Atlas of Stress-Strain Curves

SECOND EDITION

ASM INTERNATIONAL®
The Materials Information Society

Atlas of Stress-Strain Curves

Second Edition

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Comments, criticisms, and suggestions are invited, and should be forwarded to ASM International.

Prepared under the direction of the ASM International Technical Book Committee (2001–2002), Charles A. Parker, Chair. Prepared with assistance from the ASM International Materials Properties Database Committee, P.J. Sikorsky, Chair.

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Preface

In this information age, mechanical property data are plentiful. However, locating needed information quickly, judging the validity of the data, and making reasoned comparisons of data can be daunting. Stress-strain curves condense much information about the mechanical behavior of metals into a convenient form. From these basic curves the engineer can extract such information as the strength, ductility, formability, elasticity, and other information useful in predicting the performance of a particular alloy under stress.

ASM International published the first edition of the *Atlas of Stress-Strain Curves,* a collection of over 550 curves, in 1986. This book, along with the *Atlas of Fatigue Curves, Atlas of Creep and Stress-Rupture Curves,* and the *Atlas of Stress-Corrosion and Corrosion Fatigue Curves,* has formed a set of useful materials property resources for the engineer, materials scientist, and designer.

Well over three years ago—with the encouragement, assistance, and guidance of the ASM Technical Books and Materials Properties Database Committees—ASM International embarked on the project to create this updated, expanded, and improved Second Edition of the *Atlas of Stress-Strain Curves.* Some of the overriding goals of this project have been to:

- Add curves for materials that are especially useful to key industries, including aerospace, automotive, and heavy manufacturing
- Seek out curves with a "pedigree" so readers can trace the source of the information and have some indication regarding its reliability
- Include as much pertinent information as possible for each curve. Factors such as heat-treat condition, product form, thickness, specimen size, orientation, history, testing temperature, and testing rate all affect materials performance and may be helpful when interpreting the curves
- Normalize the presentation of the curves to facilitate comparisons among different materials

We feel ASM International has been reasonably successful in achieving these objectives in this edition.

Many people are involved in a project of this size, and we would like to thank those who have contributed to, or assisted, this effort. First and foremost, ASM International thanks the materials researchers who created the original curves—without their efforts this volume would not exist.

Donna M. Walker, FASM, Stressolvers Inc., and Veronica Flint, ASM staff, initiated the project to revise and expand this book. ASM International thanks them for their efforts in helping to define the goals for this project and in acquiring many of the new curves to be added to the book.

Special thanks are extended to Special Metals, Gil Kaufman, FASM, Kaufman Associates, and Bruce Boardman, FASM, Deere & Company, for their contributions of stress-strain curves.

Hiro Okamoto and his associates performed the huge task of redrawing the curves to normalize their presentation, and we are grateful for their accurate and timely work.

The organization and final quality of the data as seen in the book are my responsibility, and any errors, omissions, or misclassifications of alloys are mine. I thank Heather Lampman, the principal copy editor, and the members of the ASM International production staff, who have worked diligently to keep any errors to a minimum. However, in any endeavor of this scope, there will be mistakes. Corrections, comments, and criticisms are invited.

It should be noted that most of the data included in this book are not specified as being minimum, typical, or having any defined confidence level associated with them. The reader may want to refer to the source of a particular curve to find additional details. The "Introduction" in this book provides a review of the information that can be extracted from stress-strain curves, a clarification of terms used in describing mechanical behavior, and a guide to the limitations of the accuracy and precision of the information given.

Charles Moosbrugger
Technical Editor
ASM International

Representation of Stress-Strain Behavior

Charles Moosbrugger, ASM International

IT IS APPROPRIATE that a collection of stress-strain curves is named an atlas. An atlas is a collection of figures, charts, or maps, so named because early books pictured the Greek Titan, Atlas, on the cover or title page, straining with the weight of the world and heavens on his shoulders. This concept of visualizing the reaction to mechanical stress is central to development and use of stress-strain curves.

This introductory section provides a review of the fundamentals of the mechanical testing that is represented in the curves. The mathematical interpretation of aspects of the curves will aid in analysis of the curves. A list of terms common to stress-strain behavior is given at the end of this section. (Ref 1, 2).

Tensile Testing

The simplest loading to visualize is a one-dimensional tensile test, in which a uniform slender test specimen is stretched along its long central axis. The stress-strain curve is a representation of the performance of the specimen as the applied load is increased monotonically usually to fracture.

Stress-strain curves are usually presented as:

- "Engineering" stress-strain curves, in which the original dimensions of the specimens are used in most calculations.
- "True" stress-strain curves, where the instantaneous dimensions of the specimen at each point during the test are used in the calculations. This results in the "true" curves being above the "engineering" curves, notably in the higher strain portion of the curves.

The development of these curves is described in the following sections.

To document the tension test, an engineering stress-strain curve is constructed from the load-elongation measurements made on the test specimen (Fig. 1). The engineering stress, S, plotted on this stress-strain curve is the average longitudinal stress in the tensile specimen. It is obtained by dividing the load, P, by the original area of the cross section of the specimen, A_0:

$$S = \frac{P}{A_0} \qquad \text{(Eq 1)}$$

The strain, e, plotted on the engineering stress-strain curve, is the average linear strain, which is obtained by dividing the elongation of the gage length of the specimen, δ, by its original length, L_0:

$$\frac{\delta}{L_0} = \frac{\Delta L}{L_0} = \frac{L - L_0}{L_0} \qquad \text{(Eq 2)}$$

Because both the stress and the strain are obtained by dividing the load and elongation by constant factors, the load-elongation curve has the same shape as the engineering stress-strain curve. The two curves frequently are used interchangeably.

The units of stress are force/length squared, and the strain is unitless. The strain axis of curves traditionally are given units of in./in. or mm/mm rather than being listed as a pure number. Strain is sometimes expressed as a percent elongation.

The shape of the stress-strain curve and values assigned to the points on the stress-strain curve of a metal depend on its:

- Composition
- Heat treatment and conditioning
- Prior history of plastic deformation
- The strain rate of test
- Temperature
- Orientation of applied stress relative to the test specimens structure
- Size and shape

The parameters that are used to describe the stress-strain curve of a metal are the tensile strength, yield strength or yield point, ultimate tensile strength, percent elongation, and reduction in area. The first three are strength parameters; the last two indicate ductility.

The general shape of the engineering stress-strain curve (Fig. 1) requires further explanation. This curve represents the full loading of a specimen from initial load to rupture. It is a "full-range" curve. Often engineering curves are truncated past the 0.2% yield point. This is the case of many of the curves in this *Atlas*. Other test data are presented as a "full-range" curve with an "expanded range" to detail the initial parts of the curve.

