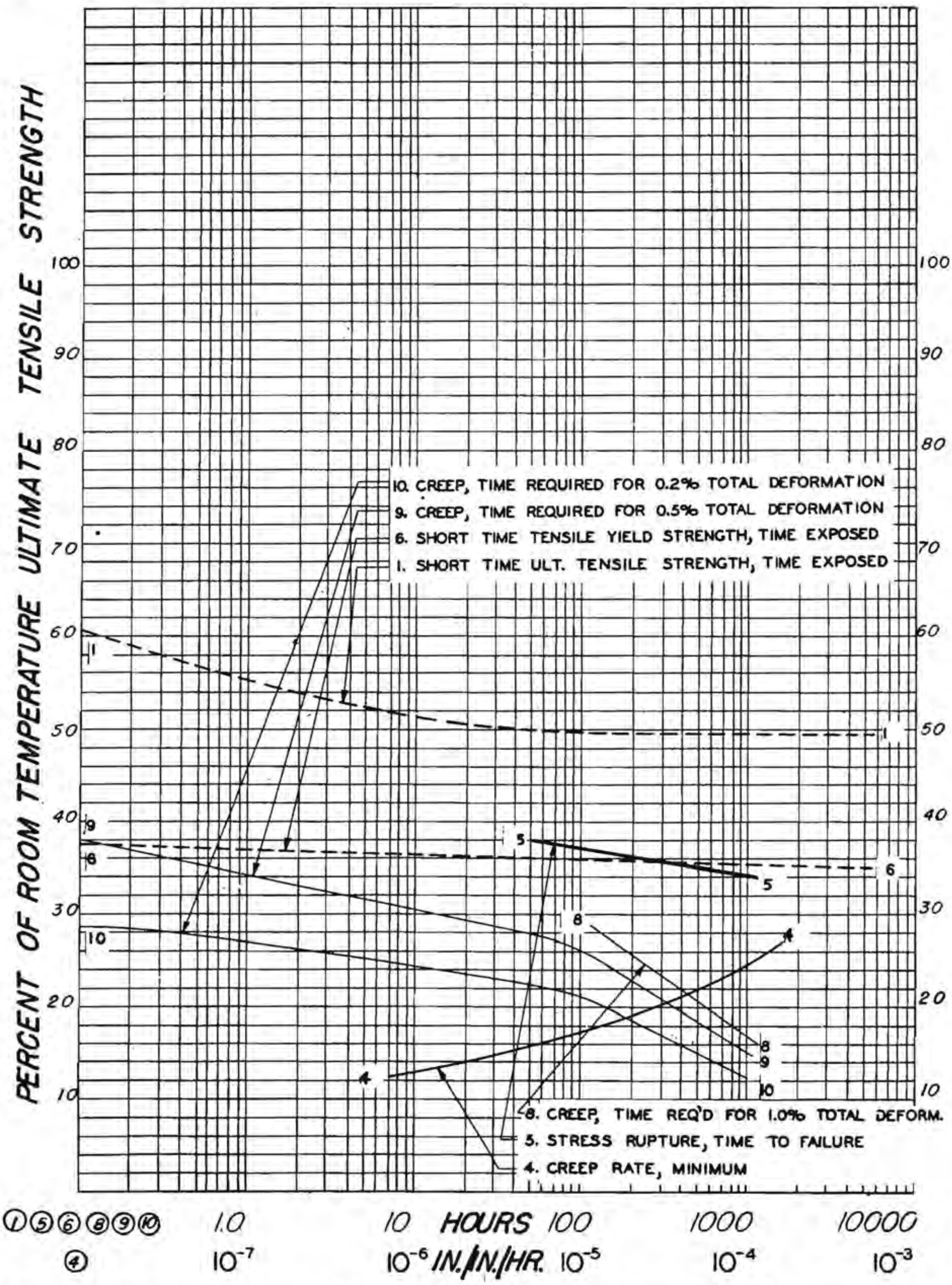


Figure 4.12211 (b). Elevated temperature properties of forged M (annealed 1 hour at 700° F.) magnesium alloy at 300° F. (tensile); (R. T. F_{tu}=33,500 p. s. i.).

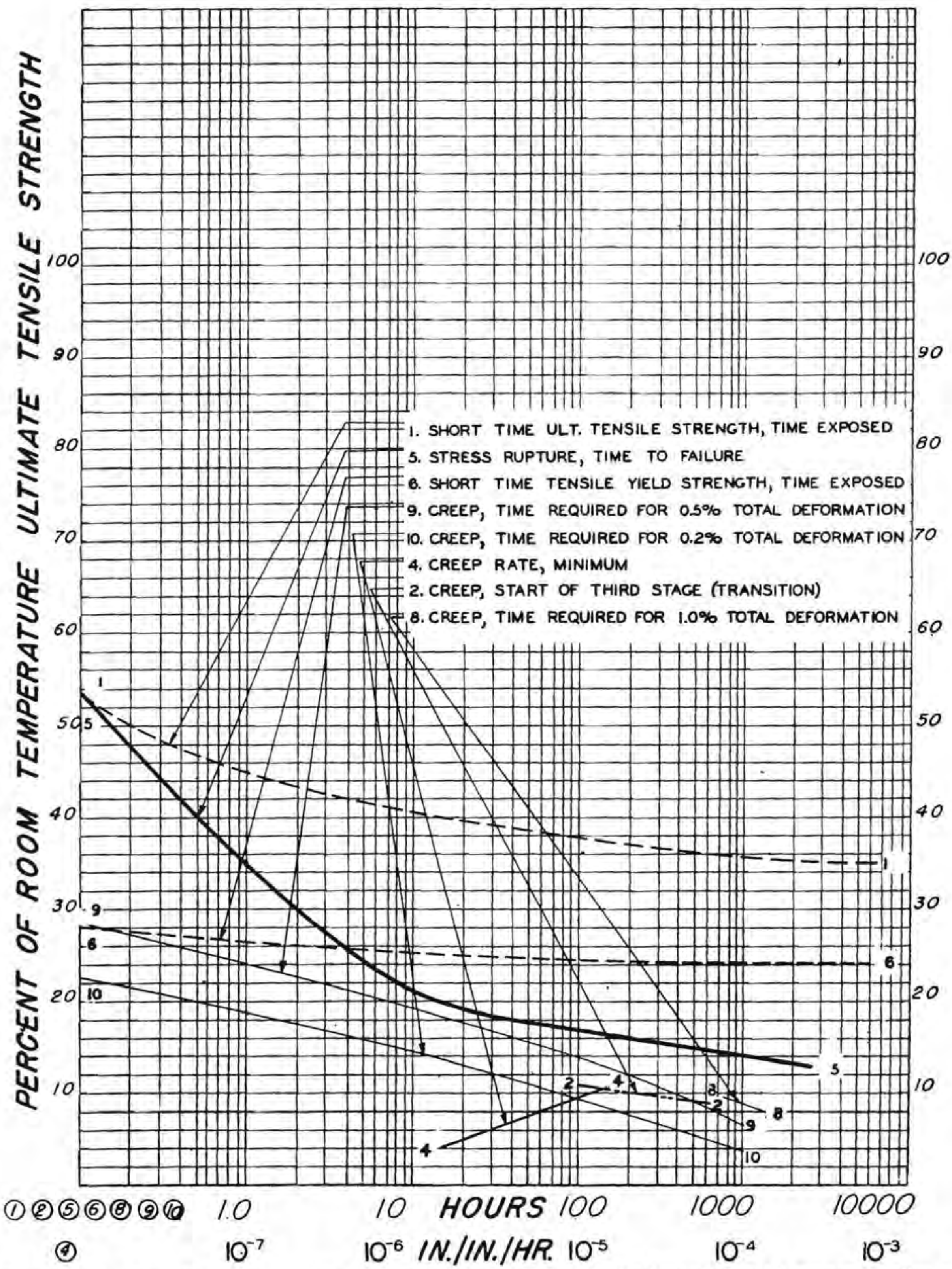


Figure 4.12211 (c). Elevated temperature properties of forged M (annealed 1 hour at 700° F.) magnesium alloy at 400° F. (tensile); (R. T. F_{tu}=33,500 p. s. i.).

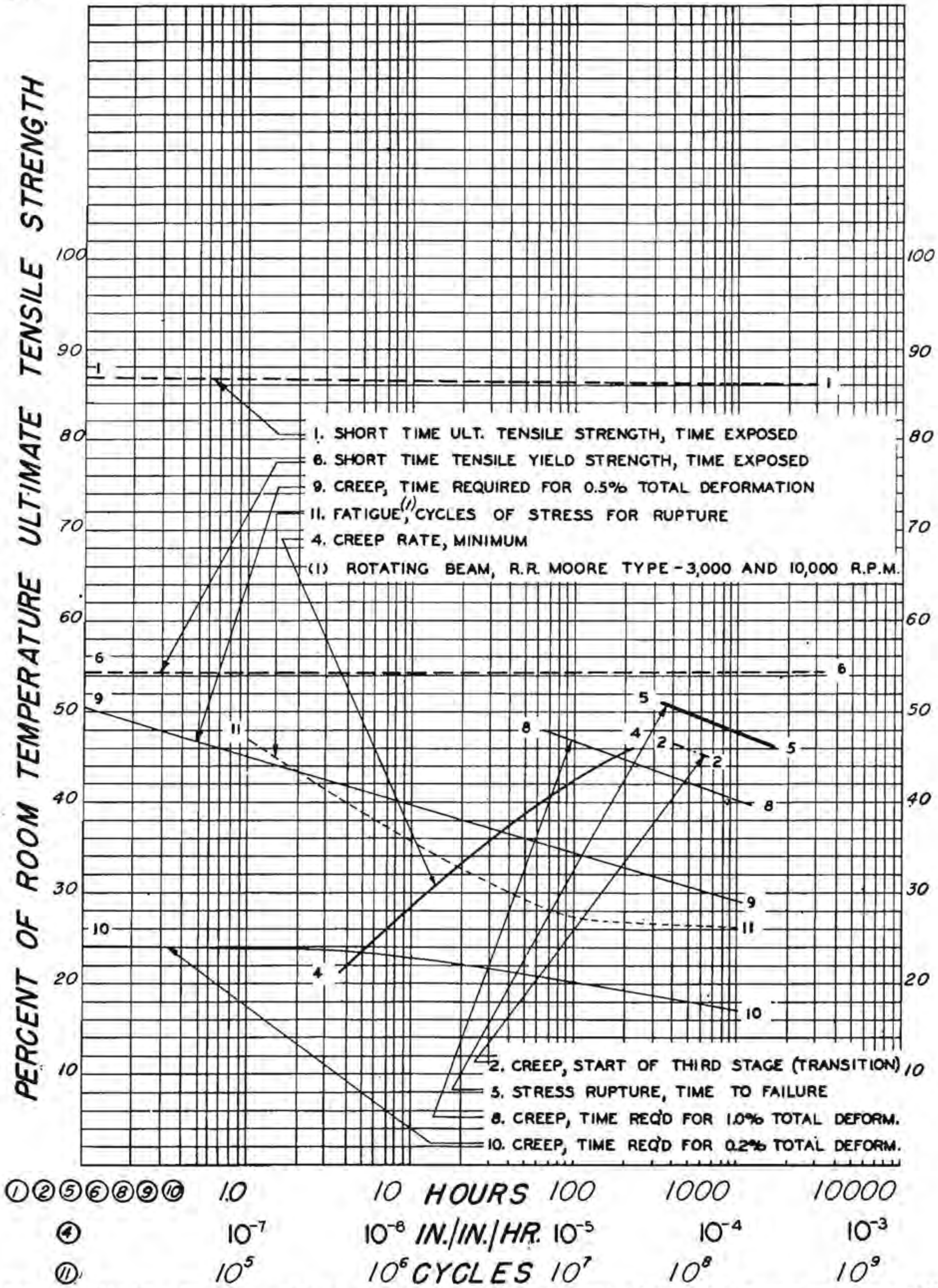


Figure 4.12211 (d). Elevated temperature properties of forged O–1HTA and AMC58S–T51 magnesium alloy at 200° F. (tensile); (R. T. F_{tu}=49,000 p. s. i.).

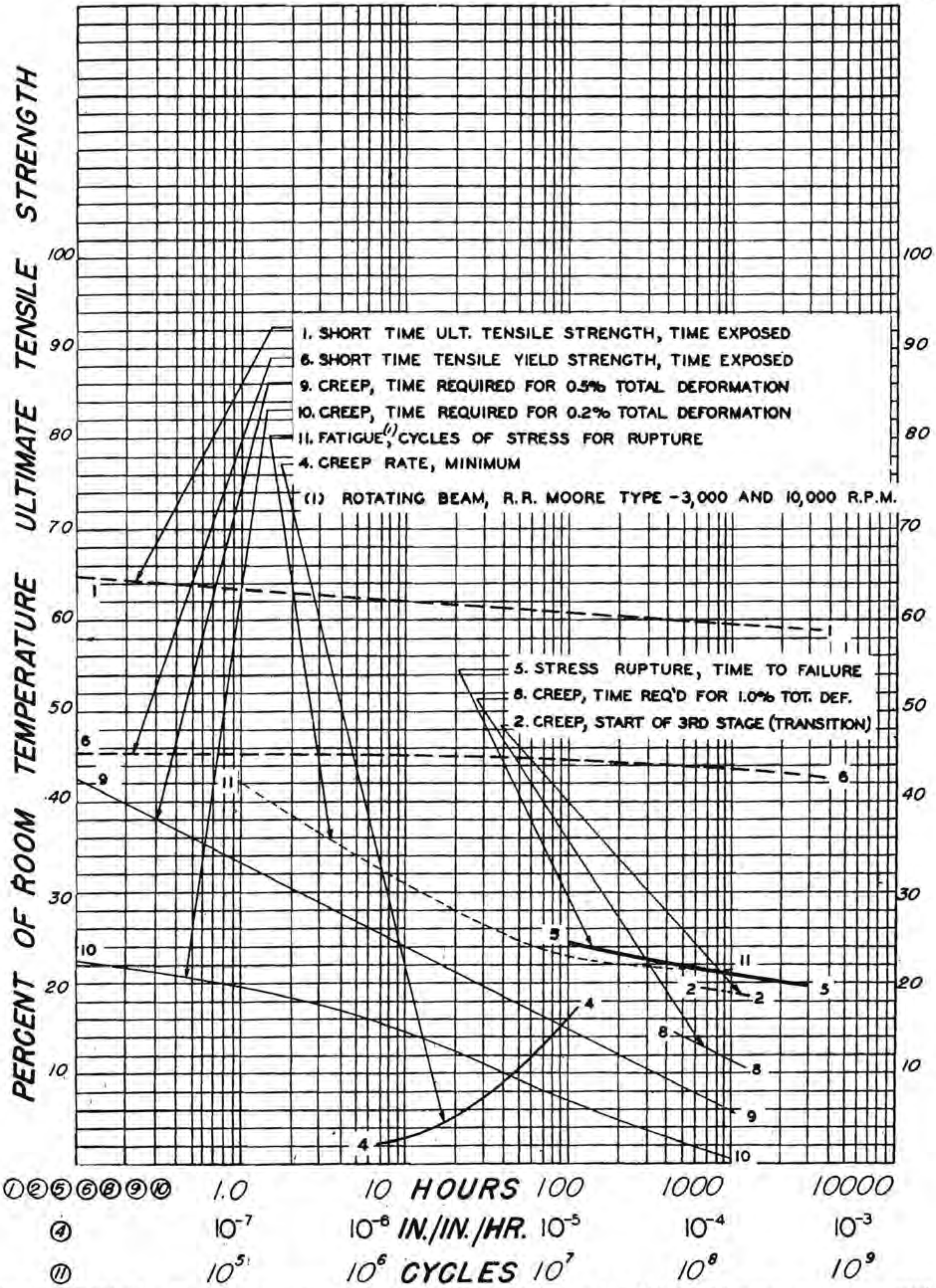


Figure 4.12211 (e). Elevated temperature properties of forged O–1HTA and AMC58S–T51 magnesium alloy at 300° F. (tensile); (R. T. F_{tu}=49.000 p. s. i.).

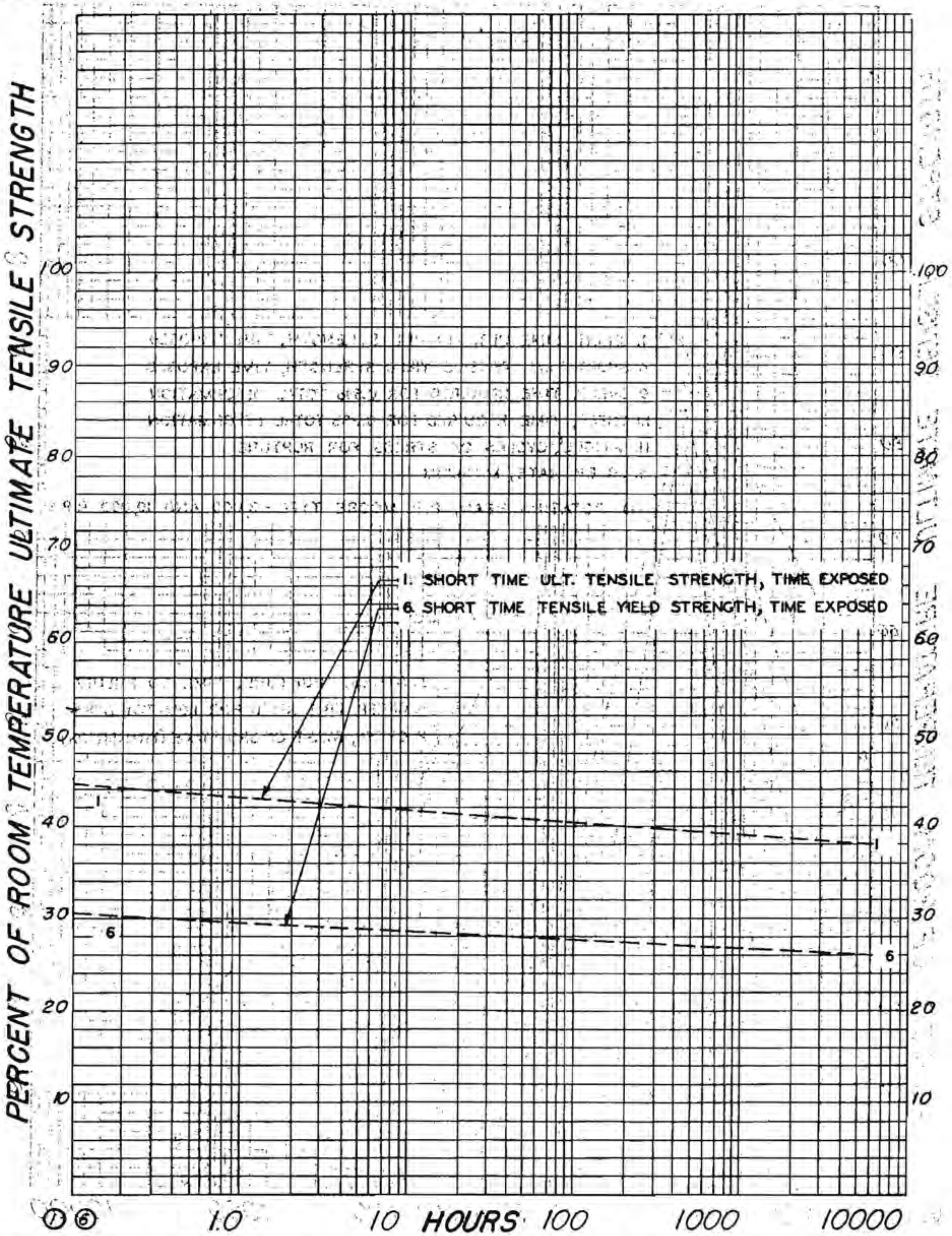


Figure 4.12211 (f). Elevated temperature properties of forged O-1HTA and AMC58S-T51 magnesium alloy at 400° F. (tensile); (R. T. F_{tu}=49,000 p. s. i.).

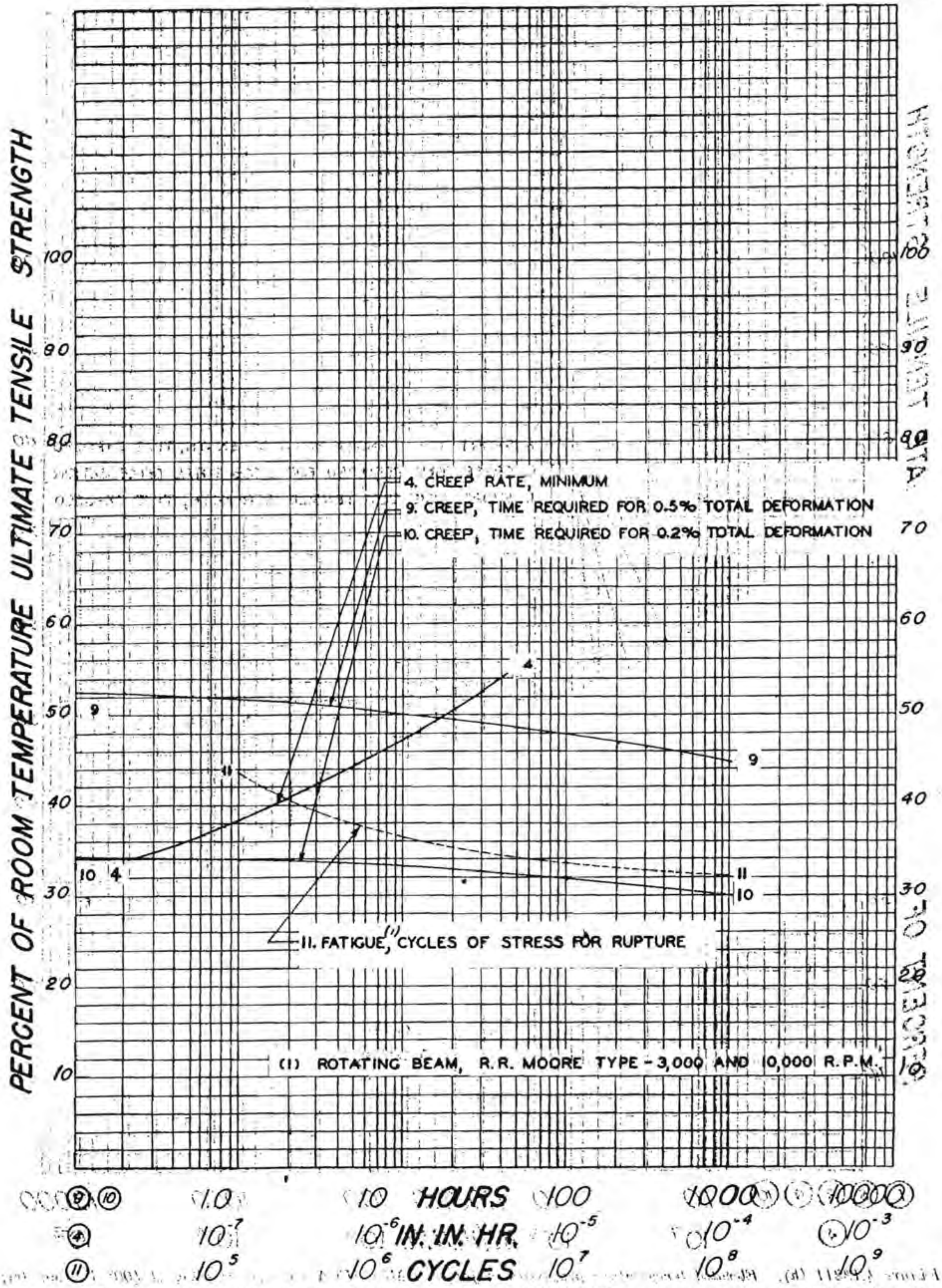


Figure 4.12211 (g). Elevated temperature properties of forged EM51–HTA magnesium alloy at 300° F. (tensile); (R. T. F_{tu}=37,000 p. s. i.).

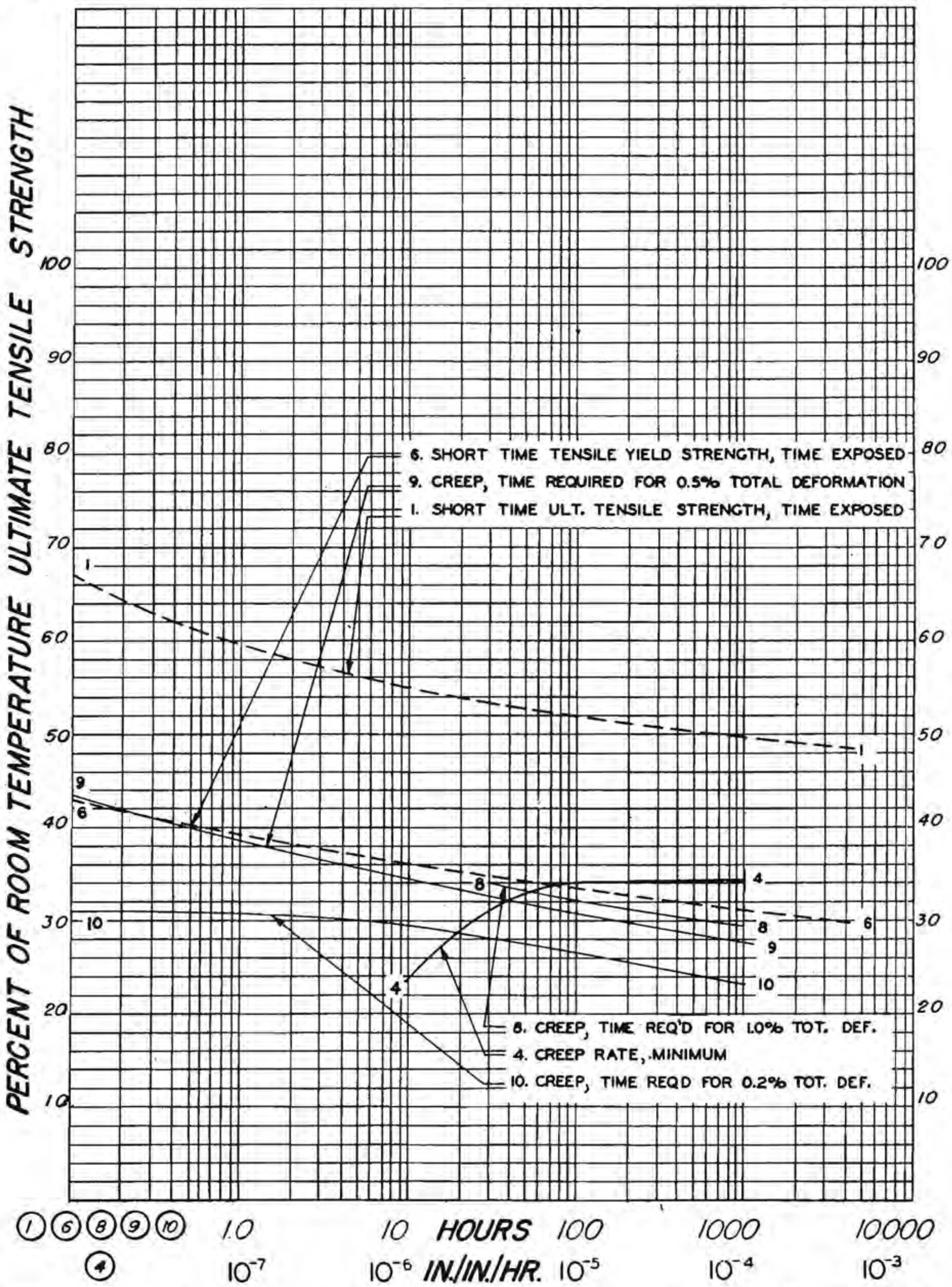


Figure 4.12211 (h). Elevated temperature properties of forged EM51–HTA magnesium alloy at 400° F. (tensile); (R. T. F_{tu}=37,000 p. s. i.).

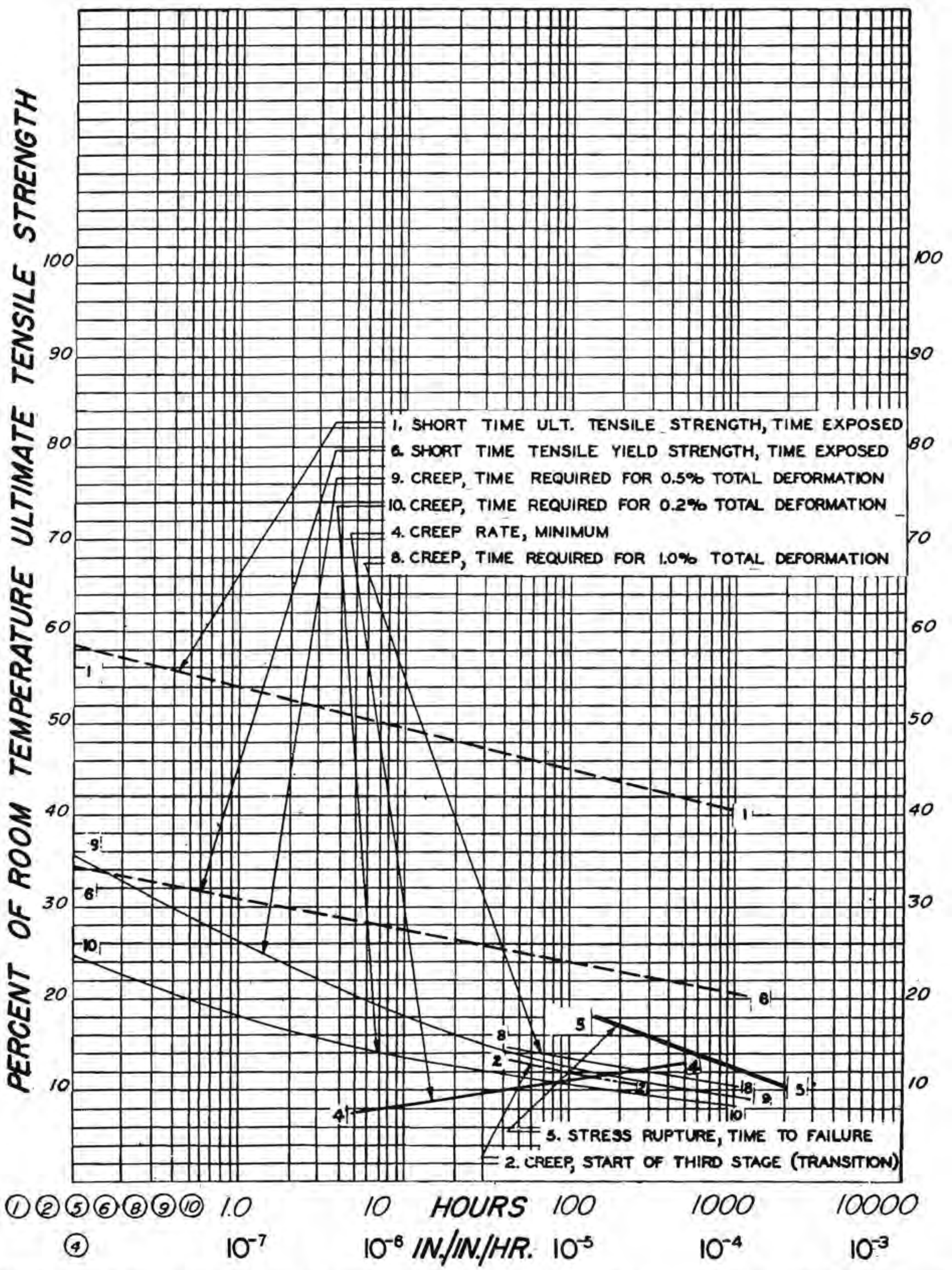


Figure 4.12211 (i). Elevated temperature properties of forged EM51-HTA magnesium alloy at 500° F. (tensile); (R. T. F_{tu}=37,000 p. s. i.).

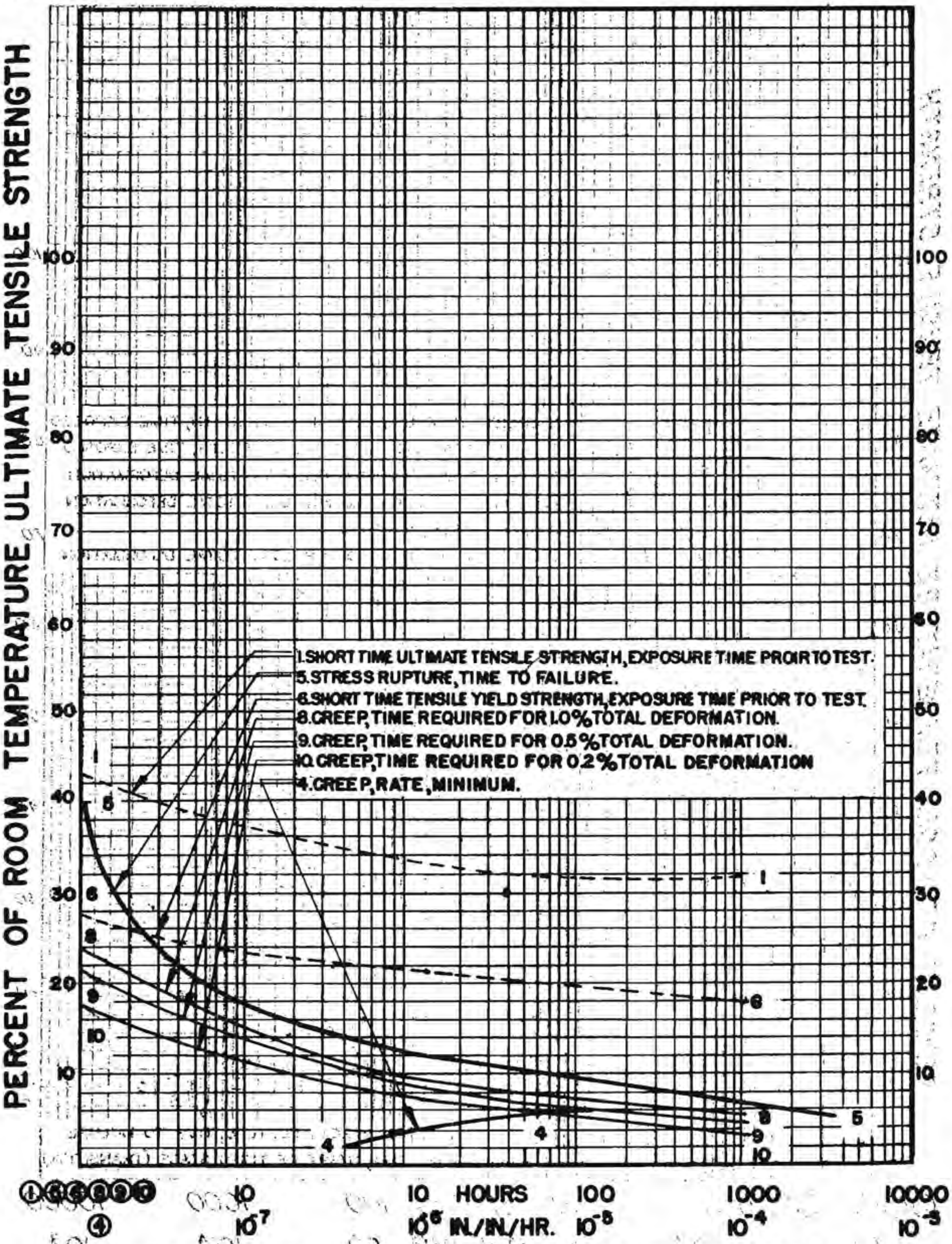


Figure 4.12211 (j). Elevated temperature properties of EM51–HTA magnesium alloy at 600° F. (tensile); (R. T. F_{tu}=37,000 p. s. i.).

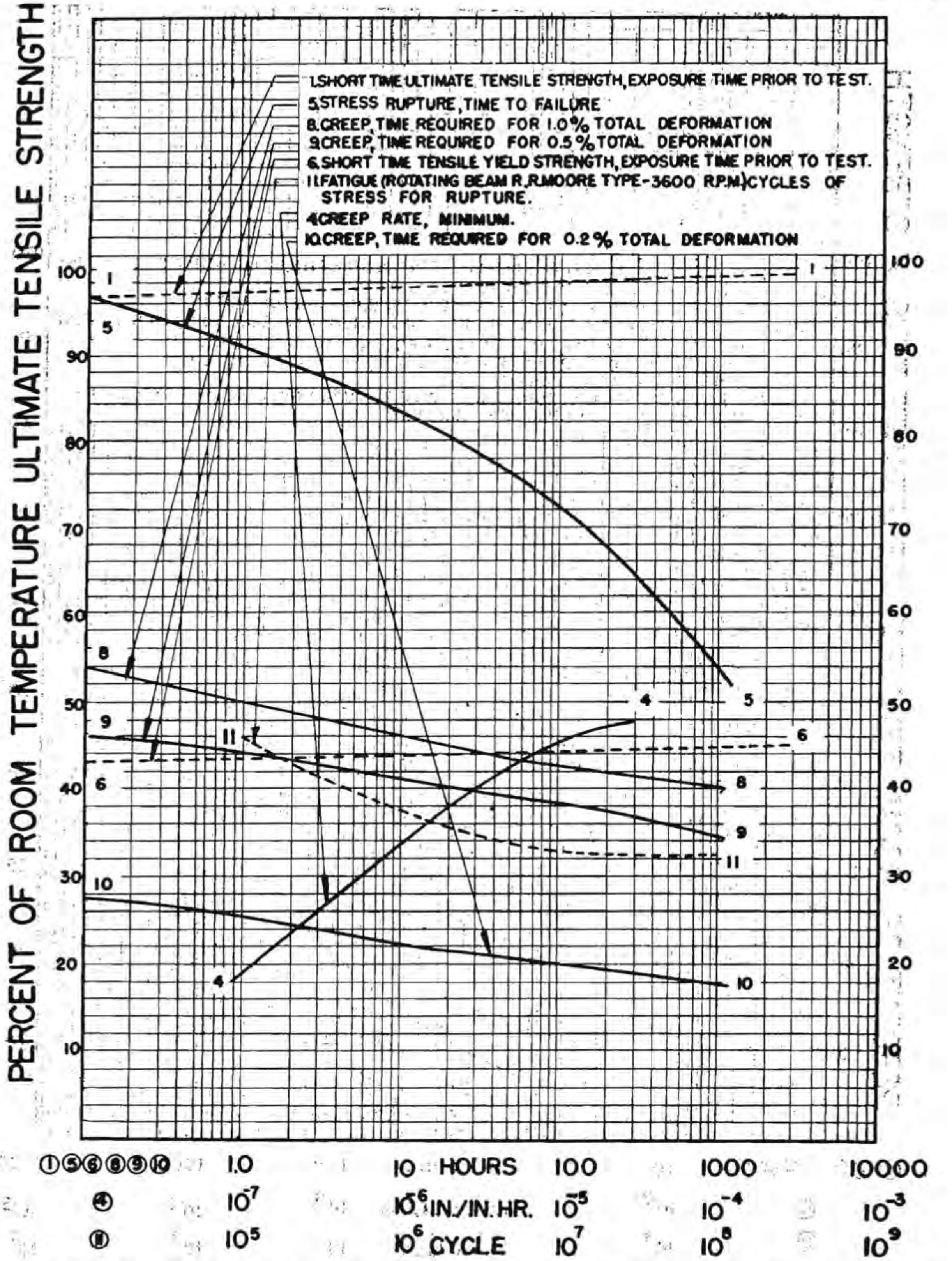


Figure 4.12211 (k). Elevated temperature properties of sandcast Dowmetal H or Mazlo AM265 magnesium alloy (heat treated and stablized) at 200° F. (tensile and fatigue).

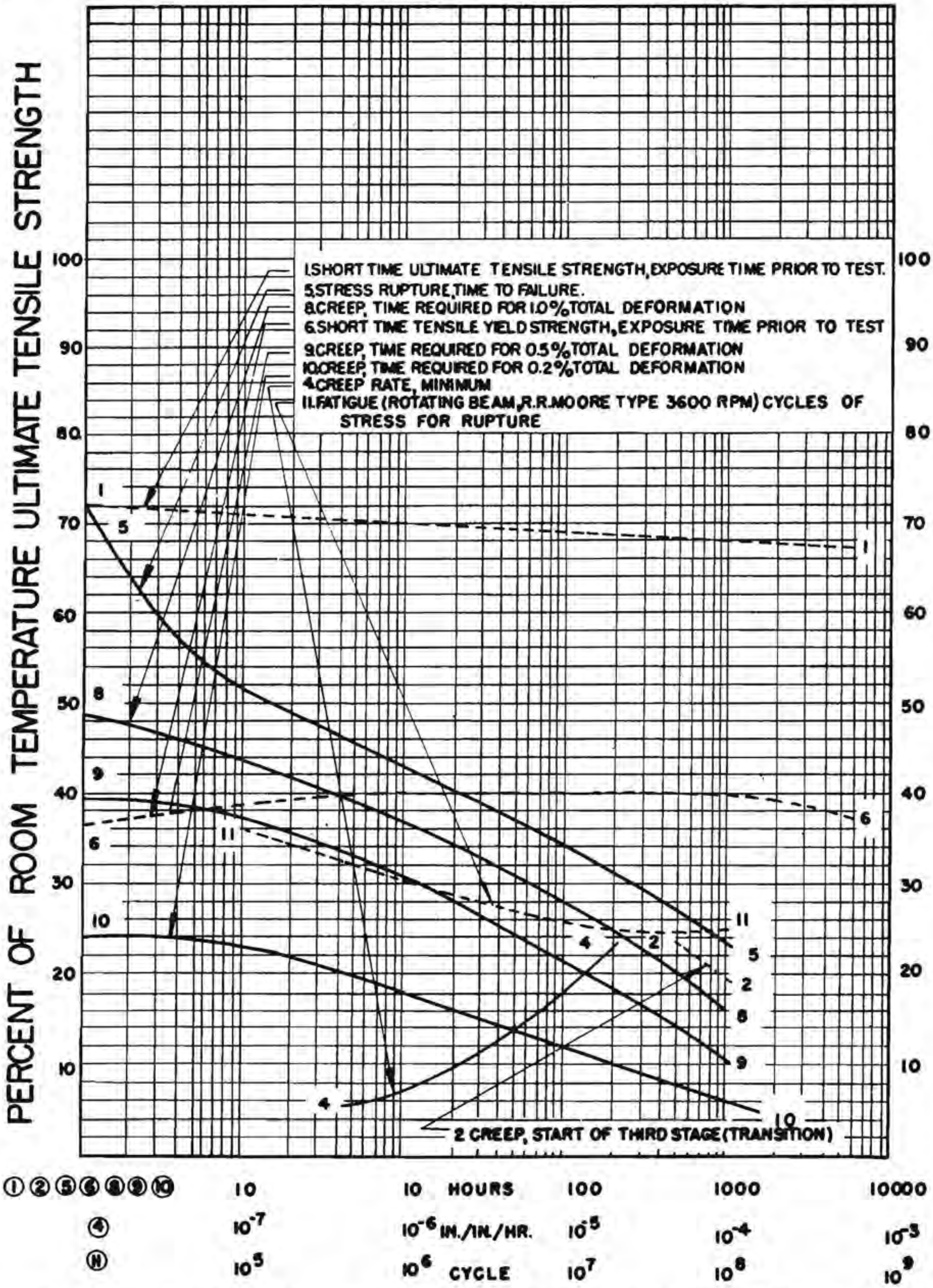


Figure 4.12211 (l). Elevated temperature properties of sandcast Dowmetal H or Mazlo AM265 magnesium alloy (heat treated and stabilized) at 300° F. (tensile and fatigue).