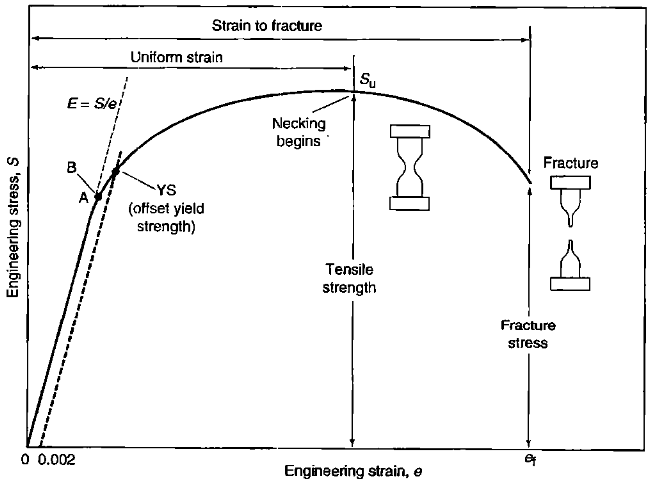

Fig. 1 Engineering stress-strain curve. Intersection of the dashed line with the curve determines the offset yield strength.

Linear Segment of Curves

From the origin, 0, the initial straight-line portion is the elastic region, where stress is linearly proportional to strain. When the stress is removed, if the strain disappears, the specimen is considered completely elastic.

The point at which the curve departs from the straight-line proportionality, A, is the proportional limit.

Modulus of elasticity, E, also known as Young's modulus, is the slope of this initial linear portion of the stress-strain curve:

$$E = \frac{S}{e} \qquad \text{(Eq 3)}$$

where S is engineering stress and se is engineering strain. Modulus of elasticity is a measure of the stiffness of the material. The greater the modulus, the steeper the slope and the smaller the elastic strain resulting from the application of a given stress. Because the modulus of elasticity is needed for computing deflections of beams and other structural members, it is an important design value.

The modulus of elasticity is determined by the binding forces between atoms. Because these forces cannot be changed without changing the basic nature of the material, the modulus of elasticity is one of the most structure-insensitive of the mechanical properties. Generally, it is only slightly affected by alloying additions, heat treatment, or cold work (Ref 3). However, increasing the temperature decreases the modulus of elasticity. At elevated temperatures, the modulus is often measured by a dynamic method (Ref 4). Typical values of modulus of elasticity for common engineering materials are given in Table 1 (Ref 5).

Resilience is the ability of a material to absorb energy when deformed elastically and to return it when unloaded. This property usually is measured by the modulus of resilience, which is the strain energy per unit volume, U_0, required to stress the material from zero stress to the yield stress, S_x. The strain energy per unit volume for any point on the line is just the area under the curve:

$$U_0 = \frac{1}{2} S_x e_x \qquad \text{(Eq 4)}$$

From the definition of modulus of elasticity and the above definition, the maximum resilience occurs at the yield point and is called the modulus of resilience, U_R:

$$U_R = \frac{1}{2} S_0 E_0 = \frac{1}{2} S_0 \frac{S_0}{E} = \frac{S_0^2}{2E} \qquad \text{(Eq 5)}$$

This equation indicates that the ideal material for resisting energy loads in applications where the material must not undergo permanent distortion, such as mechanical springs, is one having a high yield stress and a low modulus of elasticity.

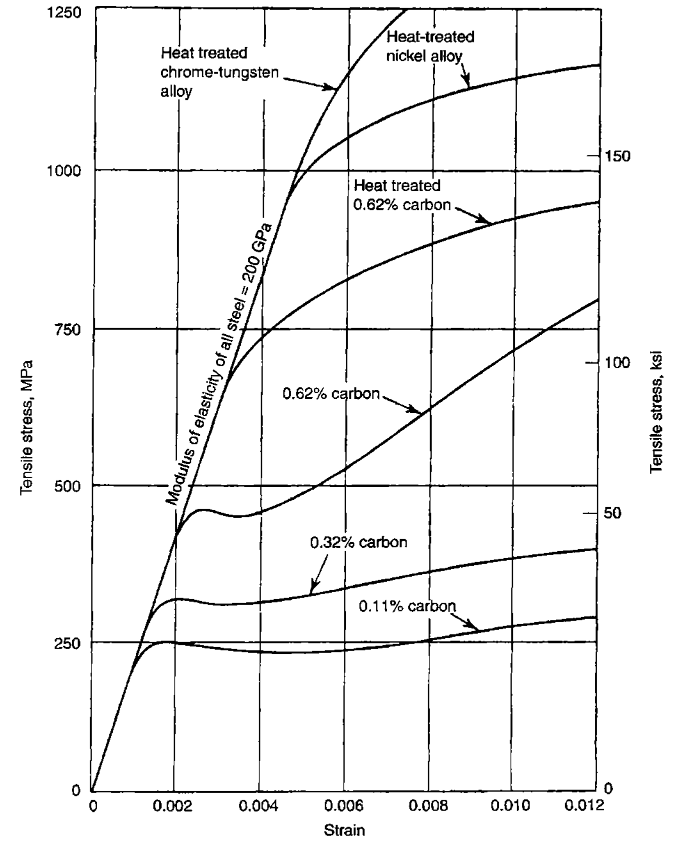

Fig. 2 Stress-strain curves for selected steels. Source: Ref 7

For various grades of steel, the modulus of resilience ranges from 100 to 4500 kJ/m^3 (14.5 to 650 lbf · in./in.^{3}), with the higher values representing steels with higher carbon or alloy contents (Ref 6). This can be seen in Fig. 2, where the modulus of resilience for the chromium-tungsten alloy would be the greatest of the steels, because it has the highest yield strength and similar modulus of elasticity. The modulus of resilience is represented as the triangular areas under the curves in Fig. 3.

Figure 2 shows that while the modulus of elasticity is consistent for the given group of steels, the shapes of the curves past their proportionality limits are quite varied (Ref 7).

Table 1 Typical values for modulus of elasticity

Metal	Elastic modulus (E) GPa	Elastic modulus (E) 10^6 psi
Aluminum	70	10.2
Brass, 30 Zn	101	14.6
Chromium	279	40.5
Copper	130	18.8
Iron		
Soft	211	30.7
Cast	152	22.1
Lead	16	2.34
Magnesium	45	6.48
Molybdenum	324	47.1
Nickel		
Soft	199	28.9
Hard	219	31.8
Nickel-silver, 55Cu-18Ni-27Zn	132	19.2
Niobium	104	15.2
Silver	83	12.0
Steel		
Mild	211	30.7
0.75 C	210	30.5
0.75 C, hardened	201	29.2
Tool steel	211	30.7
Tool steel hardened	203	29.5
Stainless, 2Ni-18Cr	215	31.2
Tantalum	185	26.9
Tin	50	7.24
Titanium	120	17.4
Tungsten	411	59.6
Vanadium	128	18.5
Zinc	105	15.2

Source: Ref 5

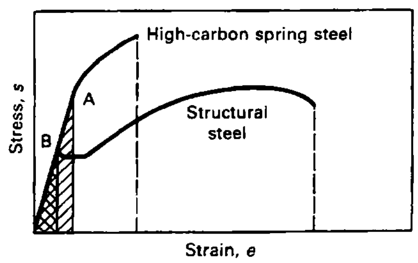

Fig. 3 Comparison of stress-strain curves for a high-strength high-carbon spring steel and a lower-strength structural steel. Point A is the elastic limit of the springsteel; point B is the elastic limit of the structural steel. The cross-hatched triangles are the modulus of resilience (U_R). These two areas are the work done on the materials to elongate them or the restoring force within the materials.

Nonlinear Segment of Curves to Yielding

The elastic limit, B, on Fig. 1, may coincide with the proportionality limit, or it may occur at some greater stress. The elastic limit is the maximum stress that can be applied without permanent deformation to the specimen. Some curves exhibit a definite yield point, while others do not. When the stress exceeds a value corresponding to the yield strength, the specimen undergoes gross plastic deformation. If the load is subsequently reduced to 0, the specimen will remain permanently deformed.

Measures of Yielding. The stress at which plastic deformation or yielding is observed to begin depends on the sensitivity of the strain measurements. With most materials, there is a gradual transition from elastic to plastic behavior, and the point at which plastic deformation begins is difficult to define with precision. In tests of materials under uniaxial loading, three criteria for the initiation of yielding have been used: the elastic limit, the proportional limit, and the yield strength.

Elastic limit, shown at point B in Fig. 1, is the greatest stress the material can withstand without any measurable permanent strain remaining after the complete release of load. With increasing sensitivity of strain measurement, the value of the elastic limit is decreased until it equals the true elastic limit determined from microstrain measurements. With the sensitivity of strain typically used in engineering studies (10^{-4} mm/mm or in./in.), the elastic limit is greater than the proportional limit. Determination of the elastic limit requires a tedious incremental loading-unloading test procedure. For this reason, it is often replaced by the proportional limit.

The yield strength, shown at point YS in Fig. 1, is the stress required to produce a small specified amount of plastic deformation. The usual definition of this property is the offset yield strength determined by the stress corresponding to the intersection of the stress-strain curve offset by a specified strain (see Fig. 1). In the United States, the offset is usually specified as a strain of 0.2% or 0.1% (e = 0.002 or 0.001).

Offset yield strength determination requires a specimen that has been loaded to its 0.2% offset yield strength and unloaded so that it is 0.2% longer than before the test. The offset yield strength is referred to in ISO Standards as the proof stress ($R_{p0,1}$ or $R_{p0,2}$). In the EN standards for materials that do not have a yield phenomenon present, the 0,2% proof strength ($R_{p0,2}$) or 0,5% ($R_{p0,5}$) is determined. The nonproportional elongation is either 0.1%, 0.2%, or 0.5%. The yield strength obtained by an offset method is commonly used for design and specification purposes, because it avoids the practical difficulties of measuring the elastic limit or proportional limit.

Some materials have essentially no linear portion to their stress-strain curve, for example, soft copper or gray cast iron. For these materials, the offset method cannot be used, and the usual practice is to define the yield strength as the stress to produce some total strain, for example, e = 0.005. The European Standard for general-purpose copper rod, EN 12163 (Ref 8), gives approximate 0,2% proof strength ($R_{p0,2}$) for information, but it is not a requirement. This approach is followed for other material forms (bar and wire), but for some copper tubes, a maximum $R_{p0,2}$ is specified For copper alloy pressure vessel plate and some spring strip, a minimum $R_{p0,2}$ is specified.

Materials with Yield Point Phenomenon. Many metals, particularly annealed low-carbon steel, show a localized, heterogeneous type of transition from elastic to plastic deformation that produces a yield point in the stress-strain curve. Rather than having a flow curve with a gradual transition from elastic to plastic behavior, such as Fig. 4(a), metals with a yield point produce a flow curve or a load-elongation diagram similar to Fig. 4(b). The load increases steadily with elastic strain,

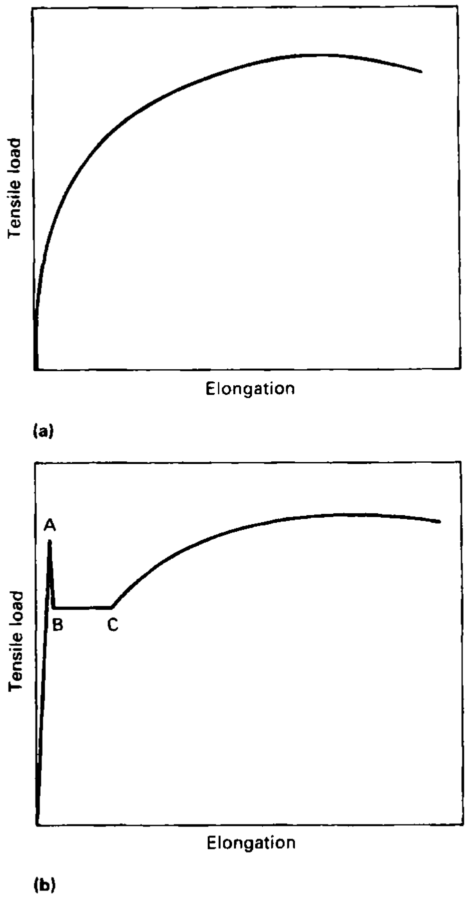

Fig. 4 Idealized plots of stress-strain. (a) Continuous yielding condition. (b) Discontinuous yielding with an upper yield point A and a relatively constant yielding stress B to C

drops suddenly, fluctuates about some approximately constant value of load, and then rises with further strain.

In EN standards for materials exhibiting a yield point, the upper yield strength, R_{eH} may be specified. The upper and lower yield stress (R_{eH}, R_{eL}) are specified in some EN and ISO standards in units of N/mm^2 (1 N/mm^2 = 1 MPa). EN 10027-1 (Ref 9) notes the term "yield strength" as used in this European standard refers to upper or lower yield strength (R_{eH} or R_{eL}), proof strength (R_p), or the proof strength total extension (R_t), depending on the requirement specified in the relevant product standard. This serves as a caution that the details on how the "yield strength" or "yield point" is defined must be known when making any comparisons or conclusions as to the materials characteristics.

Typical yield point behavior of low-carbon steel is shown in Fig. 5. The slope of the initial linear portion of the stress-strain curve, designated by E, is the modulus of elasticity. The load at which the sudden drop occurs is called the upper yield point. The constant load is called the lower yield point, and the elongation that occurs at constant load is called the yield-point elongation. The deformation occurring throughout the yield-point elongation is heterogeneous. At the upper yield point, a discrete band of deformed metal, often readily visible, appears at a stress concentration such as a fillet. Coincident with the formation of the band, the load drops to the lower yield point. The band then propagates along the length of the specimen, causing the yield-point elongation.