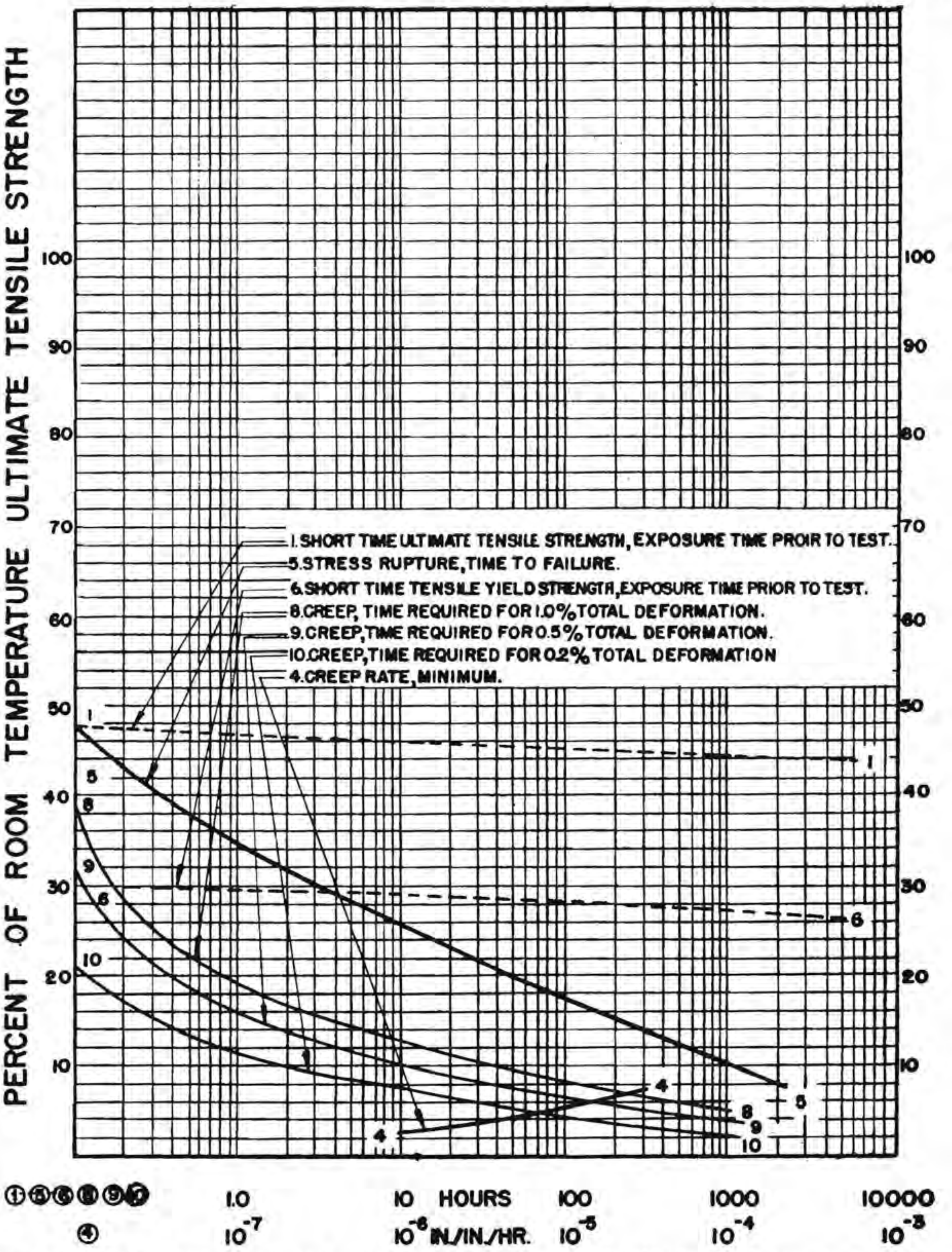
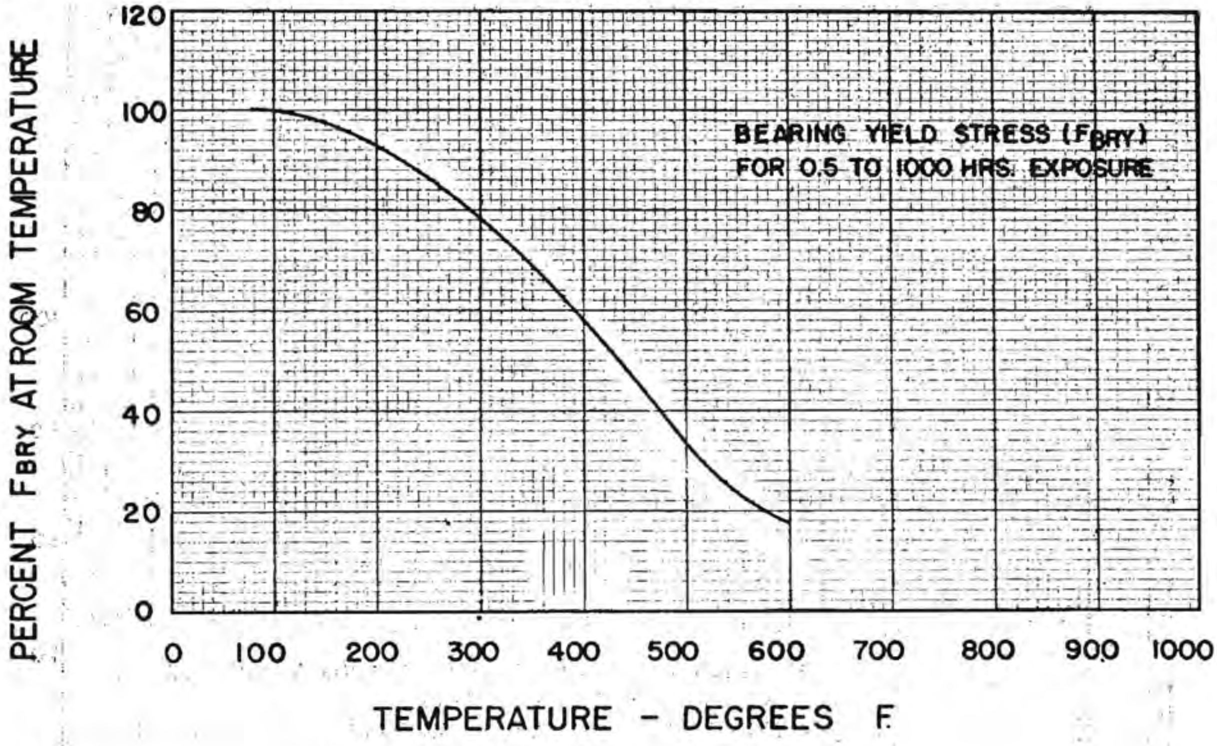


Figure 4.12211 (m). Elevated temperature properties of sandcast Dowmetal H or Mazlo AM265 magnesium alloy (heat treated and stabilized) at 400° F. (tensile).



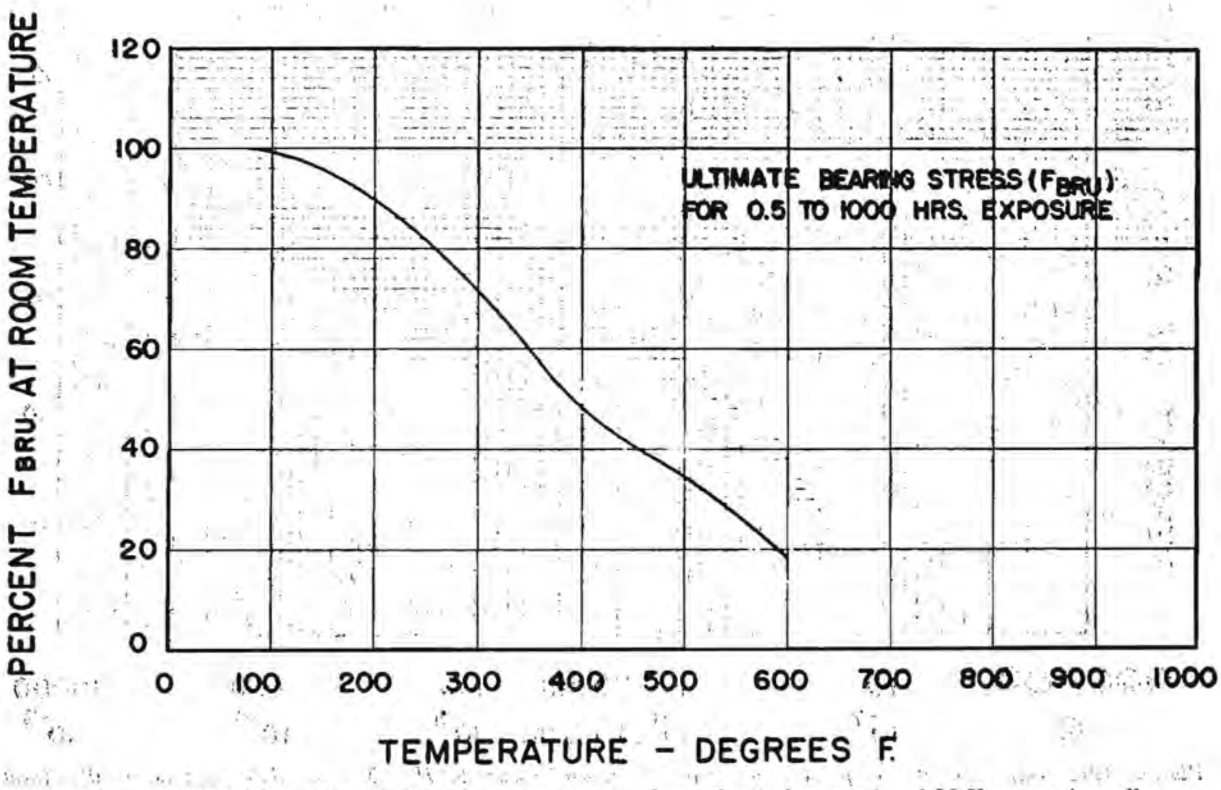


Figure 4.12211 (n). Effect of elevated temperatures on the mechanical properties of M H magnesium alloy.

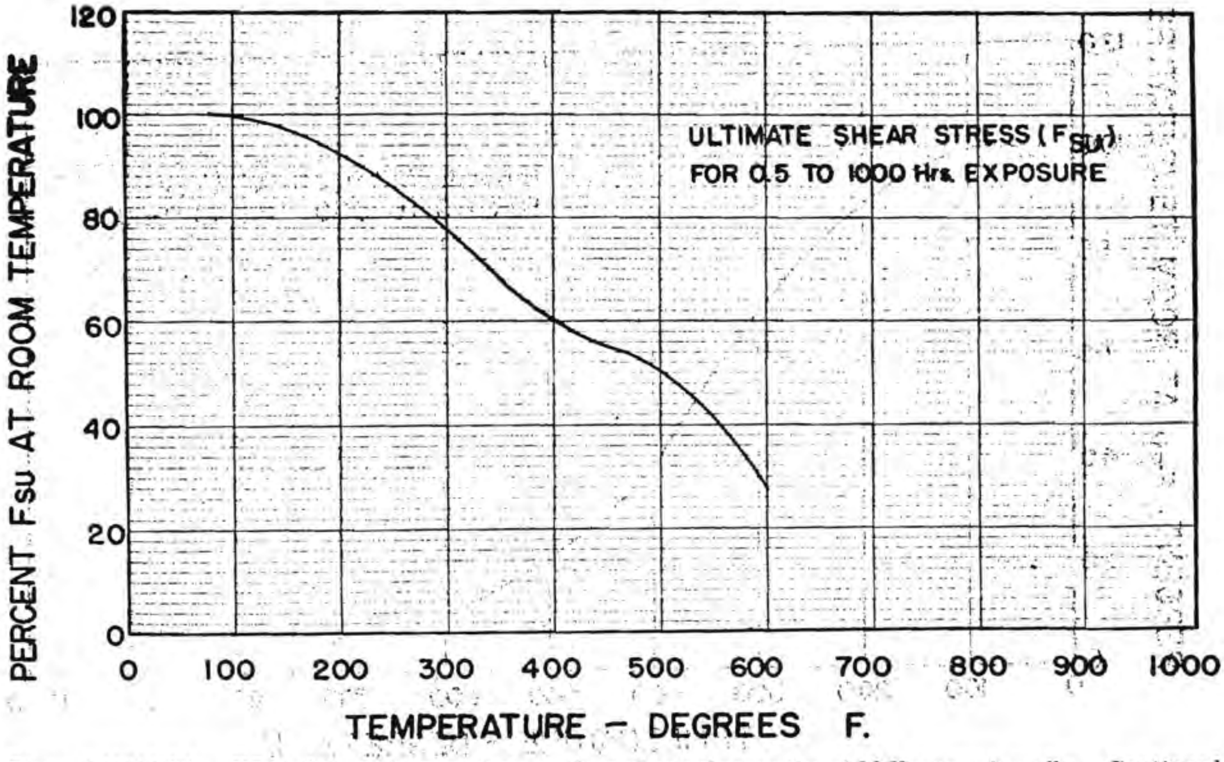


Figure 4.12211 (n). Effect of elevated temperatures on the mechanical properties of M H magnesium alloy—Continued

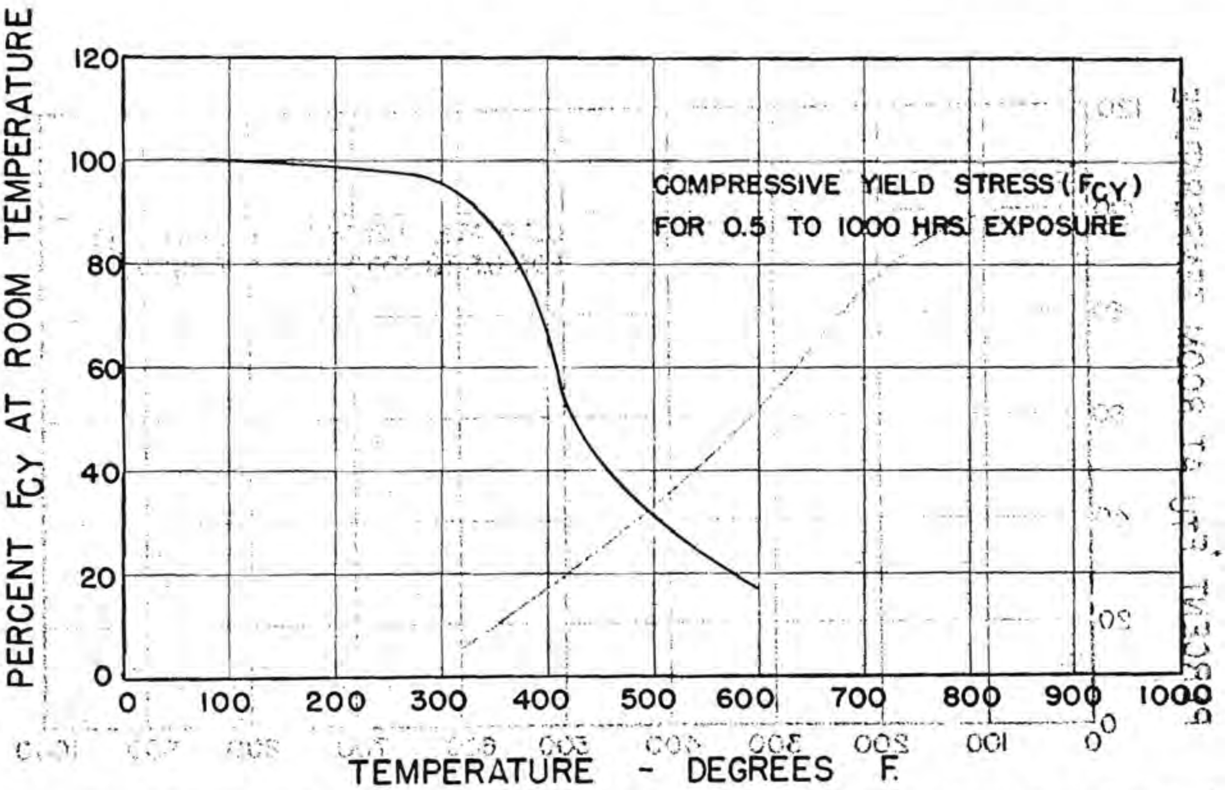
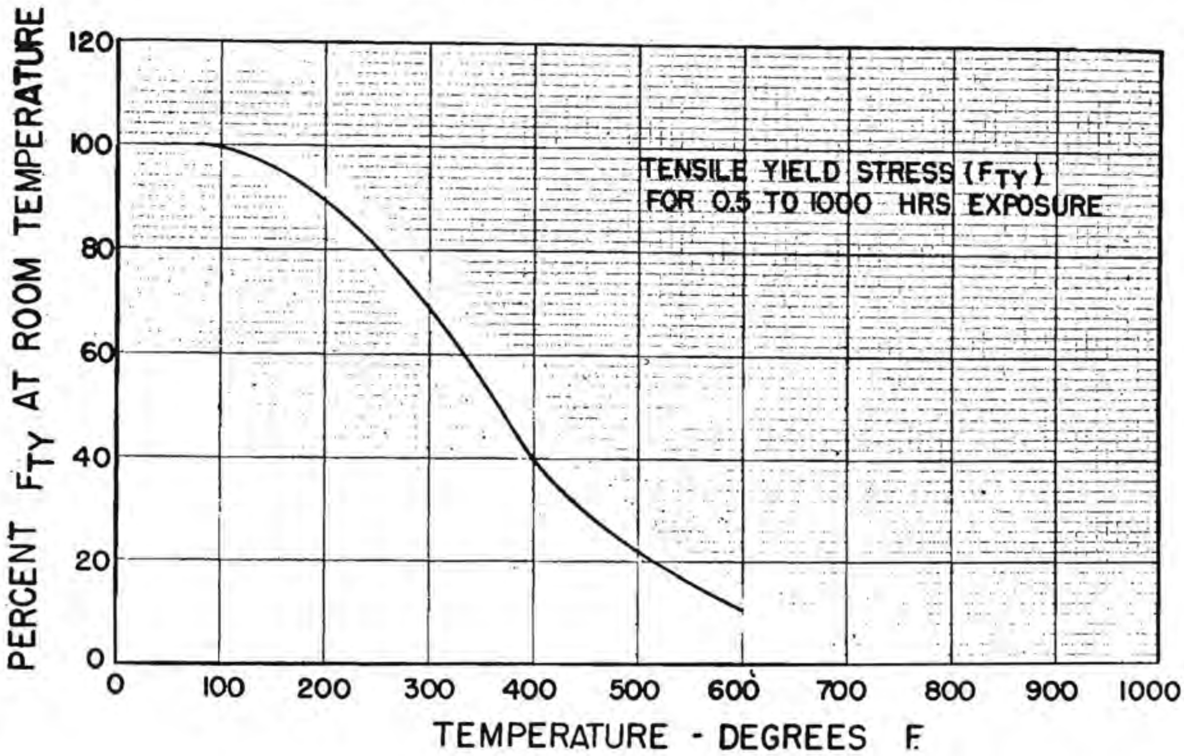


Figure 4.12211 (n). Effect of elevated temperatures on the mechanical properties of M H magnesium alloy—Continued.