In typical cases, several bands form at several points of stress concentration. These bands are generally at approximately 45° to the ten-

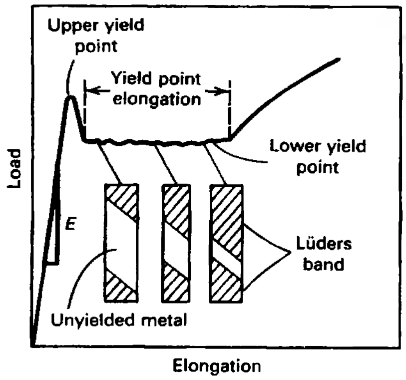

Fig. 5 Typical yield point behavior of low-carbon steel

sile axis. They are usually called Lüders bands, Hartmann lines, or stretcher strains, and this type of deformation is sometimes referred to as the Piobert effect. They are visible and can be aesthetically undesirable. When several Lüders bands are formed, the flow curve during the yield-point elongation is irregular, each jog corresponding to the formation of a new Lüders band. After the Lüders bands have propagated to cover the entire length of the specimen test section, the flow will increase with strain in the typical manner. This marks the end of the yield-point elongation. The transition from undeformed to deformed material at the Lüders front can be seen at low magnification in Fig. 6. The rough surface areas are the Lüders bands in the low-carbon steel. These bands are also formed in certain aluminum-magnesium alloys.

Nonlinear Segment of Continued Deformation

Strain Hardening. The stress required to produce continued plastic deformation increases with increasing plastic strain; that is, the metal strain hardens. The volume of the specimen (area × length) remains constant during plastic deformation, $AL = A_0L_0$, and as the specimen elongates, its cross-sectional area decreases uniformly along the gage length.

Initially, the strain hardening more than compensates for this decrease in area, and the engineering stress (proportional to load P) continues to rise with increasing strain. Eventually, a point is reached where the decrease in specimen cross-sectional area is greater than the increase in deformation load arising from strain hardening. This condition will be reached first at some point in the specimen that is slightly weaker than the rest. All further plastic deformation is concentrated in this region, and the specimen begins to neck or thin down locally. The strain up to this point has been uniform, as indicated on Fig. 1. Because the cross-sectional area is now decreasing far more rapidly than the ability to resist the deformation by strain hardening, the actual load required to deform the specimen decreases and the engineering stress defined in Eq 1 continues to decrease until fracture occurs, at X.

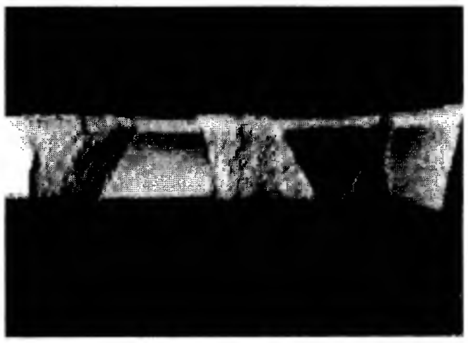

Fig. 6 Lüders bands (roughened areas), which have propagated along the length of a specimen of annealed steel sheet that was tested in tension. Unpolished, unetched. Low magnification

The tensile strength, or ultimate tensile strength, S_u, is the maximum load divided by the original cross-sectional area of the specimen:

$$S_u = \frac{P_{max}}{A_0} \quad \text{(Eq 6)}$$

The tensile strength is the value most frequently quoted from the results of a tension test. Actually, however, it is a value of little fundamental significance with regard to the strength of a metal. For ductile metals, the tensile strength should be regarded as a measure of the maximum load that a metal can withstand under the very restrictive conditions of uniaxial loading. This value bears little relation to the useful strength of the metal under the more complex conditions of stress that usually are encountered.

For many years, it was customary to base the strength of structural members on the tensile strength, suitably reduced by a factor of safety. The current trend is to the more rational approach of basing the static design of ductile metals on the yield strength. However, because of the long practice of using the tensile strength to describe the strength of materials, it has become a familiar property, and as such, it is a useful identification of a material in the same sense that the chemical composition serves to identify a metal or alloy. Furthermore, because the tensile strength is easy to determine and is a reproducible property, it is useful for the purposes of specification and for quality control of a product. Extensive empirical correlations between tensile strength and properties such as hardness and fatigue strength are often useful. For brittle materials, the tensile strength is a valid design criterion.

Measures of Ductility. Currently, ductility is considered a qualitative, subjective property of a material. In general, measurements of ductility are of interest in three respects (Ref 10):

- To indicate the extent to which a metal can be deformed without fracture in metalworking operations such as rolling and extrusion
- To indicate to the designer the ability of the metal to flow plastically before fracture. A high ductility indicates that the material is "forgiving" and likely to deform locally without fracture should the designer err in the stress calculation or the prediction of severe loads.
- To serve as an indicator of changes in impurity level or processing conditions. Ductility measurements may be specified to assess material quality, even though no direct relationship exists between the ductility measurement and performance in service.

The conventional measures of ductility that are obtained from the tension test are the engineering strain at fracture, e_f, (usually called the elongation) and the reduction in area at fracture, q. Elongation and reduction in area usually are expressed as a percentage. Both of these properties are obtained after fracture by putting the specimen back together and taking measurements of the final length, L_f, and final specimen cross section, A_f:

$$e_f = \frac{L_f - L_0}{L_0} \quad \text{(Eq 7)}$$

$$q = \frac{A_0 - A_f}{A_0} \quad \text{(Eq 8)}$$

Because an appreciable fraction of the plastic deformation will be concentrated in the necked region of the tension specimen, the value of

e_f will depend on the gage length L_0 over which the measurement was taken (see the section of this article on ductility measurement in tension testing). The smaller the gage length, the greater the contribution to the overall elongation from the necked region and the higher the value of e_f. Therefore, when reporting values of percentage elongation, the gage length, L_0, should always be given.

Reduction in area does not suffer from this difficulty. These values can be converted into an equivalent zero-gage-length elongation, e_0. From the constancy of volume relationship for plastic deformation ($AL = A_0L_0$):

$$\frac{L}{L_0} = \frac{A_0}{A} = \frac{1}{1-q}$$

$$e_0 = \frac{L-L_0}{L_0} = \frac{A_0}{A} - 1 = \frac{1}{1-q} - 1 = \frac{1}{1-q} \quad \text{(Eq 9)}$$

This represents the elongation based on a very short gage length near the fracture. Another way to avoid the complications resulting from necking is to base the percentage elongation on the uniform strain out to the point at which necking begins. The uniform elongation, e_u, correlates well with stretch-forming operations. Because the engineering stress-strain curve often is quite flat in the vicinity of necking, it may be difficult to establish the strain at maximum load without ambiguity. In this case, the method suggested in Ref 11 is useful.

The toughness of a material is its ability to absorb energy up to the point of fracture or rupture. The ability to withstand occasional stresses above the yield stress without fracturing is particularly desirable in parts such as freight-car couplings, gears, chains, and crane hooks. Toughness is a commonly used concept that is difficult to precisely define. Toughness may be considered to be the total area under the stress-strain curve to the point of fracture. This area, which is referred to as the modulus of toughness, U_T, is the amount of work per unit volume that can be done on the material without causing it to rupture.

Figure 3 shows the stress-strain curves for high- and low-toughness materials. The high-carbon spring steel has a higher yield strength and tensile strength than the medium-carbon structural steel. However, the structural steel is more ductile and has a greater total elongation. The total area under the stress-strain curve is greater for the structural steel; therefore, it is a tougher material. This illustrates that toughness is a parameter that comprises both strength and ductility.