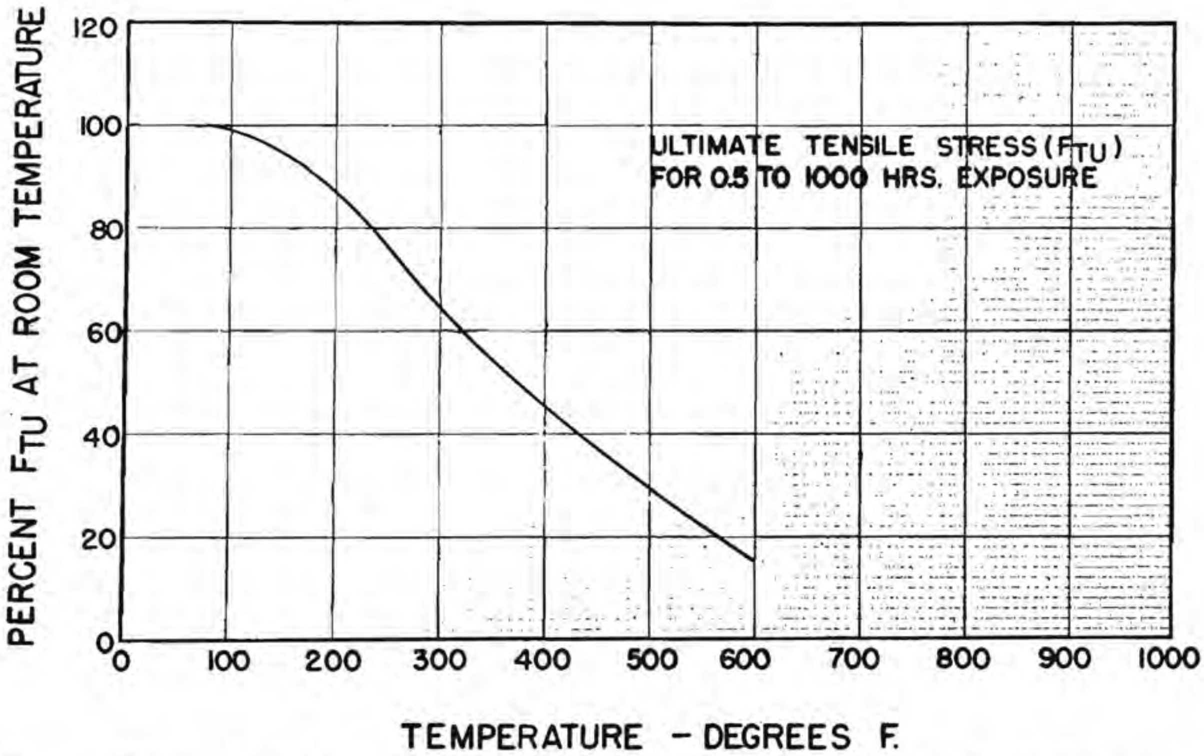
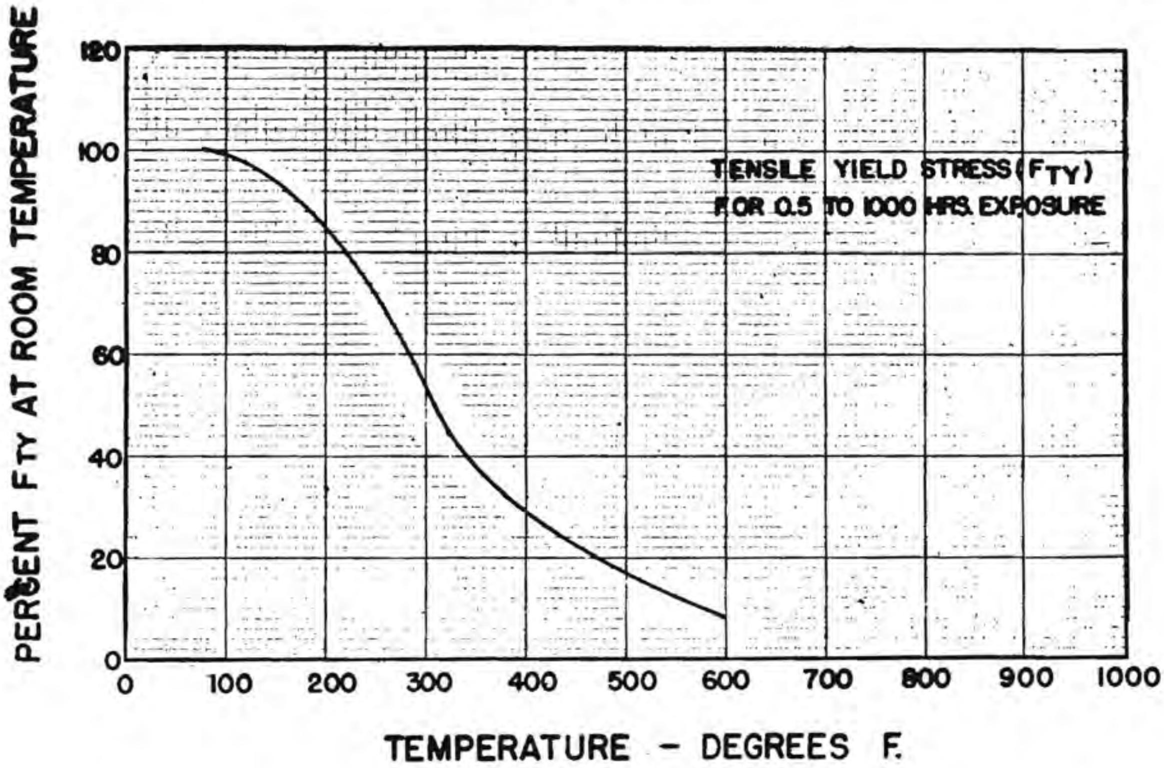


Figure 4.12211 (n). Effect of elevated temperatures on the mechanical properties of M H magnesium alloy—Concluded.



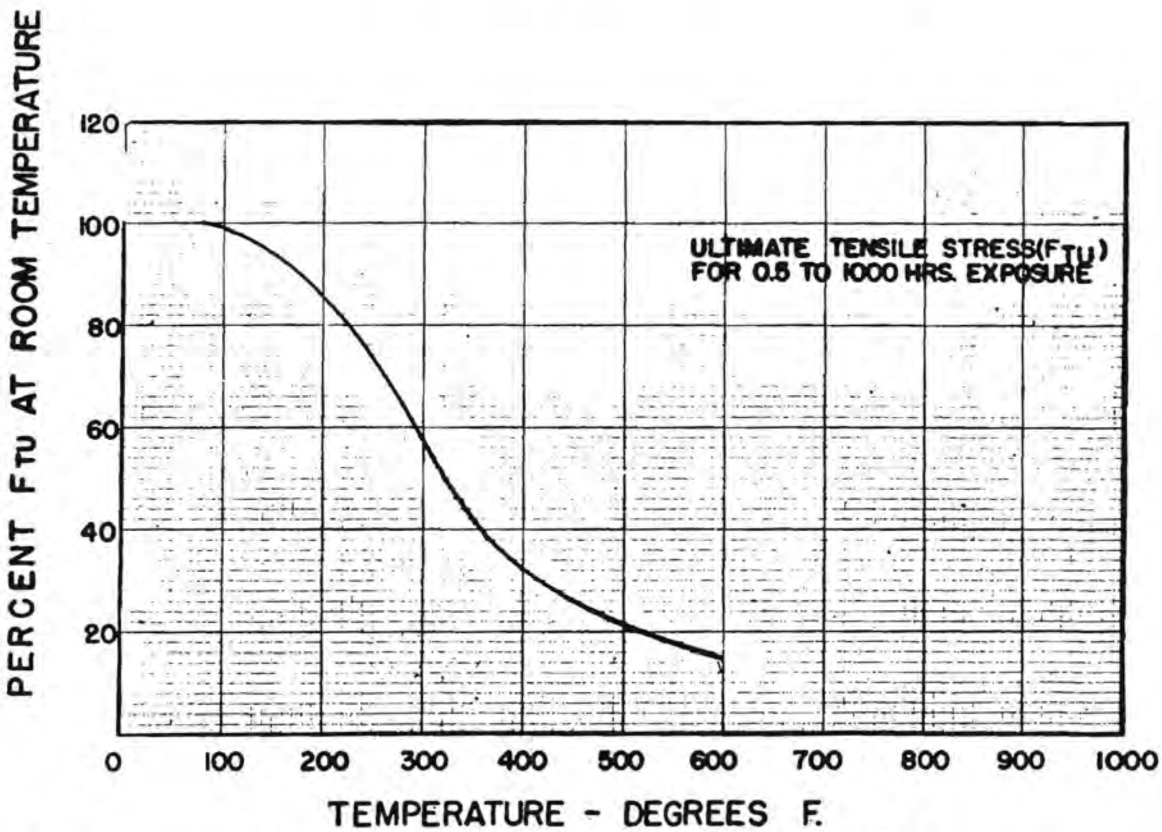
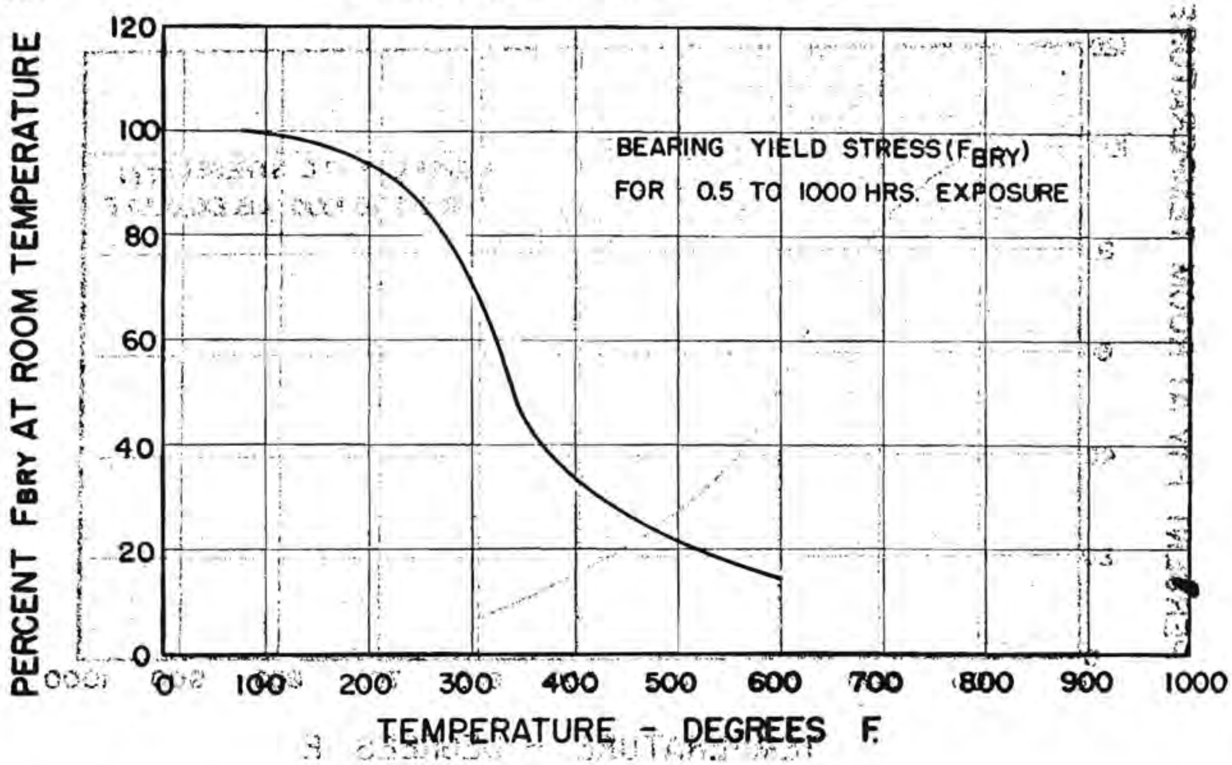


Figure 4.12211 (o). Effect of elevated temperatures on the mechanical properties of FS–1h magnesium alloy.



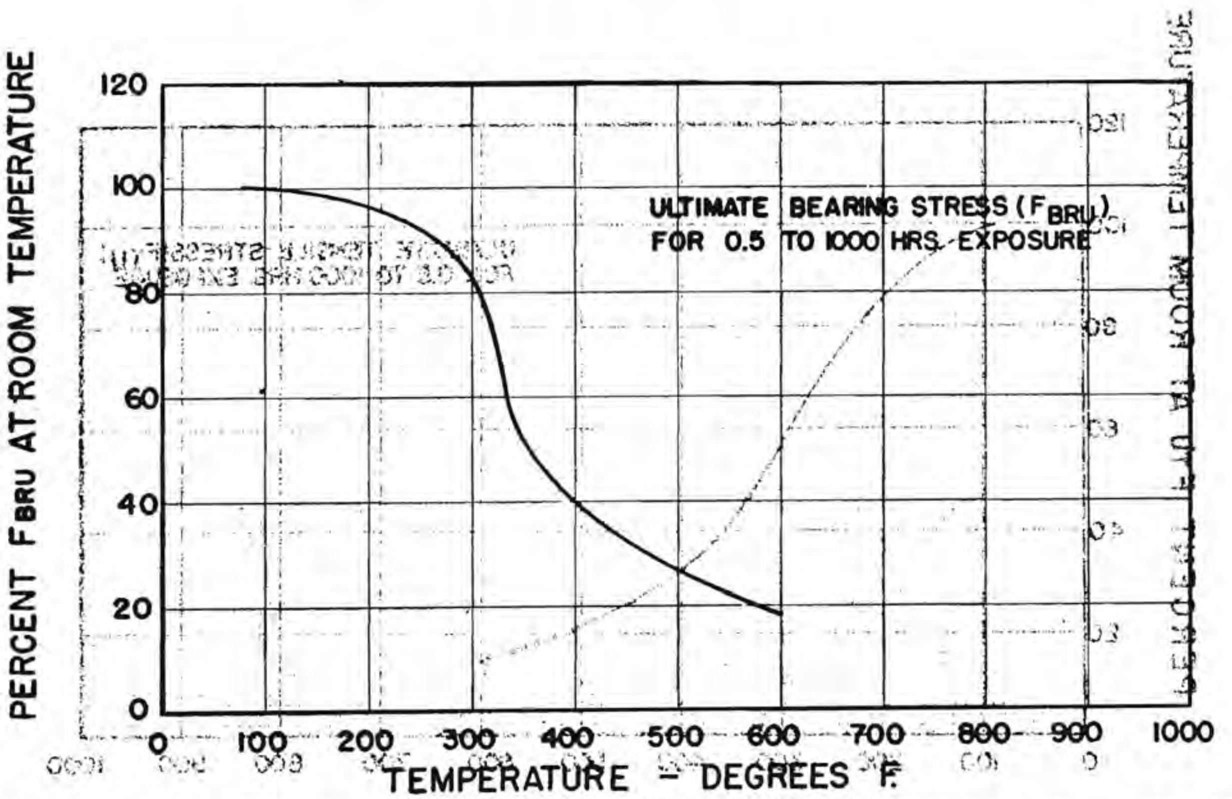


Figure 4.12211 (o). Effect of elevated temperatures on the mechanical properties of FS–1h magnesium alloy—Continued.

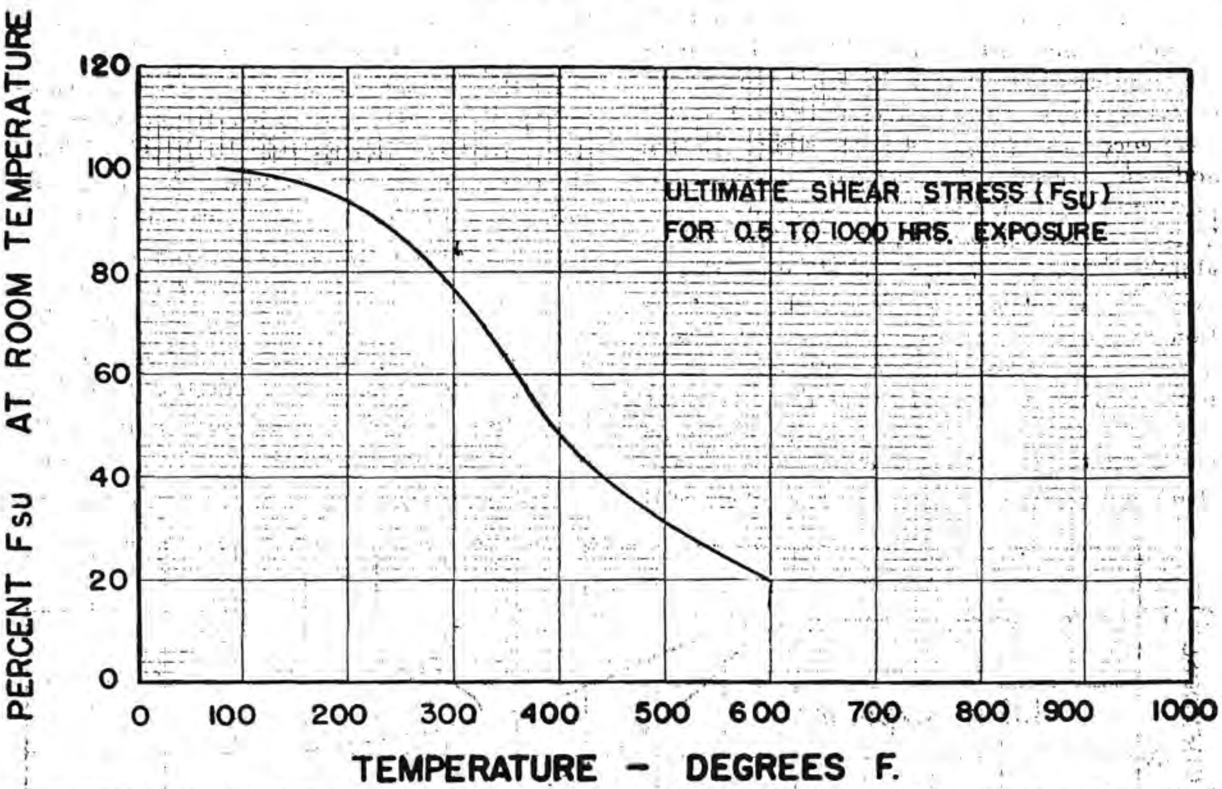


Figure 4.12211 (o). Effect of elevated temperatures on the mechanical properties of FS–1h magnesium alloy—Con'

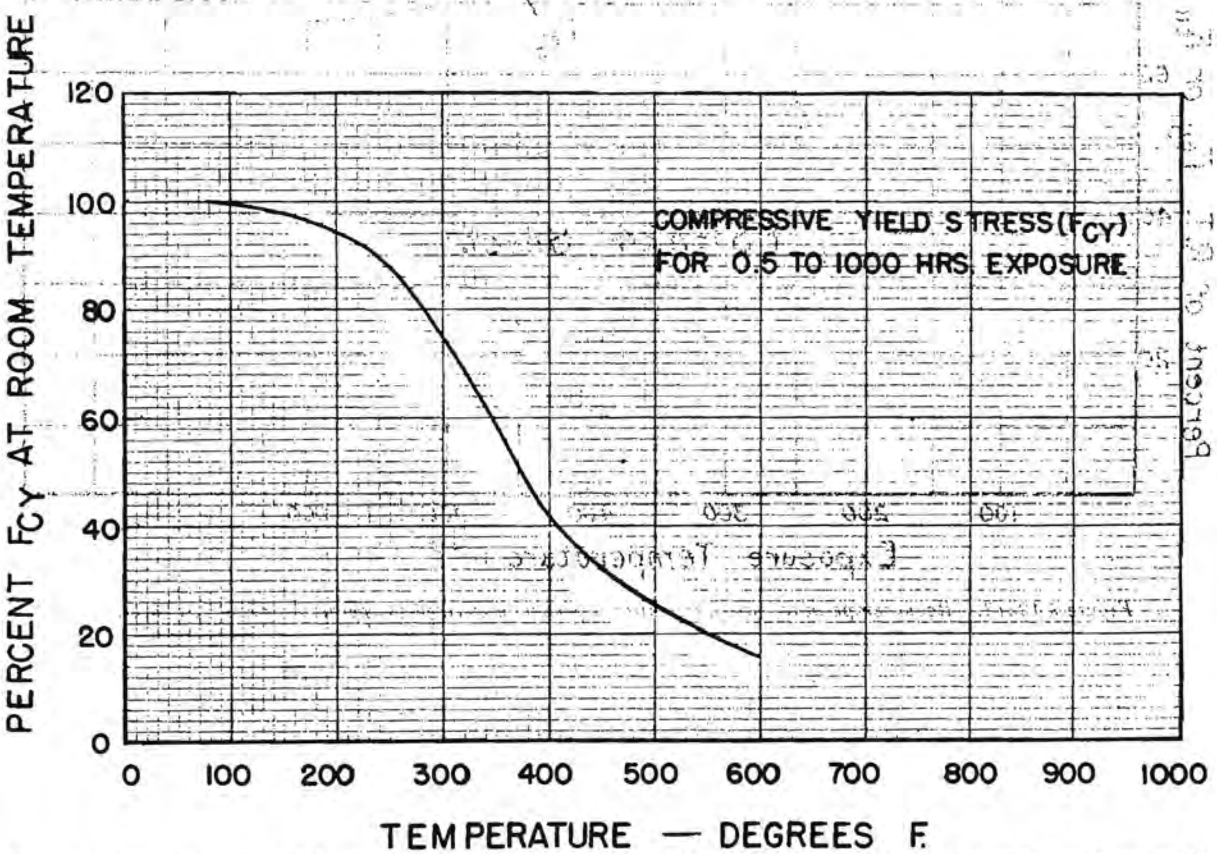


Figure 4.12211 (o). Effect of elevated temperatures on the mechanical properties of FS–1h magnesium alloy—Concluded.

4.12212 *Effect of exposure.* The tensile strength of magnesium alloys FS1-h24 at room temperature after exposure for 1 hour to various elevated temperatures is given in figure 4.12212. References 3.12231 and 4.12212 indicate some additional decrease in strength at room temperature with increase in exposure time. This decrease will not be nearly as large as for aluminum alloys. Insufficient data exist however to establish the specific percentage reduction in strength at room temperature with increase in exposure time. Figure 4.12212 presents data on effect of elevated temperature exposure on tensile properties only. No data are available for effect of exposure on room-temperature compressive, bearing, and shear properties. Further information on tensile properties is given in reference 4.12212.

4.1222 *Fatigue properties.* Curves for computing approximate elevated temperature fatigue strengths for O-1HTA, AMC58S-T51, H, and AMC-265 magnesium alloy materials subjected to reversed rotating cantilever bending are shown in figures 4.12211 (*d*), (*e*), (*k*) and (*l*). For situations involving fatigue stresses in which the mean stresses are other than zero, consideration must be given to creep-rupture properties in addition to fatigue properties. The effect of variation in frequency of stress application should also be considered.

4.1223 *Creep and stress rupture properties.*

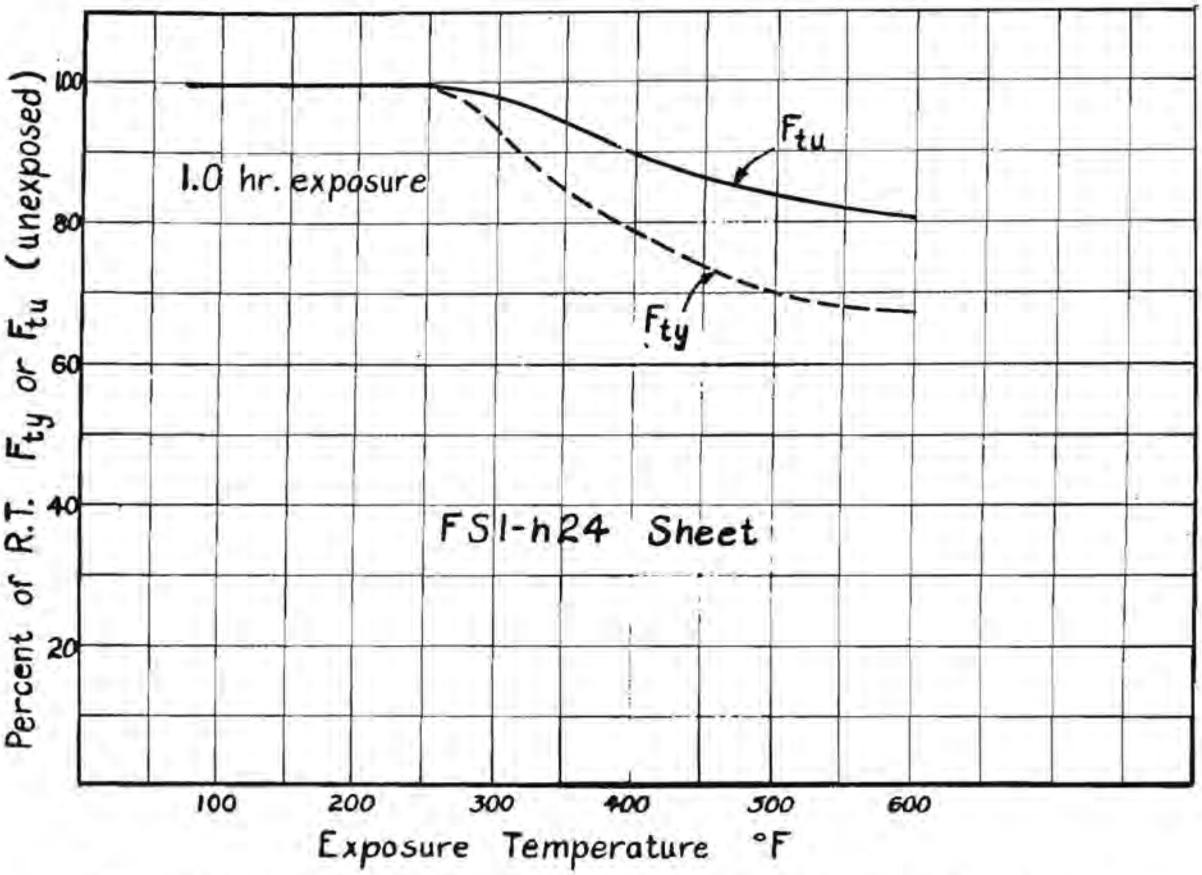


Figure 4.12212. Room-temperature properties after exposure to elevated temperature (FS1–h 24 sheet.)

Curves for computing the approximate reduction in ultimate tensile strength under long time loads, and for predicting corresponding deformation, for M, O-1HTA, AMC58S-T51, H, AMC-265 and EM51-HTA magnesium alloys are given in figures 4.12211 (*a*) to 4.12211 (*m*).

4.12231 *Short time creep.* Figures 4.12231 (*a*) through (*h*) present the effects of short times at temperature on the creep properties of magnesium alloy sheet materials. See reference 3.12231 for further details concerning testing procedure and source of information.

4.13 CRITERIA FOR DESIGN MECHANICAL PROPERTIES. The test methods used to establish the design mechanical properties appearing in this chapter were the same as those described in sections 3.131, 3.132, and 3.133.

4.2 Column

4.21 PRIMARY FAILURE. The general formulas for primary instability are given in section 1.38. Formulas applicable to magnesium alloy columns are given in tables 4.21 (*a*) and (*b*).

Table 4.21(a). Column Formulas for Magnesium Alloy Extruded Open Shapes [a]

General Formula $P/A=\frac{K(F_{cy})^n}{(L'/\rho)^m}$ *(Stress values are in ksi)*

Alloy	K	n	m	Max. P/A
M, AM3S	180	½	1.0	0.90 F_{cy}
FS-1, J-1, O-1, AMC52S, AMC57S.	2,900	¼	1.5	F_{cy}
O-1HTA, AMC58S-T5, ZK60A-T5.	3,300	¼	1.5	0.96 F_{cy}

[a] Formulas given above are for members that do *not* fail by local buckling. Reference fig. 4.23 (*a*).

Table 4.21 (b). Column Formula for FS-1h Magnesium Alloy Sheet

$$\frac{P}{A}=1.05\,F_{cy}-\frac{(1.05\,F_{cy})^2(L'/\rho)^2}{4\pi^2E}$$

$$\text{Max. }\frac{P}{A}=F_{cy}=24ksi$$

Reference Fig. 4.23 (*b*)

4.22 LOCAL FAILURE

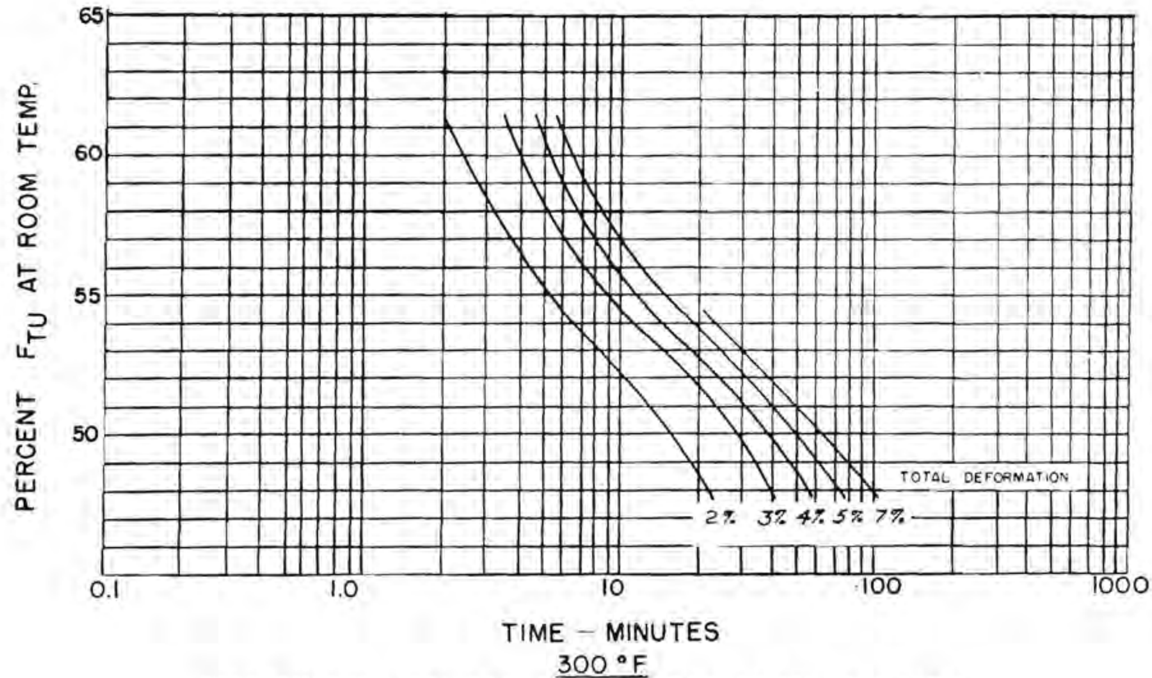


Figure 4.12231 (a). Short time creep curves for M-1 magnesium alloy sheet (hard rolled) (Dowmetal M and AM-3S).

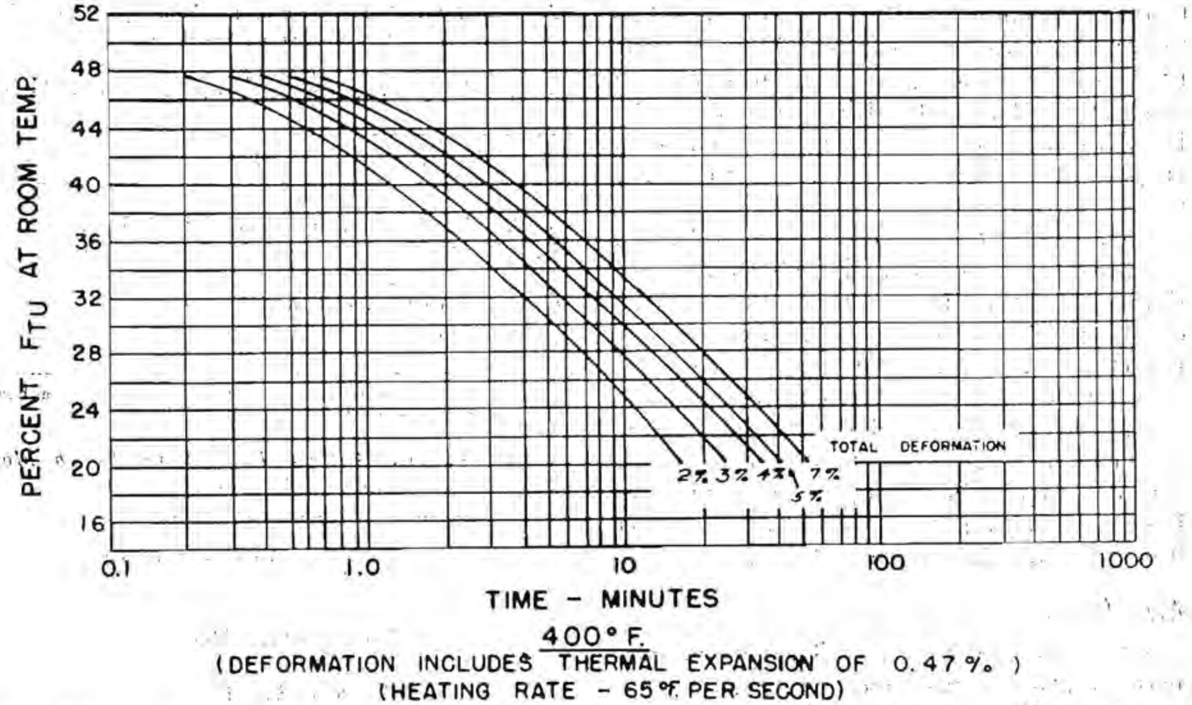


Figure 4.12231 (b). Short time creep curves for M–1 magnesium alloy sheet (hard rolled) (Dowmetal M and AM–3S).

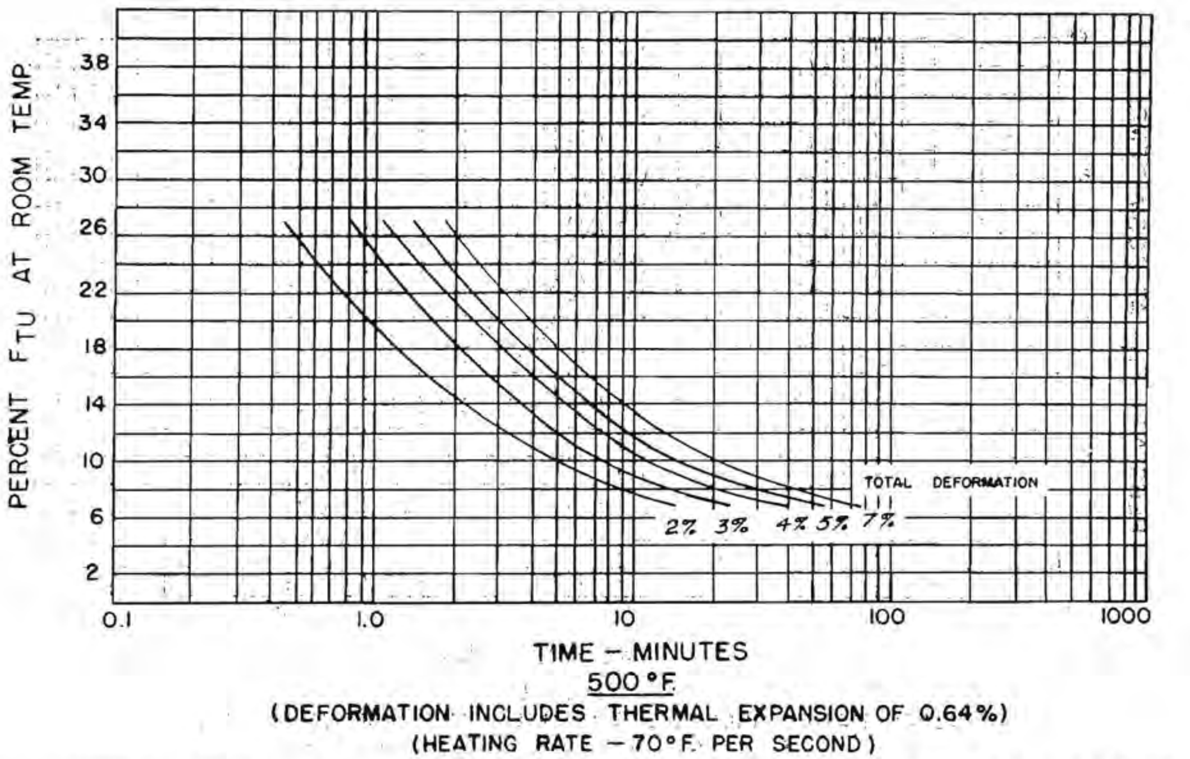


Figure 4.12231 (c). Short time creep curves for M–1 magnesium alloy sheet (hard rolled) (Dowmetal M and AM–3S).

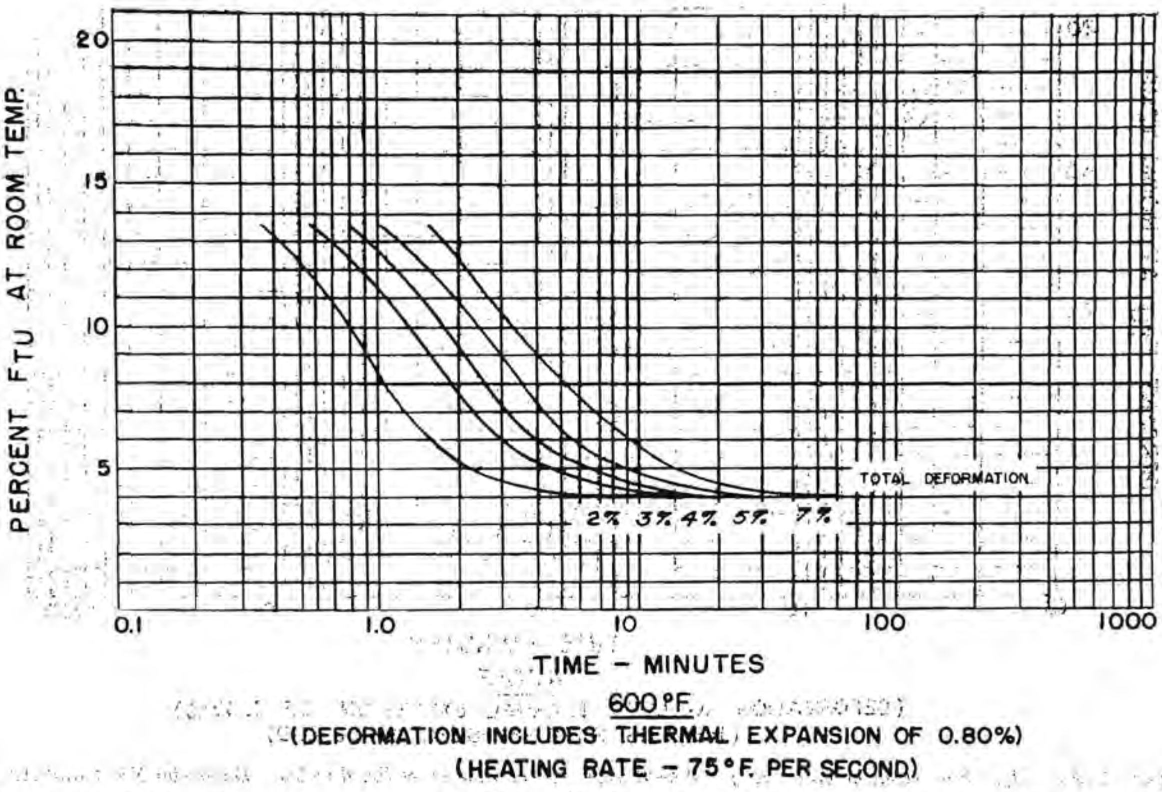


Figure 4.12231 (d). Short time creep curves for M–1 magnesium alloy sheet (hard rolled) (Dowmetal M and AM–3S)

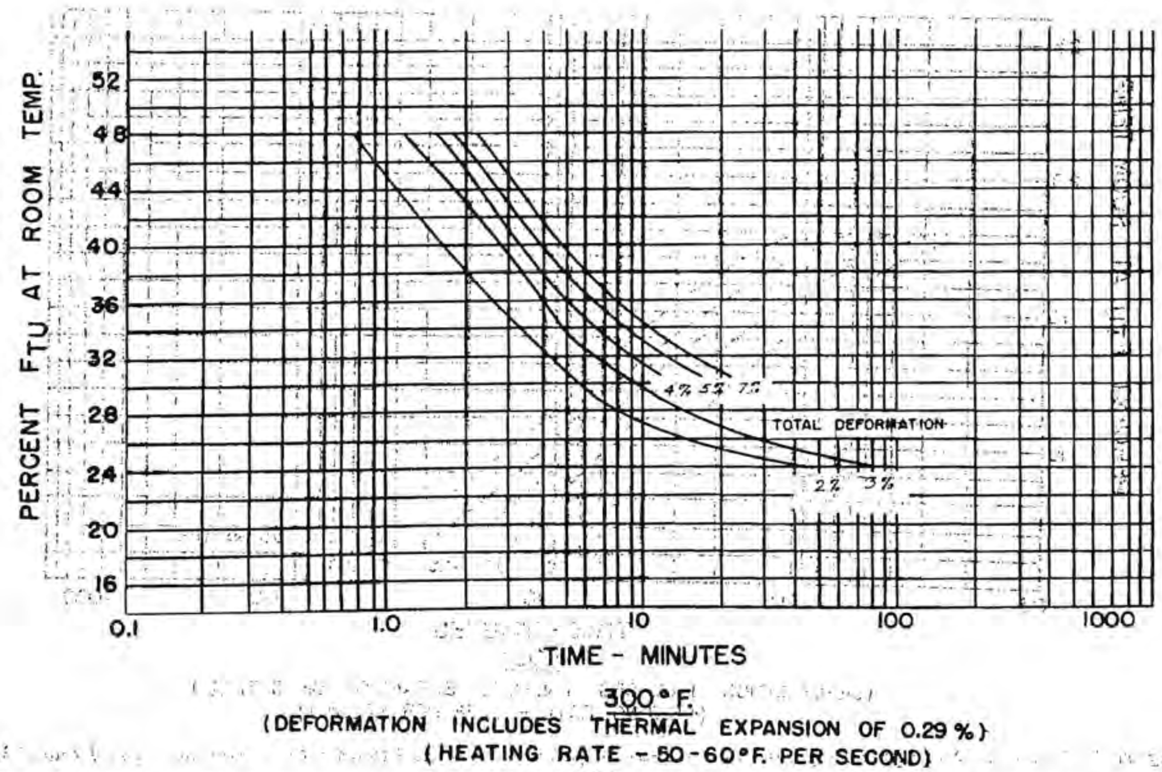


Figure 4.12231 (e). Short time creep curves for AZ–31 magnesium alloy sheet (hard rolled) (Dowmetal FS-1 and AM-C52S).

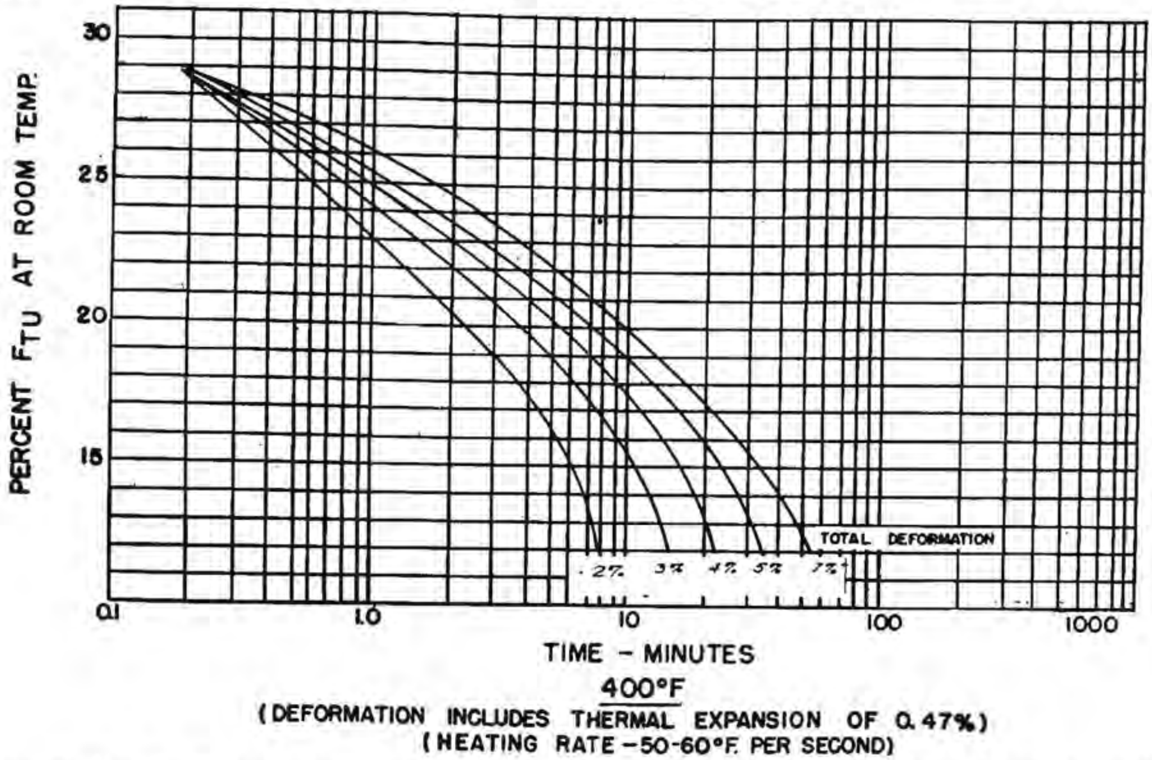


Figure 4.12231 (f). Short time creep curves for AZ-31 magnesium alloy sheet (hard rolled) (Dowmetal FS-1 and AM-C52S).