True Stress-Strain Curves

The engineering stress-strain curve does not give a true indication of the deformation characteristics of a metal, because it is based entirely on the original dimensions of the specimen and these dimensions change continuously during the test. Also, a ductile metal that is pulled in tension becomes unstable and necks down during the course of the test. Because the cross-sectional area of the specimen is decreasing rapidly at this stage in the test, the load required to continue deformation lessens.

The average stress based on the original area likewise decreases, and this produces the downturn in the engineering stress-strain curve beyond the point of maximum load. Actually, the metal continues to strain harden to fracture, so that the stress required to produce further deformation should also increase. If the true stress, based on the actual cross-sectional area of the specimen, is used, the stress-strain curve increases continuously to fracture. If the strain measurement is also based on instantaneous measurement, the curve that is obtained is known as true-stress/true-strain curve.

Flow Curve. The true stress-strain curve is also known as a flow curve, because it represents the basic plastic-flow characteristics of the material. Any point on the flow curve can be considered the yield stress for a metal strained in tension by the amount shown on the curve. Thus, if the load is removed at this point and then reapplied, the material will behave elastically throughout the entire range of reloading.

The true stress, σ, is expressed in terms of engineering stress, S, by:

$$\sigma = \frac{P}{A_0}(e+1) = S_1(e+1) \quad \text{(Eq 10)}$$

The derivation of Eq 10 assumes both constancy of volume ($AL = A_0L_0$) and a homogeneous distribution of strain along the gage length of the tension specimen. Thus, Eq 10 should be used only until the onset of necking. Beyond the maximum load, the true stress should be determined from actual measurements of load and cross-sectional area.

$$\sigma = \frac{P}{A} \quad \text{(Eq 11)}$$

The true strain, ε, may be determined from the engineering or conventional strain, e. From Eq 2:

$$e = \frac{\Delta L}{L_0} = \frac{L-L_0}{L_0} = \frac{L}{L_0} - 1 \quad \text{(Eq 12)}$$

To determine the true strain, the instantaneous change in length (dl) is divided by the length, l:

$$\varepsilon = \int_{L_0}^{L} \frac{dl}{l} = \ln\left(\frac{L}{L_0}\right) \quad \text{(Eq 13)}$$

$$\varepsilon = \ln(e+1) \quad \text{(Eq 14)}$$

This equation is applicable only to the onset of necking for the reasons discussed above. Beyond maximum load, the true strain should be based on actual area or diameter, D, measurements:

$$\varepsilon = \ln\frac{A_0}{A} = \ln\frac{(\pi D_0^2)/4}{(\pi D^2)/4} = 2\ln\frac{D_0}{D} \quad \text{(Eq 15)}$$

Figure 7 compares the true-stress/true-strain curve with its corresponding engineering stress-strain curve. Note that, because of the relatively large plastic strains, the elastic region has been compressed into the y-axis. In agreement with Eq 10 and 14, the true-stress/true-strain curve is always to the left of the engineering curve until the maximum load is reached.

Necking. Beyond maximum load, the high, localized strains in the necked region that are used in Eq 15 far exceed the engineering strain

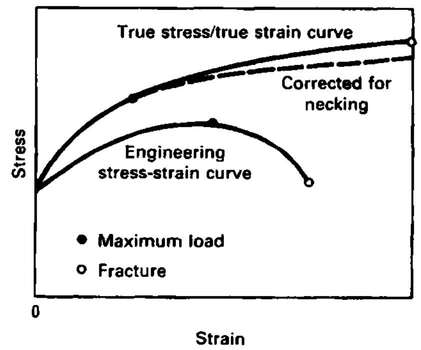

Fig. 7 Comparison of engineering and true-stress/true-strain curves

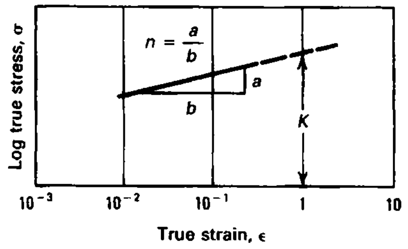

Fig. 8 Log-log plot of true-stress/true-strain curve. n is the strain-hardening exponent; K is the strength coefficient.

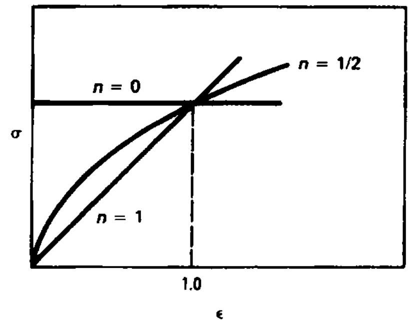

Fig. 9 Various forms of power curve $\sigma = K\varepsilon^n$

calculated from Eq 2. Frequently, the flow curve is linear from maximum load to fracture, while in other cases its slope continuously decreases to fracture. The formation of a necked region or mild notch introduces triaxial stresses that make it difficult to determine accurately the longitudinal tensile stress from the onset of necking until fracture occurs. This concept is discussed in greater detail in the section "Corrected Stress-Strain Curves" in this article. The following parameters usually are determined from the true-stress/true-strain curve.

The true stress at maximum load corresponds to the true tensile strength. For most materials, necking begins at maximum load at a value of strain where the true stress equals the slope of the flow curve. Let σ_u and ε_u denote the true stress and true strain at maximum load when the cross-sectional area of the specimen is A_u. From Eq 6 the engineering ultimate tensile strength can be defined as:

$$S_u = \frac{P_{max}}{A_0} \qquad \text{(Eq 16)}$$

and the true ultimate tensile strength is:

$$\sigma_u = \frac{P_{max}}{A_u} \qquad \text{(Eq 17)}$$

Eliminating P_{max} yields:

$$\sigma_u = S_u \frac{A_0}{A_u} \qquad \text{(Eq 18)}$$

and from Eq 15:

$$A_0/A = e^{\varepsilon} \qquad \text{(Eq 19)}$$

where e is the base of natural logarithm, so

$$\sigma_u = S_u e^{\varepsilon_u} \qquad \text{(Eq 20)}$$

The true fracture stress is the load at fracture divided by the cross-sectional area at fracture. This stress should be corrected for the triaxial state of stress existing in the tensile specimen at fracture. Because the data required for this correction frequently are not available, true fracture stress values are frequently in error.

The true fracture strain, ε_f, is the true strain based on the original area, A_0, and the area after fracture, A_f:

$$\varepsilon_f = \ln \frac{A_0}{A_f} \qquad \text{(Eq 21)}$$

This parameter represents the maximum true strain that the material can withstand before fracture and is analogous to the total strain to fracture of the engineering stress-strain curve. Because Eq 14 is not valid beyond the onset of necking, it is not possible to calculate ε_f from measured values of e_f. However, for cylindrical tensile specimens, the reduction in area, q, is related to the true fracture strain by:

$$\varepsilon_f = \ln \frac{1}{1-q} \qquad \text{(Eq 22)}$$

The true uniform strain, ε_u, is the true strain based only on the strain up to maximum load. It may be calculated from either the specimen cross-sectional area, A_u, or the gage length, L_u, at maximum load. Equation 15 may be used to convert conventional uniform strain to true uniform strain. The uniform strain frequently is useful in estimating the formability of metals from the results of a tension test:

$$\varepsilon_u = \ln \frac{A_0}{A_u} \qquad \text{(Eq 23)}$$

The true local necking strain, ε_n, is the strain required to deform the specimen from maximum load to fracture:

$$\varepsilon_n = \ln \frac{A_u}{A_f} \qquad \text{(Eq 24)}$$

Mathematical Expression of the Flow Curve. The flow curve of many metals in the region of uniform plastic deformation can be expressed by the simple power-curve relation:

$$\sigma = K\varepsilon^n \qquad \text{(Eq 25)}$$

where n is the strain-hardening exponent and K is the strength coefficient. A log-log plot of true stress and true strain up to maximum load will result in a straight line if Eq 25 is satisfied by the data (Fig. 8).

The linear slope of this line is n, and K is the true stress at $\varepsilon = 1.0$ (corresponds to $q = 0.63$). As shown in Fig. 9, the strain-hardening exponent may have values from $n = 0$ (perfectly plastic solid) to $n = 1$ (elastic solid). For most metals, n has values between 0.10 and 0.50 (see Table 2).

Table 2 Values for n and K for metals at room temperature

Metals	Condition	n	K MPa	K ksi	Ref
0.05% carbon steel	Annealed	0.26	530	77	12
SAE 4340 steel	Annealed	0.15	641	93	12
0.6% carbon steel	Quenched and tempered at 540 °C (1000 °F)	0.10	1572	228	13
0.6% carbon steel	Quenched and tempered at 705 °C (1300 °F)	0.19	1227	178	13
Copper	Annealed	0.54	320	46.4	12
70/30 brass	Annealed	0.49	896	130	13

The rate of strain hardening $d\sigma/d\varepsilon$ is not identical to the strain-hardening exponent. From the definition of n:

$$n = \frac{d\,(\log \sigma)}{d\,(\log \varepsilon)} = \frac{d\,(\ln \sigma)}{d\,(\ln \varepsilon)} = \frac{\varepsilon d\sigma}{\sigma d\varepsilon}$$

or

$$\frac{d_\sigma}{d_\varepsilon} = \frac{n\sigma}{\varepsilon} \qquad \text{(Eq 26)}$$

Deviations from Eq 25 frequently are observed, often at low strains (10^{-3}) or high strains ($\varepsilon = 1.0$). One common type of deviation is for a log-log plot of Eq 25 to result in two straight lines with different slopes. Sometimes data that do not plot according to Eq 25 will yield a straight line according to the relationship:

$$\sigma = K(\varepsilon_0 + \varepsilon)^n \qquad \text{(Eq 27)}$$

ε_0 can be considered to be the amount of strain hardening that the material received prior to the tension test (Ref 14). Another common variation on Eq 25 is the Ludwik equation:

$$\sigma = \sigma_0 + K\varepsilon^n \qquad \text{(Eq 28)}$$

where σ_0 is the yield stress, and K and n are the same constants as in Eq 25. This equation may be more satisfying than Eq 25, because the latter implies that at 0 true strain the stress is 0. It has been shown that σ_0 can be obtained from the intercept of the strain-hardening portion of the stress-strain curve and the elastic modulus line by (Ref 15):

$$\sigma_0 = \left(\frac{K}{E^n}\right)^{1/(1-n)} \qquad \text{(Eq 29)}$$

The true-stress/true-strain curve of metals such as austenitic stainless steel, which deviate markedly from Eq 25 at low strains (Ref 16), can be expressed by:

$$\sigma = K\varepsilon^n + e^{K_1} + e^{K_1}\, e^{n_1 \varepsilon} \qquad \text{(Eq 30)}$$

where e^{K_1} is approximately equal to the proportional limit, and n_1 is the slope of the deviation of stress from Eq 25 plotted against ε. Other expressions for the flow curve are available (Ref 17, 18).

The true strain term in Eq 25 to 28 properly should be the plastic strain,

$$\varepsilon_p = \varepsilon_{total} - \varepsilon_E$$

$$\varepsilon_p = \varepsilon_{total} - \frac{\sigma}{E} \qquad \text{(Eq 31)}$$

where ε_E represents elastic strain.

Graphically, this is shown on the engineering curve as a region of elastic elongation and a region of plastic elongation summed together to make the total elongation.

Instability in Tension. Necking generally begins at maximum load during the tensile deformation of ductile metal. An ideal plastic material in which no strain hardening occurs would become unstable in tension and begin to neck as soon as yielding occurred. However, an actual metal undergoes strain hardening, which tends to increase the load-carrying capacity of the specimen as deformation increases. This effect is opposed by the gradual decrease in the cross-sectional area of the specimen as it elongates. Necking or localized deformation begins at maximum load, where the increase in stress due to decrease in the cross-sectional area of the specimen becomes greater than the increase in the load-carrying ability of the metal due to strain hardening. This condition of instability leading to localized deformation is defined by the condition that P is at its maximum, $dP = 0$:

$$P = \sigma A \qquad \text{(Eq 32)}$$

$$dP = \sigma dA + A d\sigma = 0 \qquad \text{(Eq 33)}$$

From the constancy-of-volume relationship:

$$\frac{dL}{L} = -\frac{dA}{A} = d\varepsilon \qquad \text{(Eq 34)}$$

and from the instability condition (Eq 32):

$$-\frac{dA}{A} = \frac{d\sigma}{\sigma} \qquad \text{(Eq 35)}$$

so that at a point of tensile instability:

$$\frac{d\sigma}{d\varepsilon} = \sigma \qquad \text{(Eq 36)}$$

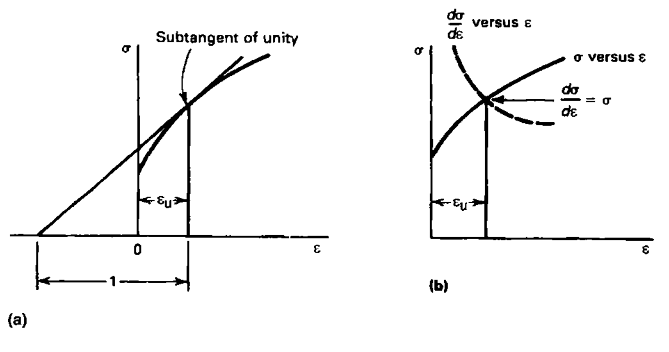

Fig. 10 Graphical interpretation of necking criterion. The point of necking at maximum load can be obtained from the true-stress/true-strain curve by finding (a) the point on the curve having a subtangent of unity or (b) the point where $d\sigma/d\varepsilon = \sigma$.