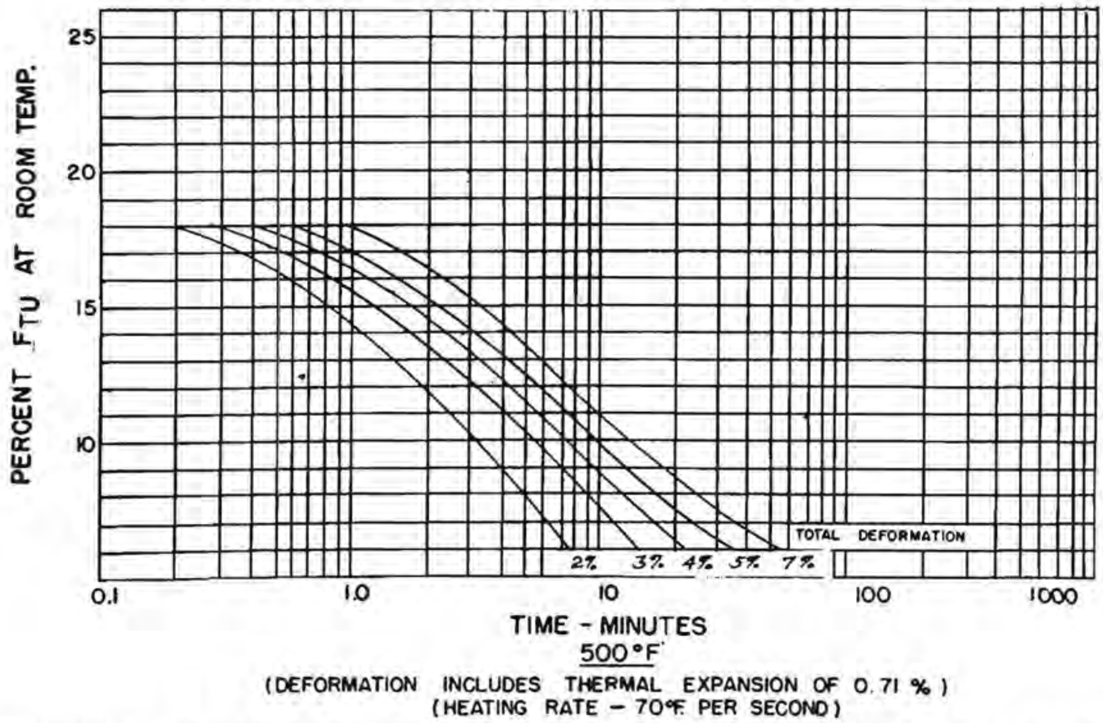


Figure 4.12231 (g). Short time creep curves for AZ-31 magnesium alloy sheet (hard rolled) (Dowmetal FS-1 and AM-C52S).

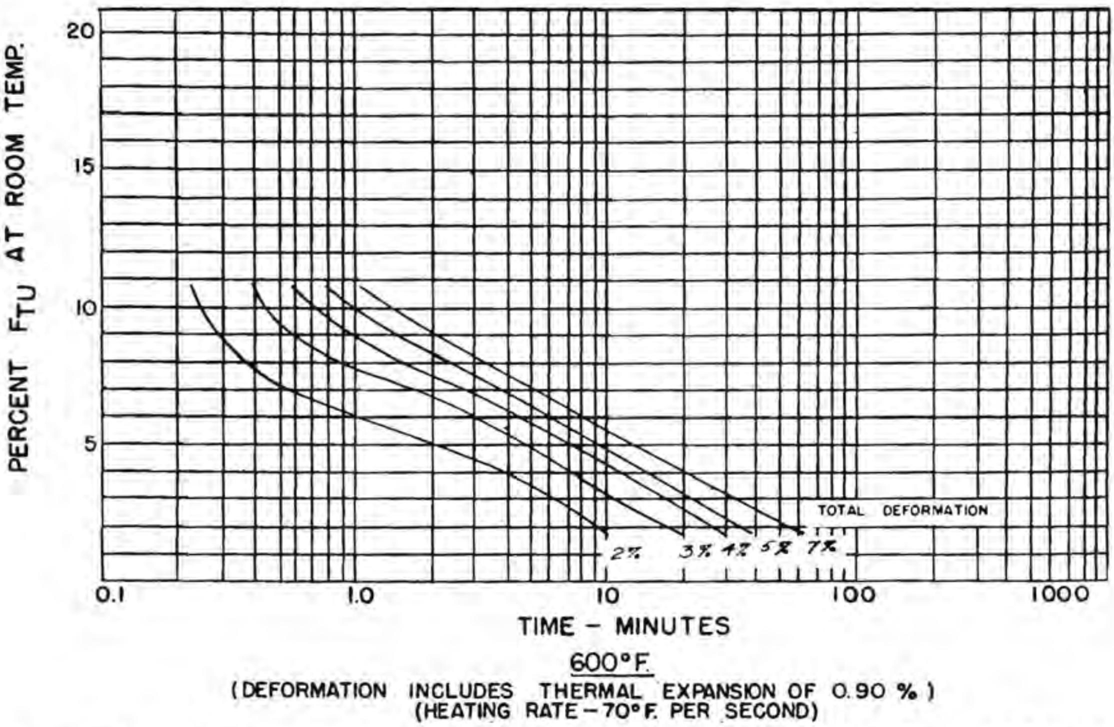


Figure 4.12231 (h). Short time creep curves for AZ–31 magnesium alloy sheet (hard rolled) (Dowmetal FS–1 and AM–C52S).

4.23 COLUMN STRESS CURVES. Curves of the allowable column stresses for various magnesium alloy columns are given in figures 4.23 (*a*) and (*b*). The allowable stress is plotted against the effective slenderness ratio defined by equation 3.231.

4.3 Beams

4.31 GENERAL. See equation 1.323; section 1.525; and reference 1.71 for general information on stress analysis of beams.

4.32 SIMPLE BEAMS

4.321 *Round tubes.* For round tubes the value of F_b will depend on the D/t ratio as well as the compressive yield stress. The bending modulus of rupture of magnesium alloy round tubes is given in figure 4.321. It should be noted that these values apply only when the tubes are restrained against local buckling at the loading points.

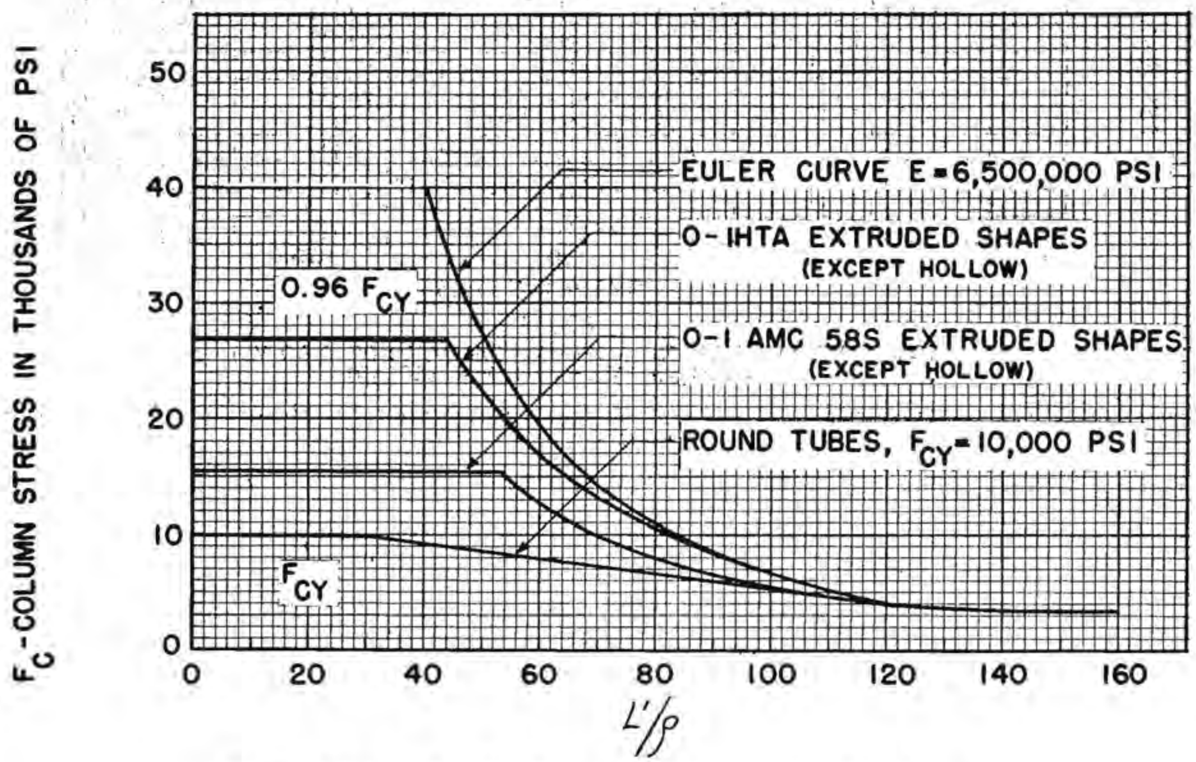


Figure 4.23 (a). Allowable column stresses for magnesium alloy columns.

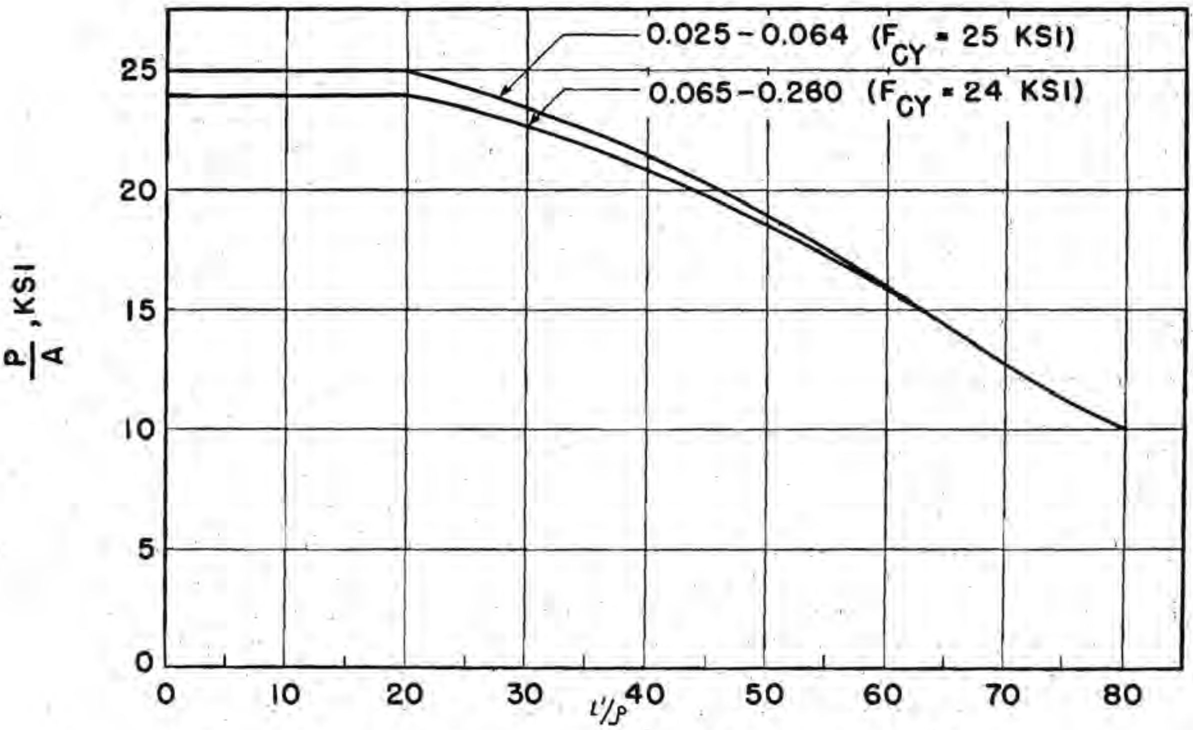
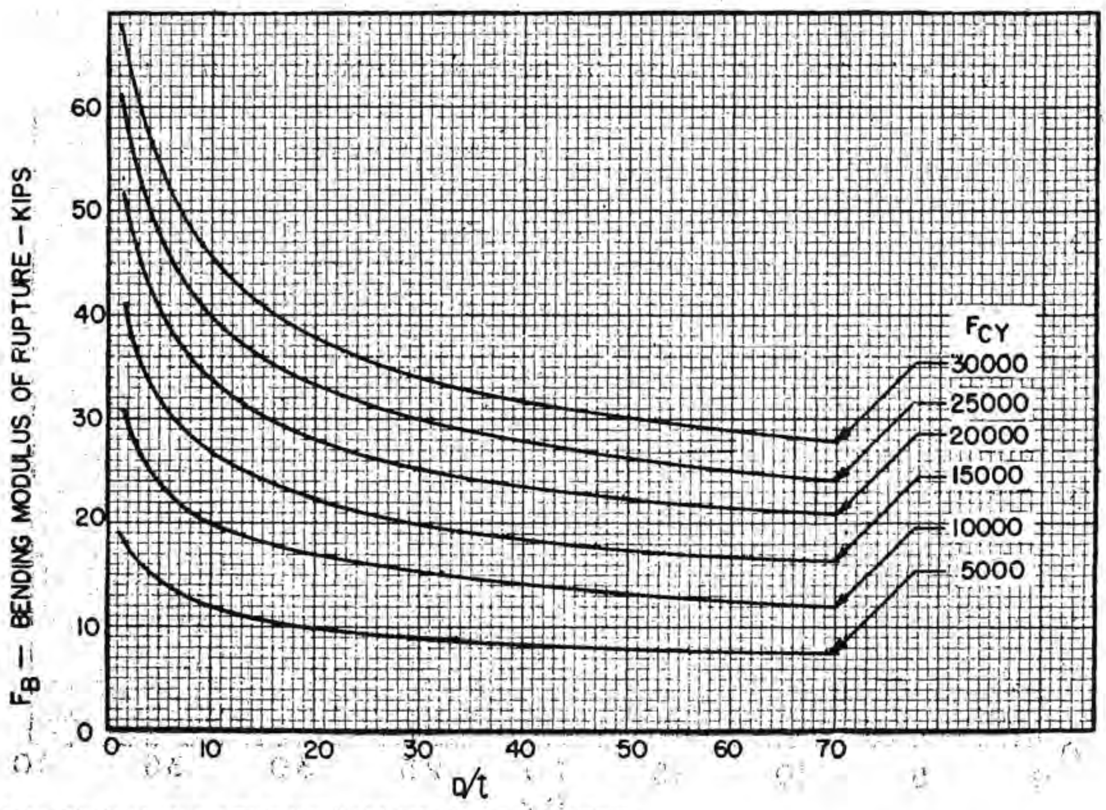


Figure 4.23 (b). Allowable column stresses for FS–1H magnesium alloy sheet.



Note.—The date for figure 4.321 are for tubes fabricated from magnesium sheet.

Figure 4.321. Bending modulus of rupture of magnesium alloy round tubing.

4.4 Torsion

4.41 GENERAL. The general statements relating to aluminum alloy tubing, section 3.4, are applicable to magnesium tubing.

4.42 ALLOWABLE TORSION SHEAR STRESSES. An empirical curve of the allowable torsional modulus of rupture for magnesium alloy round tubing (Specification WW–T–825) is given in figure 4.42.

4.5 Combined loadings

4.6 Joints and parts

4.61 JOINTS

4.611 *Riveted and bolted joints*

4.6111 *Protruding head rivets and bolts.* The loads per rivet at which the shear or bearing type of failure occurs are separately calculated and the lower of the two governs the design. The basic shear strengths for protruding head aluminum alloy rivets are given in tables 3.6111 (*a*) and 3.6113 (*a*). (For magnesium alloy riveting it is unnecessary to use the correction factors of table 3.6111 (*a*) which account for high bearing stresses on the rivet.) The design bearing stresses for magnesium alloys given in tables 4.111 (*a*) through (*d*) are applicable to riveted joints (or bolted joints) wherein circular holes are used and where $D/t<5.5$; where $D/t>5.5$, tests to substantiate yield and ultimate bearing strengths must be made. (A determination as to whether or not yield strength in bearing is more critical than ultimate strength may be necessary for $D/t<5.5$.)

4.6112 *Flush rivets.* Information on this subject is to be supplied at a later date.

4.6113 *Blind rivets.* Table 4.6113 contains ultimate and yield allowable single shear strengths for protruding-head and flush-head blind 56S aluminum rivets in magnesium alloy sheet. These strengths are applicable only when the grip lengths and rivet hole tolerances are as recommended by the rivet manufacturer.

The strength values were established from test data obtained from tests of specimens having edge distances e/D equal to or greater than 2.0. Where e/D values less than 2.0 are used, tests to substantiate yield and ultimate strengths must be made. Ultimate strength values of protruding and flush blind rivets were obtained from the average failing load of test

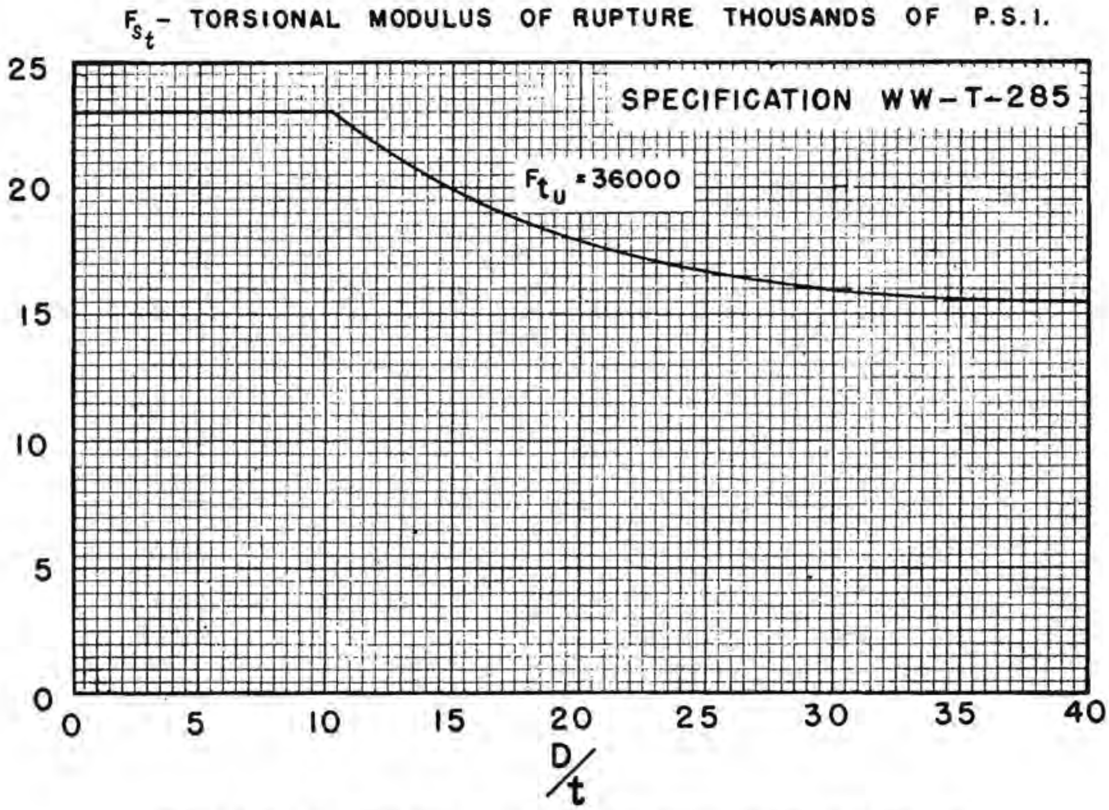


Figure 4.42. Torsional modulus of rupture for magnesium alloy round tubing.

specimens divided by 1.15. Yield strength values were obtained from average yield load test data wherein the yield load is defined as the load at which the following permanent set across the joint is developed:

(*a*) 0.005 inch up to and including 3/16 inch diameter rivets.

(*b*) 2.5 percent of the rivet diameter for rivet sizes larger than 3/16 inch diameter.

Blind rivets should not be used in applications where appreciable tensile loads on the rivets will exist. Reference should be made to the requirements of the applicable procuring or certificating agency relative to the use of blind rivets.