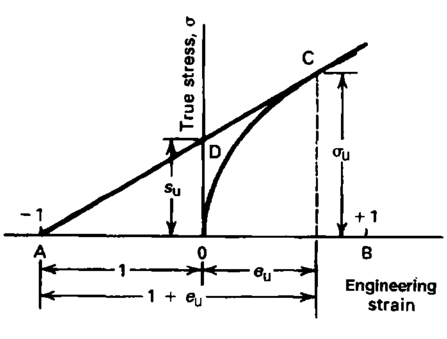

Fig. 11 Considére's construction for the determination of the point of maximum load. Source: Ref 19

Therefore, the point of necking at maximum load can be obtained from the true-stress/true-strain curve by finding the point on the curve having a subtangent of unity (Fig. 10a) or the point where the rate of strain hardening equals the stress (Fig. 10b). The necking criterion can be expressed more explicitly if engineering strain is used. Starting with Eq 36:

$$\frac{d\sigma}{d\varepsilon} = \frac{d\sigma}{de}\frac{de}{d\varepsilon} = \frac{d\sigma}{de}\frac{\frac{dL}{L_0}}{\frac{dL}{L}} = \frac{d\sigma}{de}\frac{L}{L_0} = \frac{d\sigma}{de}(1+e) = \sigma$$

$$\frac{d\sigma}{de} = \frac{\sigma}{1+e} \qquad \text{(Eq 37)}$$

Equation 37 permits an interesting geometrical construction for the determination of the point of maximum load (Ref 19). In Fig. 11, the stress-strain curve is plotted in terms of true stress against engineering strain. Let point A represent a negative strain of 1.0. A line drawn from point A, which is tangent to the stress-strain curve, will establish the point of maximum load, because according to Eq 37, the slope at this point is $\sigma/(1 + e)$.

By substituting the necking criterion given in Eq 36 into Eq 26, a simple relationship for the strain at which necking occurs is obtained. This strain is the true uniform strain, ε_u:

$$\varepsilon_u = n \qquad \text{(Eq 38)}$$

Although Eq 26 is based on the assumption that the flow curve is given by Eq 25, it has been shown that $\varepsilon_u = n$ does not depend on this power-law behavior (Ref 20).

Corrected Stress-Strain Curves

Stress Distribution at the Neck. The formation of a neck in the tensile specimen introduces a complex triaxial state of stress in that region. The necked region is in effect a mild notch. A notch under tension produces radial stress, σ_r, and transverse stress, σ_t, which raise the value of longitudinal stress required to cause the plastic flow. Therefore, the average true stress at the neck, which is determined by dividing the axial tensile load by the minimum cross-sectional area of the specimen at the neck, is higher than the stress that would be required to cause flow if simple tension prevailed.

Figure 12 illustrates the geometry at the necked region and the stresses developed by this localized deformation. R is the radius of curvature of the neck, which can be measured either by projecting the contour of the necked region on a screen or by using a tapered, conical radius gage.

Bridgman made a mathematical analysis that provides a correction to the average axial stress to compensate for the introduction of transverse stresses (Ref 21). This analysis was based on the following assumptions:

- The contour of the neck is approximated by the arc of a circle.
- The cross section of the necked region remains circular throughout the test.
- The von Mises criterion for yielding applies.
- The strains are constant over the cross section of the neck.

According to this analysis, the uniaxial flow stress corresponding to that which would exist in the tension test if necking had not introduced triaxial stresses is:

$$\sigma = \frac{(\sigma_x)_{avg}}{\left(1 + \frac{2R}{a}\right)\left[\ln\left(1 + \frac{a}{2R}\right)\right]} \qquad \text{(Eq 39)}$$

where $(\sigma_x)_{avg}$ is the measured stress in the axial direction (load divided by minimum cross section). Figure 7 shows how the application of the Bridgman correction changes the true-stress/true-strain curve. A correction for the triaxial stresses in the neck of a flat tensile specimen has been considered (Ref 22). The values of a/R needed for the analysis can be obtained either by straining a specimen a given amount beyond necking and unloading to measure a and R directly, or by measuring these parameters continuously past necking using photography or a tapered ring gage (Ref 23).

To avoid these measurements, Bridgman presented an empirical relation between a/R and the true strain in the neck. Figure 13 shows that this gives close agreement for steel specimens, but not for other metals with widely different necking strains. A much better correlation is obtained between the Bridgman correction and the true strain in the neck minus the true strain at necking, ε_u (Ref 25).

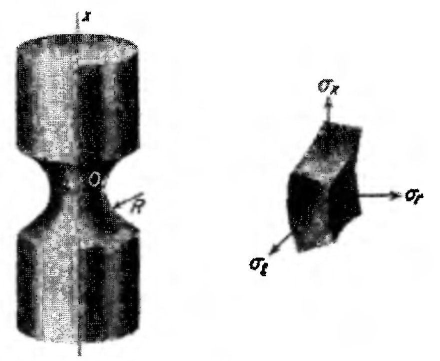

Fig. 12 Stress distribution at the neck of a tensile specimen. (a) Geometry of necked region. R is the radius of curvature of the neck; a is the minimum radius at the neck. (b) Stresses acting on element at point O. σ_x is the stress in the axial direction; σ_r is the radial stress; σ_t is the transverse stress.

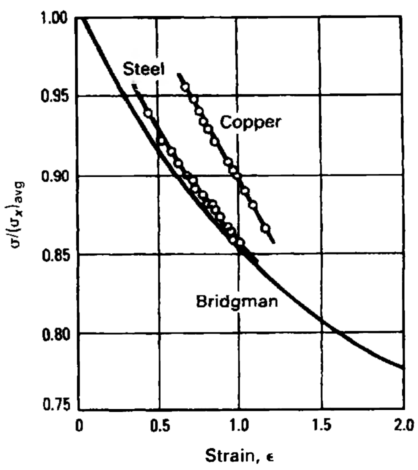

Fig. 13 Relationship between Bridgman correction factor $\sigma/(\sigma_x)_{avg}$ and true tensile strain. Source: Ref 24

Ductility

Ductility Measurement in Tension Testing. The measured elongation from a tension specimen depends on the gage length of the specimen or the dimensions of its cross section. This is because the total extension consists of two components: the uniform extension up to necking and the localized extension once necking begins (Fig. 1). The extent of uniform extension depends on the metallurgical condition of the material (through ε_n) and the effect of specimen size and shape on the development of the neck.

The shorter the gage length, the greater the influence of localized deformation at the neck on the total elongation of the gage length. The extension of a specimen at fracture can be expressed by:

$$L_f - L_0 = \alpha + e_u L_0 \qquad \text{(Eq 40)}$$

where α is the local necking extension and $e_u L_0$ is the uniform extension. The tensile elongation is then:

$$e_f = \frac{L_f - L_0}{L_0} = \frac{\alpha}{L_0} + e_u \qquad \text{(Eq 41)}$$

This clearly indicates that the total elongation is a function of the specimen gage length. The shorter the gage length, the greater the percent elongation.

Numerous attempts have been made to rationalize the strain distribution in the tension test. Perhaps the most general conclusion that can be drawn is that geometrically similar specimens develop geometrically similar necked regions.

Further details on the necking phenomenon can be found in the article "Mechanical Behavior under Tensile and Compressive Loads" in *Mechanical Testing and Evaluation,* Volume 8 of the *ASM Handbook* (Ref 26).