4.612 *Welded joints*

4.6121 *Fusion welds*

4.6122 *Spot welding.* The permissibility of the use of spot welding on structural parts is governed by the requirements of the procuring or certificating agency. Design shear strength allowables for spotwelds in various magnesium

Table 4.6113. Ultimate and Yield Strengths for Blind 56S Aluminum Cherry Rivets in Magnesium Sheet (Pounds) [a] [h]

ULTIMATE STRENGTHS

Installation	Protruding head			100° double dimpled [b] [c]			100° machine countersunk [d]		
Rivet type	CR 157 [d]			CR 156 [e]					
Sheet material	FS-1h								
Rivet diameter	1/8	5/32	3/16	1/8	5/32	3/16	1/8	5/32	3/16
Sheet thickness: [f]									
0.020				95					
0.025	200	214		140	240				
0.032	244	320	338	200	270	330			
0.040	290	360	430	225	300	370	200		
0.051	345	424	526	260	340	430	260	320	
0.064	390	490	620		390	495	305	380	[g] 510
0.072	395	530	680			515	340	410	520
0.081		580	750			535	370	450	540
0.091		605	825					495	590
0.102			875					550	660
0.125								570	820
YIELD STRENGTHS									
Sheet thickness: [f]									
0.020				73					
0.025	177	214		112	190				
0.032	220	295	320	182	253	288			
0.040	275	360	415	190	259	288	190		
0.051	334	424	510	260	267	356	230	241	
0.064	365	490	600		356	450	288	345	310
0.072	380	530	640			483	316	386	374
0.081		560	690			512	357	426	443
0.091		580	730					472	495
0.102			765					530	563
0.125								565	690

[a] The strength values listed were based on laboratory tests conducted under optimum conditions and should be used with caution.

[b] The double-dimpled allowables also apply to dimpled-machine countersunk joints. In this case the allowable is determined by the gage of the upper dimpled sheet. The gage of the lower machine countersunk sheet must be at least 2½ times the height of the preformed rivet head.

[c] In dimpled installations allowables shall not be obtained by extrapolation for skin gages other than those shown.

[d] In the case of machine countersunk joints where the lower sheet is thinner than the upper, the bearing allowable for the lower sheet-rivet combination should be computed.

[e] See table 3.6112 (*a*) for rivet shear strengths.

[f] Sheet gage is that of the thinnest sheet for protruding head and double-dimpled installations. For machine countersunk installations sheet gage is that of the upper sheet.

[g] Yield values of the sheet-rivet combinations marked thus (*) are less than ⅔ of the indicated ultimate values.

[h] Other sheet-rivet combinations may be used subject to specific approval of the procuring or certificating agency.

alloys are given in table 4.6122 (*a*); the thickness ratio of the thickest sheet to the thinnest outer sheet in the combination should not exceed 3:1. Table 4.6122 (*b*) gives the minimum allowable edge distance for spotwelds in magnesium alloys; these values may be reduced for nonstructural applications, or for applications not depended upon to develop the full tabulated weld strength.

Table 4.6122 (a). Spotweld Maximum Design Shear Strength Standards for Magnesium Alloys [a]

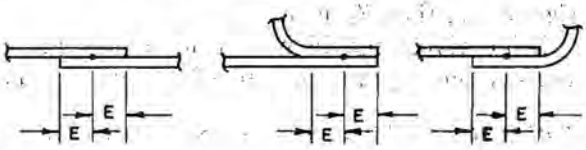
Nominal thickness of thinner sheet (inch)	Magnesium alloys		Nominal thickness of thinner sheet (inch)	Magnesium alloys	
	QQ-M-54	QQ-M-44		QQ-M-54	QQ-M-44
	Pounds	*Pounds*		*Pounds*	*Pounds*
0.020	51	69	0.072	279	378
0.025	71	97	0.081	320	434
0.032	102	139	0.091	368	498
0.040	137	185	0.102	433	586
0.051	186	251	0.114	488	658
0.064	242	328	0.125	544	735

[a] *Magnesium Alloys.* Magnesium alloys, conforming to Specifications QQ-M-44 and QQ-M-54, may be spotwelded in any combination.

Where alloys listed in table 4.6122 (*a*) are spotwelded in combination the lower spotweld strength shall be used.

4.613 *Adhesive bonded joints.* Joints may in some instances be made to advantage by the use of an adhesive suitable for the structural bonding of metals. This subject is discussed in reference 2.613.

Table 4.6122 (b). Minimum Edge Distances for Spot-Welded Joints [a] [b]



Thickness thinner sheet	Edge distance (*E*)	Thickness thinner sheet	Edge distance (*E*)
Inch	*Inch*	*Inch*	*Inch*
0.016	3/16	0.060	11/32
0.020	3/16	0.070	3/8
0.025	7/32	0.080	13/32
0.030	1/4	0.090	7/16
0.035	1/4	0.100	7/16
0.040	9/32	0.120	1/2
0.045	5/16	0.125	9/16
0.050	5/16	0.157	5/8

[a] Intermediate gages will conform to the requirement for the next thinner gage shown.

[b] For edge distances less than those specified above, appropriate reductions in the spotweld allowable loads shall be made. These reductions shall be subject to approval by the procuring or certificating agency.

CHAPTER 5

TITANIUM AND ITS ALLOYS

5.1 General Properties

5.11 NORMAL (ROOM) TEMPERATURE PROPERTIES

5.111 *Design mechanical properties.* Table 5.111 presents design mechanical properties at normal (room) temperature for those commercially available titanium base materials, the tensile properties of which are covered by several procurement specifications. The remaining properties given have been derived from test data and are the minimum values expected.

Table 5.111 is not meant to be a comprehensive listing of all the currently available titanium alloys. Vigorous research in the development of titanium alloys is underway and it is expected that new and improved alloys will be added to those already available. When these new materials are covered by procurement specifications, their appropriate mechanical properties will be inserted in the tables.

In the definition of bearing values, D is equal to the hole diameter and e is equal to the edge distance measured from the hole center to the edge of the material in the direction of applied stress. Values of $e/D=2.0$ shall be used for larger values of edge distance; values of e/D less than 1.5 shall be substantiated by adequate tests subject to the approval of

Table 5.111 Design Mechanical Properties of Titanium and Titanium Alloys—Sheet and Bar (Kips per Square Inch)

Type		Plate, Sheet, Strip			Bar	
Alloy		99+Ti	99 Ti	91 Ti 8.0 Mn	99 Ti	91 Ti 4Mn 4Al
Specification		MIL-T-7993 AMS 4900	MIL-T-7993 AMS 4901	MIL-T-9046 AMS 4908	MIL-T-9011 AMS 4921	MIL-T-9047 AMS 4925
Condition		Annealed	Annealed	Annealed	Annealed	Annealed
Thickness					Up to 3 inches in diameter	Up to 3 inches in diameter
Basis		A	A	A	A	A
F_{tu}	L	60	80	120	80	140
	T	60	80	120	80	140
F_{ty}	L	50	70	110	70	130
	T	50	70	110	70	130
F_{cy}	L	50	70	110		
	T					
F_{su}		36	42	84		
F_{bru} $(e/D=1.5)$		99	120	170		
F_{bru} $(e/D=2.0)$						
F_{bry} $(e/D=1.5)$		82	101	130		
F_{bry} $(e/D=2.0)$						
e		22	15	10	15	12
E		15, 500	15, 500	15, 500	15, 500	15, 500
w		0. 164	0. 164	0. 171	0. 164	0. 164

the procuring or certificating agency. For values of edge distance between $e/D=2.0$ and $e/D=1.5$, linear interpolation may be employed.

5.12 TEMPERATURE EFFECTS

5.121 *Low temperature.* The effect of low temperatures on the behavior of commercially pure and alloy titanium has not been too well established, due partly to the newness of the material and partly to the large number of different materials being developed. However, generally, the static strength properties of titanium are increased more than for most other materials. These results are presented in reference 2.121 (*b*).

5.122 *Elevated temperatures.* The effects of elevated temperature on titanium are based on continuous heating. Insufficient data are available to state definitely whether the information is also applicable to intermittently heated titanium materials. However, it is probable that intermittent heating would be directly cumulative as described in section 3.12211.

5.1221 *Static properties.* Curves for computing the reduction due to elevated temperature of tensile, compressive, bearing, and shear properties, are presented in figures 5.1221 (*a*) through (*h*). These curves are for commercially pure titanium held unstressed for ½ and 100 hours at various temperatures up to 1,000° F., and then tested statically at the exposure temperature.

5.13 CRITERIA FOR DESIGN MECHANICAL PROPERTIES. The test methods used to establish the design mechanical properties were the same as those described in sections 3.131, 3.132, and 3.133, except that all shear allowables are based on pin tests.

5.14 RATE OF STRAINING EFFECTS. The strength properties of titanium, particularly in the commercially pure product, are more sensitive to variations in the rate of straining than are most other aircraft structural metals. Insufficient data are available to provide specific values for various strain rates. However, some data are available in reference 5.14 (*a*) and (*b*). The general effect is for an increase in strength properties as the strain rate is increased so that for high strain rates the strength values would be higher than those listed in table 5.111 for static conditions. However, for applications where relatively high loads will be applied for a considerable length of time (i. e., very slow strain rates) the strength properties may be lower than those presented in table 5.111 The effect of strain rate should therefore be considered in the application of titanium, particularly in the commercially pure products.

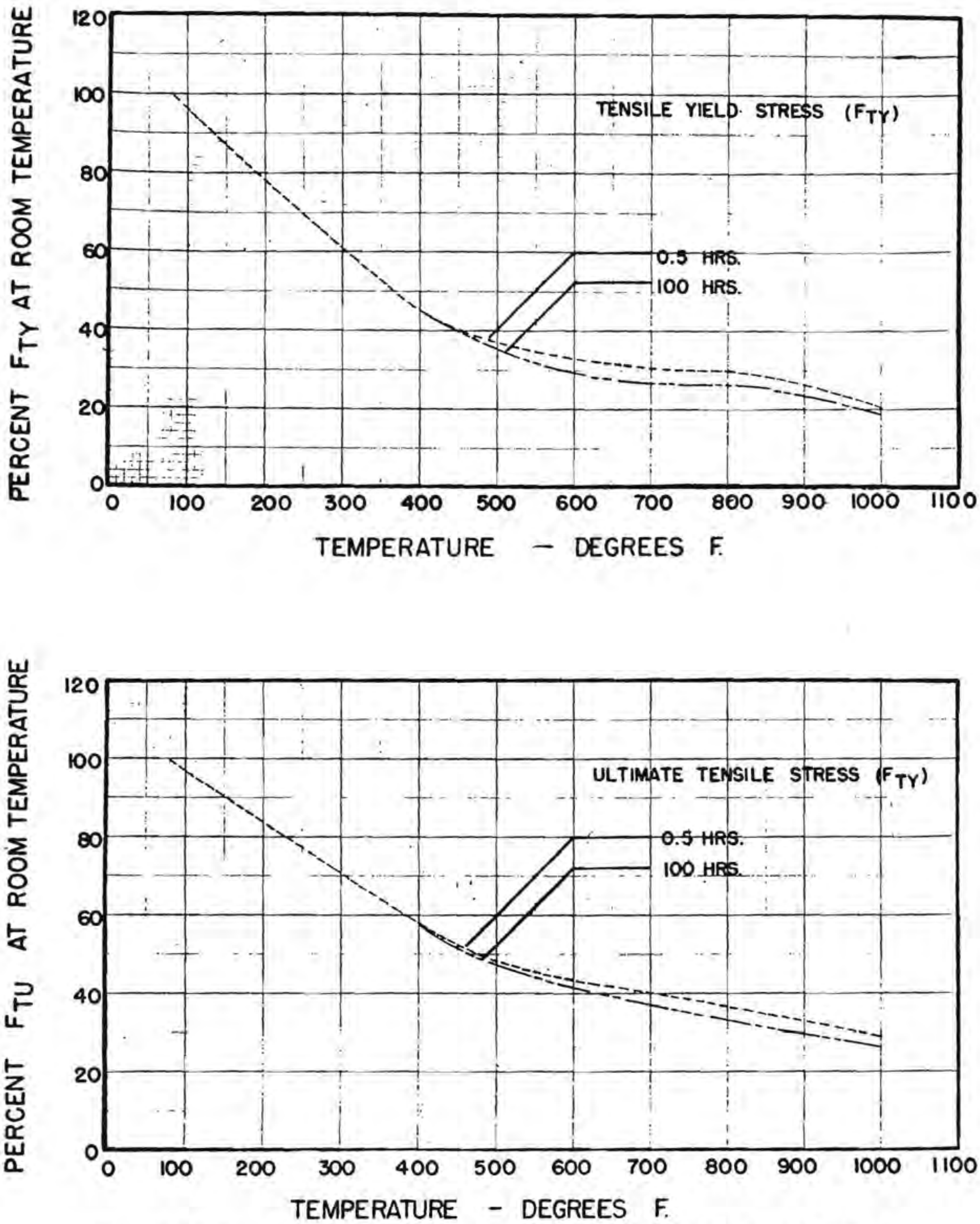
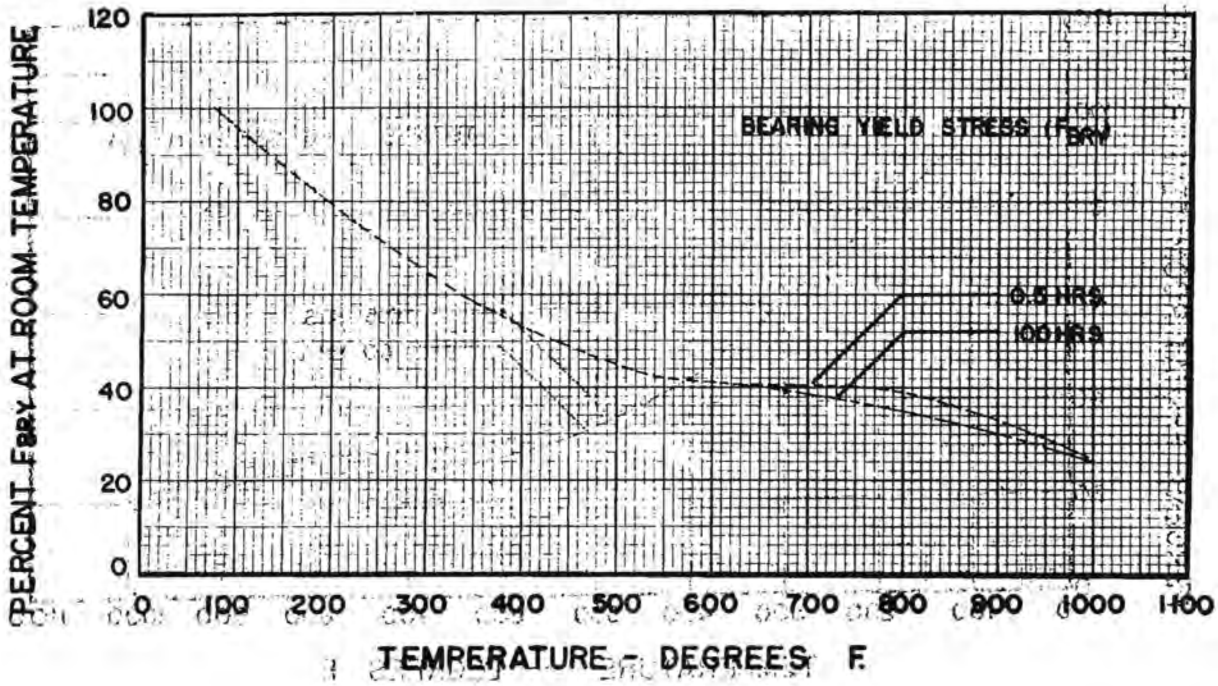


Figure 5.1221 (a). Effect of elevated temperatures on the tensile properties of annealed titanium.



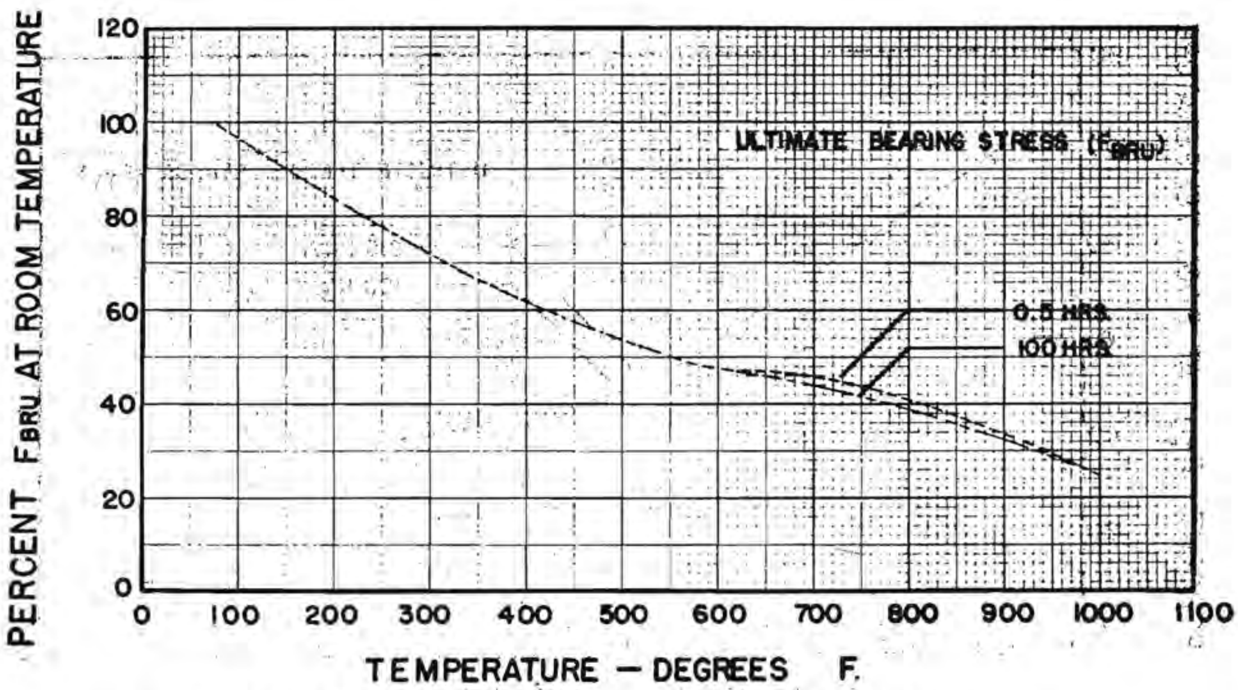


Figure 5.1221 (b). Effect of elevated temperatures on the bearing properties of annealed titanium.

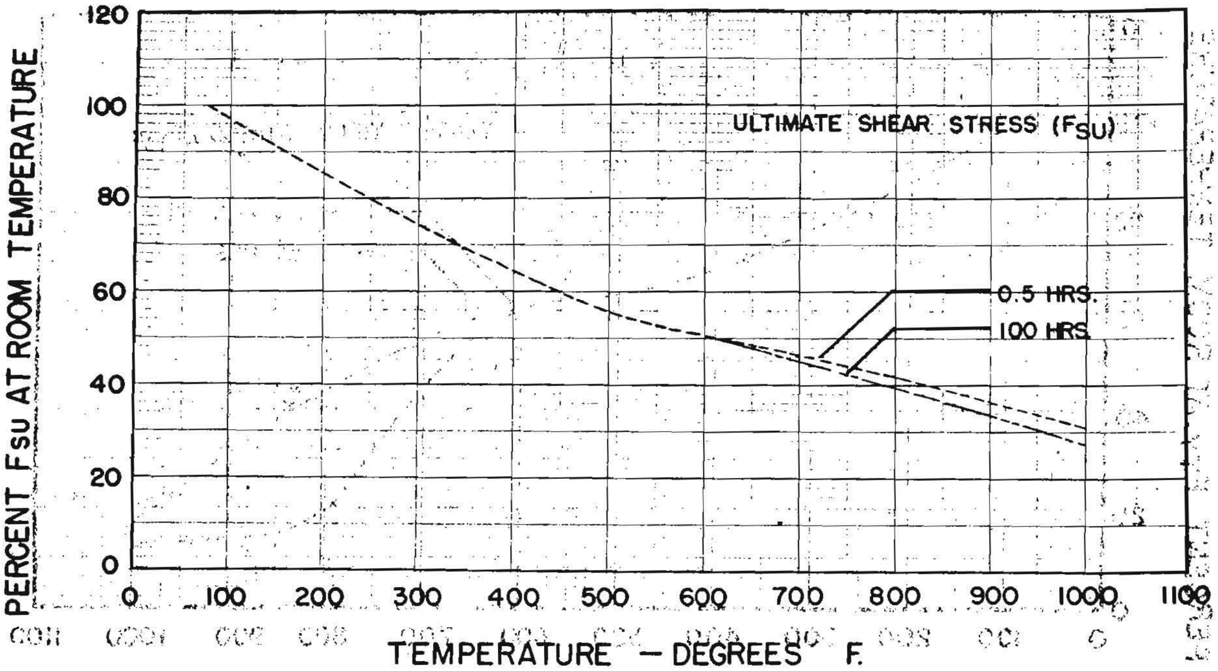


Figure 5.1221 (c). *Effect of elevated temperatures on the shear properties of annealed titanium.*

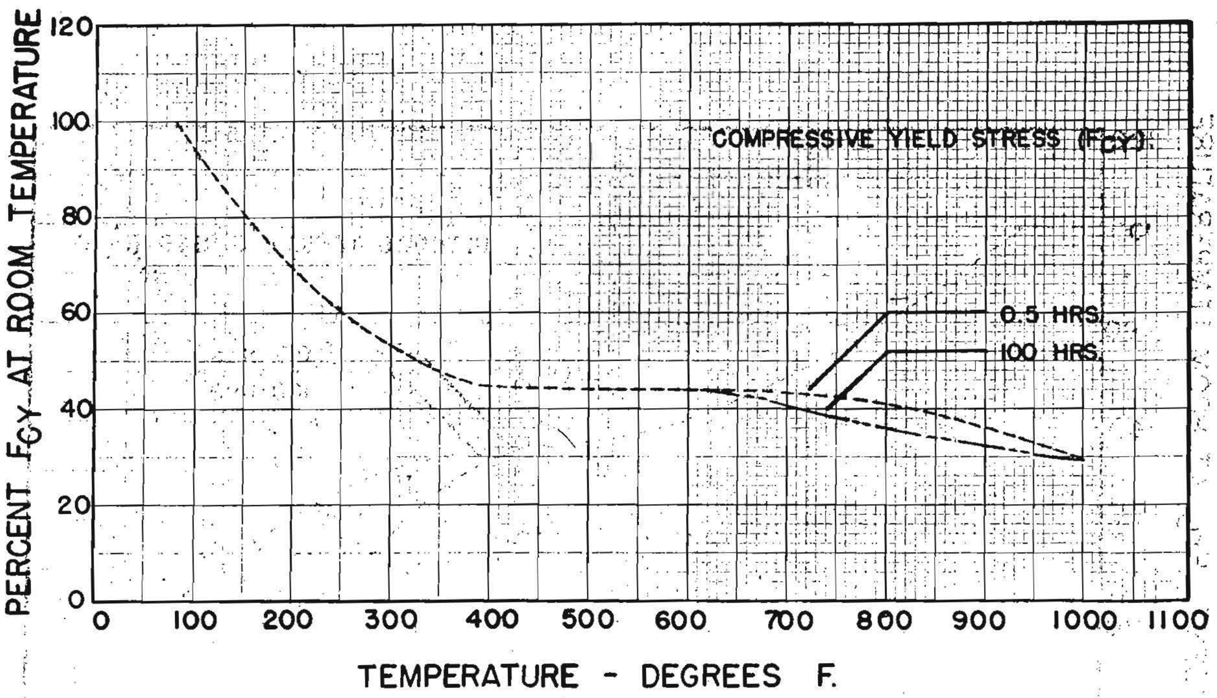
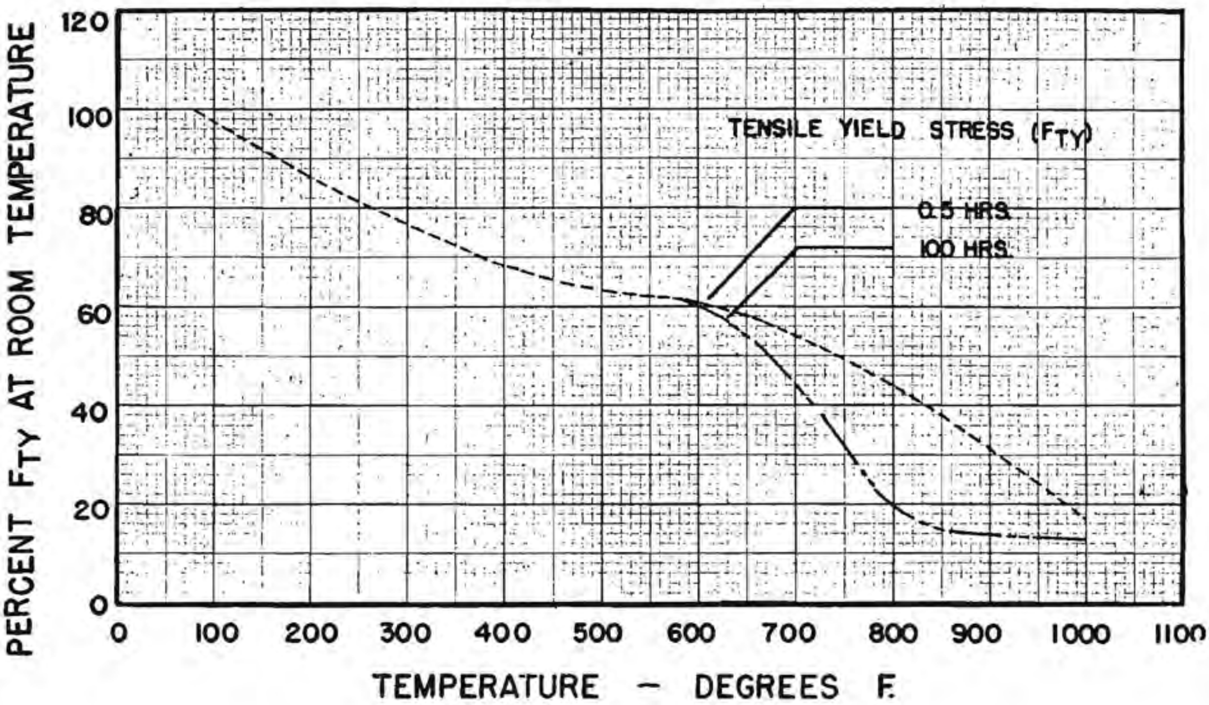


Figure 5.1221 (d). *Effect of elevated temperatures on the compressive yield properties of annealed titanium.*



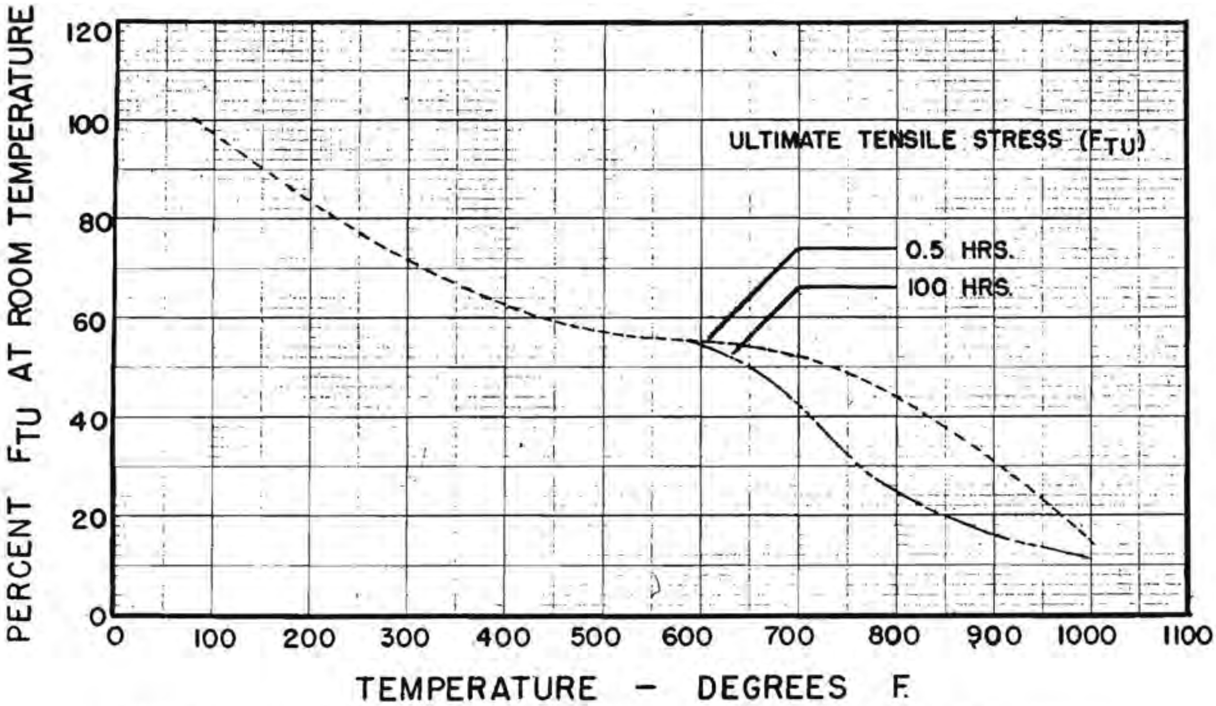
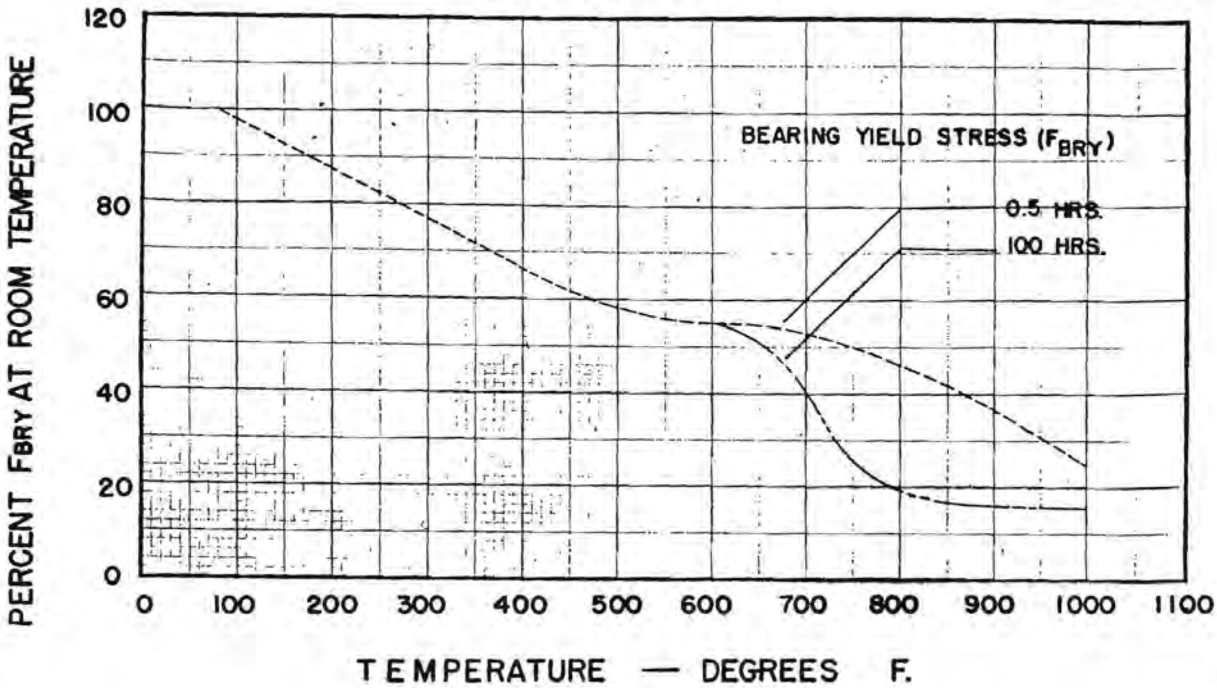


Figure 5.1221 (e). Effect of elevated temperatures on the tensile properties of cold-rolled titanium.



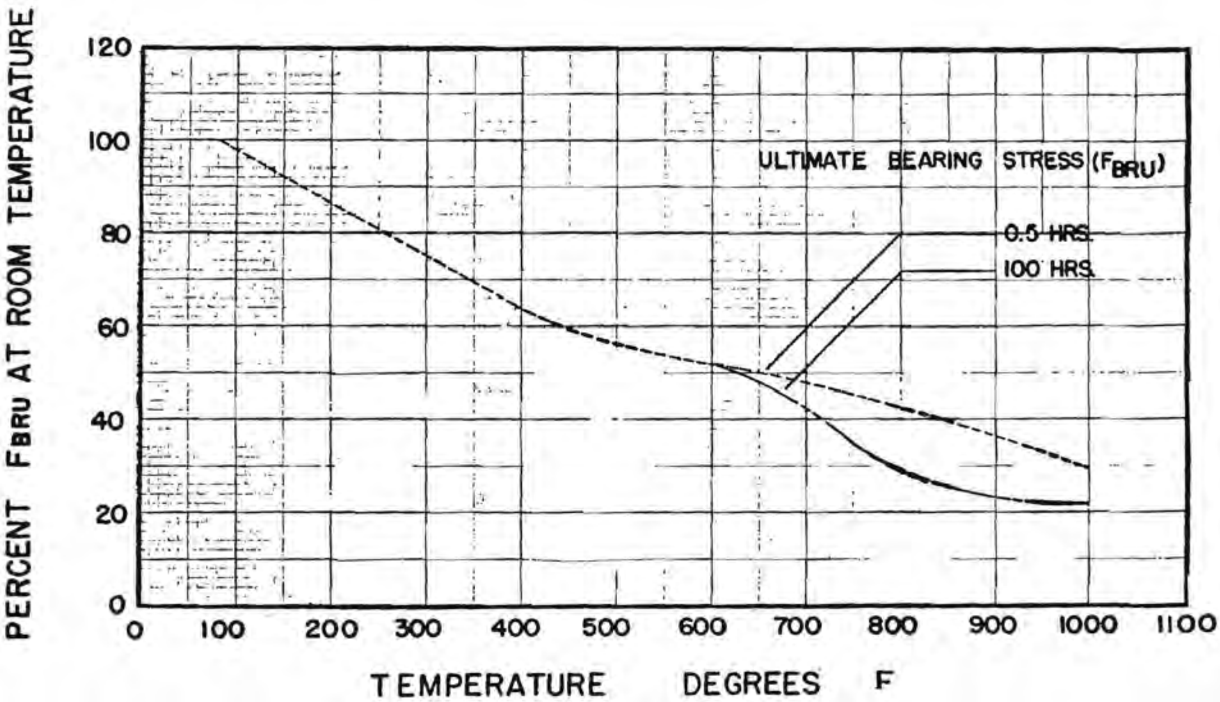


Figure 5.1221 (f). Effect of elevated temperatures on the bearing properties of cold-rolled titanium.

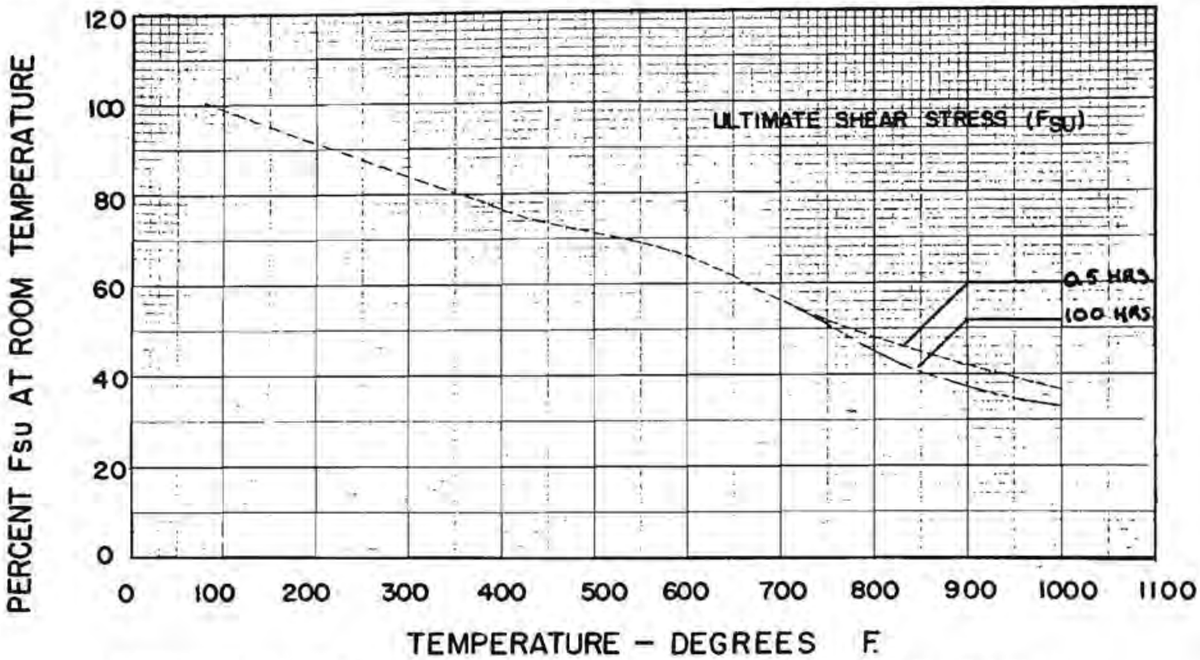


Figure 5.1221 (g). Effect of elevated temperatures on the shear properties of cold-rolled titanium.

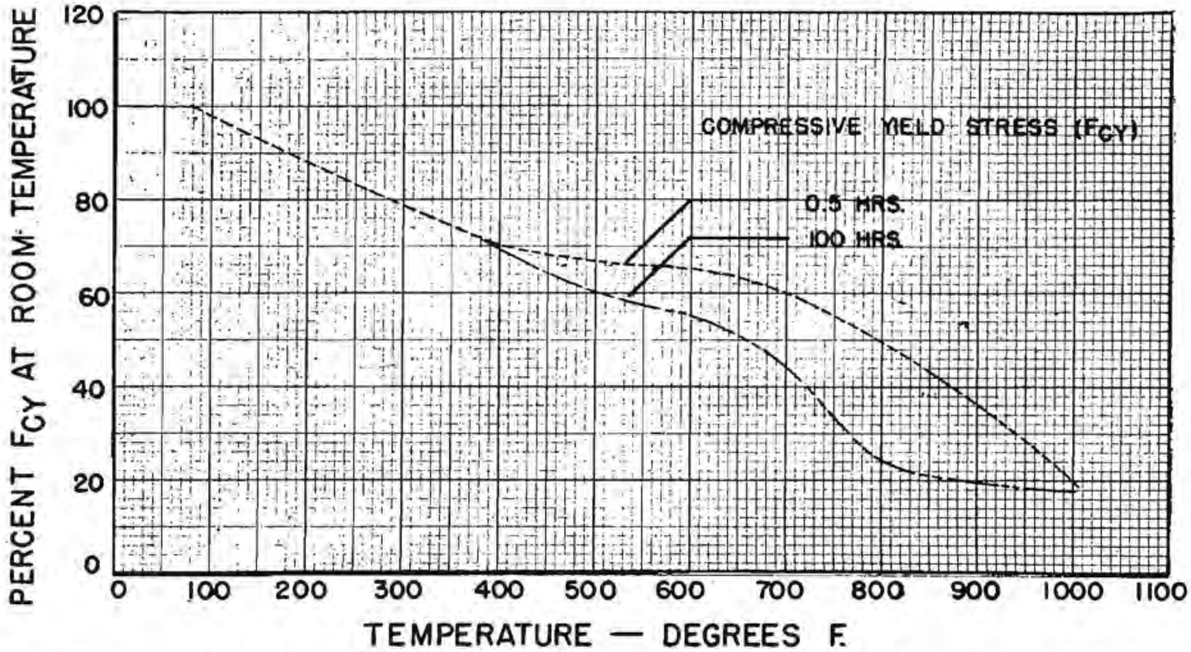


Figure 5.1221 (h). Effect of elevated temperatures on the compressive yield properties of cold-rolled titanium.

CHAPTER 6

MISCELLANEOUS METALS

6.1 General Properties.

6.11 NORMAL (ROOM) TEMPERATURE PROPERTIES.

6.111 *Design mechanical properties.* The general strength properties and related characteristics for bronze castings and several copper alloys at normal (room) temperatures are listed in the tables 6.111 (*a*) and (*b*). These values have been derived from test data and experience gained in individual applications, and are not necessarily covered by procurement specifications.

In the definition of bearing values, D is equal to the hole diameter and e is equal to the edge distance measured from the hole center to the edge of the material in the direction of applied stress. Values of $e/D=2.0$ shall be used for larger values of edge distance; values of e/D less than 1.5 shall be substantiated by adequate tests subject to the approval of the procuring or certificating agency. For values of edge distance between $e/D=2.0$ and $e/D=1.5$, linear interpolation may be employed.

Table 6.111 (a). Design Mechanical Properties of Bronze Castings (Kips per Square Inch) [a]

Alloy		Aluminum bronze							Manganese bronze				Hydraulic bronze	Phosphor bronze
Specification		QQ-D-671							QQ-B-726				QQ-B-691b (Composition 2)	QQ-B-691b (Composition 6)
Condition		As cast							As cast				As cast	As cast
Class		1	2	3	4	2	3	4	A	B	C	D		
F_{tu}	L	65	65	75	90	80	90	110	65	90	110	60	30	36
F_{ty}	L	[b]25	[b]25	[b]30	[b]40	[b]40	[b]45	[b]60	25	45	60	20	14	16
F_{cy}	L	—	—	—	—	—	—	—	—	—	—	—	—	—
F_{su}		40	40	—	—	—	—	—	40	—	—	—	—	—
F_{bru} $(e/D=1.5)$		—	—	—	—	—	—	—	—	—	—	—	—	—
F_{bru} $(e/D=2.0)$		80	80	—	—	—	—	—	80	—	—	—	—	—
F_{bry} $(e/D=1.5)$		—	—	—	—	—	—	—	—	—	—	—	—	—
F_{bry} $(e/D=2.0)$		—	—	—	—	—	—	—	—	—	—	—	—	—
e		20	20	12	6	12	6	5	20	20	12	15	20	18
E		15,000							15,000				—	—
E_c		15,000							15,000				—	—
G		4,500							4,500				—	—

[a] Values are minimum values obtained from cast test bar specimens. Reference should be made to the specific requirements of the procuring or certificating agency with regard to the use of the above values in the design of castings.

[b] As determined by extension under load method. Limiting extension=0.005 inch per inch of gage length.

Table 6.111 (b). Design Mechanical Properties for Copper Alloys (Kips per Square Inch)

Type	Bar								Strip	
Alloy	Aluminum bronze				Beryllium copper				Beryllium copper	
Specification	AMS 4631				QQ-C-530				QQ-C-533	
Condition					AT	HT			AT	HT
Thickness	Up to 0.500 inch	0.501 to 1.000 inch	1.001 to 2.000 inches	2.001 to 3.000 inches		0.020 to 0.375 inch	0.376 to 1.000 inch	Over 1.000 inch	Up to 0.187 inch	Up to 0.187 inch
F_{tu}	90	88	85	75	160	185	180	175	165	190
F_{ty}	45	44	42.5	37.5	120	130	130	130	120	140
F_{cy}	45	44	42.5	37.5	120	130	130	130	120	140
F_{su}	50	48	47	41	87	101	99	96	90	104
F_{bru} $(e/D=1.5)$	100	97	94	83	160	185	180	175	165	190
F_{bru} $(e/D=2.0)$	110	105	101	90	175	200	195	190	180	205
F_{bry} $(e/D=1.5)$	50	48	47	41	120	130	130	130	120	140
F_{bry} $(e/D=2.0)$	54	53	51	45	132	143	143	143	132	152

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