Notch Tensile Test. Ductility measurements on standard smooth tensile specimens do not always reveal metallurgical or environmental changes that lead to reduced local ductility. The tendency for reduced ductility in the presence of a triaxial stress field and steep stress gradients (such as a rise at a notch) is called notch sensitivity. A common way of evaluating notch sensitivity is a tension test using a notched specimen.

Compression Testing

The compression test consists of deforming a cylindrical specimen to produce a shorter cylinder of larger diameter (upsetting). The compression test is a convenient method for determining the stress-strain response of materials at large strains ($\varepsilon > 0.5$) because the test is not subject to the instability of necking that occurs in a tension test. Also, it may be convenient to use the compression test because the specimen is relatively easy to make, and it does not require a large amount of material. The compression test is frequently used in conjunction with evaluating the workability of materials, especially at elevated temperature, because most deformation processes, such as forging, have a high component of compressive stress. The test is also used with brittle materials, which are difficult to machine into test specimens and difficult to tensile test in perfect alignment.

There are two inherent difficulties with the compression test that must be overcome by the test technique: buckling of the specimen and barreling of the specimen. Both conditions cause nonuniform stress and strain distributions in the specimen that make it difficult to analyze the results.

Buckling is a mode of failure characterized by an unstable lateral material deflection caused by compressive stresses. Buckling is controlled by selecting a specimen geometry with a low length-to-diameter ratio. *L/D* should be less than 2, and a compression specimen with *L/D* = 1 is often used. It also is important to have a very well-aligned load train and to ensure that the end faces of the specimen are parallel and perpendicular to the load axis (Ref 27). Often a special alignment fixture is used with the testing machine to ensure an accurate load path (Ref 28).

Barreling is the generation of a convex surface on the exterior of a cylinder that is deformed in compression. The cross section of such a specimen is barrel shaped. Barreling is caused by the friction between the end faces of the compression specimen and the anvils that apply the load. As the cylinder decreases in height (h), it wants to increase in diameter (D) because the volume of an incompressible material must remain constant:

$$\frac{\pi D_1^2 h_1}{4} = \frac{D_2^2 h_2}{4} \qquad \text{(Eq 42)}$$

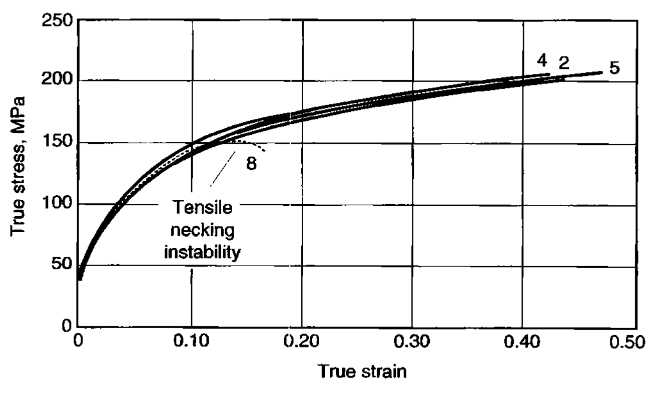

Fig. 14 Comparison of true stress-true strain curves in tension and compression (various lubricant conditions) for Al-2Mg alloy. Curve 2, Molykote spray; curve 4, boron nitride + alcohol; curve 5, Teflon + Molykote spray; curve 8, tensile test. Source: Ref 30

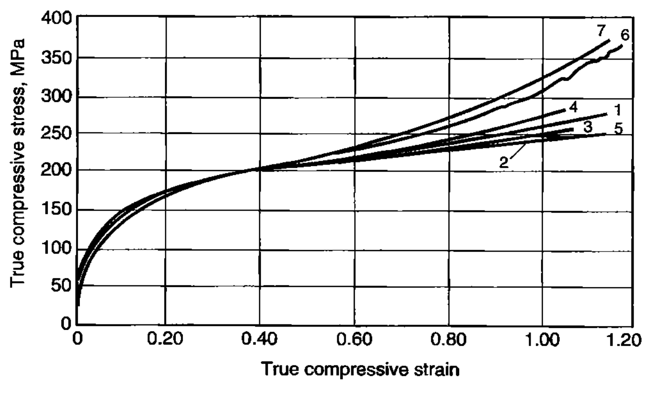

Fig. 15 Flow curves for Al-2Mg alloy tested in compression for various lubricant conditions out to $\varepsilon \approx 1.0$. Curve 1, molygrease; curve 2, Molykote spray; curve 3, boron-nitride spray; curve 4, boron-nitride and alcohol; curve 5, Teflon and Molykote spray; curve 6, polished dry anvils; curve 7, grooved anvils. Source: Ref 30

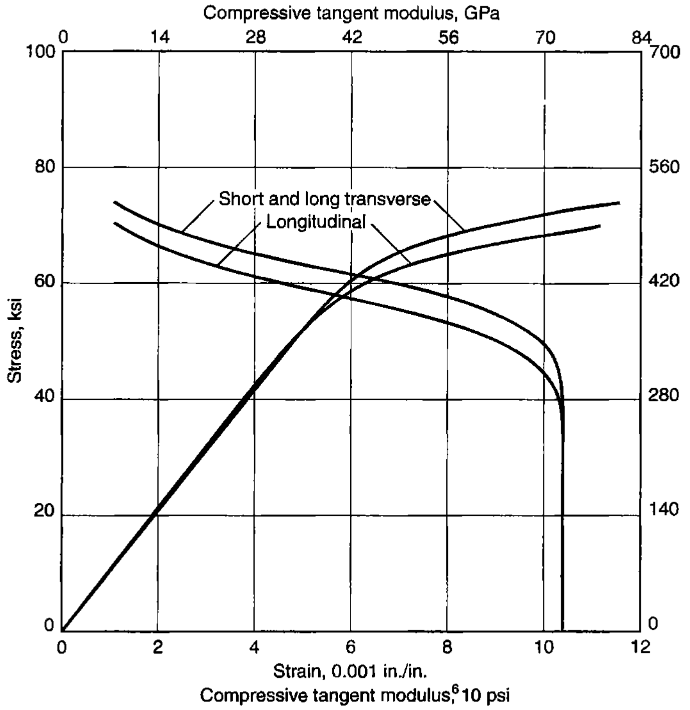

Fig. 16 Curve combining compressive stress-strain with compressive tangent modulus

As the material spreads outward over the anvils, it is restrained by the friction at this interface. The material near the midheight position is less restrained by friction and spreads laterally to the greatest extent. The material next to the anvil surfaces is restrained from spreading the most; thus, the creation of a barreled profile. This deformation pattern also leads to the development of a region of relatively undeformed materials under the anvil surfaces.

This deformation behavior clearly means that the stress state is not uniform axial compression. In addition to the axial compressive stress, a circumferential tensile stress develops as the specimen barrels (Ref 29). Because barreling increases with the specimen ratio D/h, the force to deform a compression cylinder increases with D/h.

Calculation of Compressive Stress and Strain. The calculation of stress and strain for the compression test is based on developing a test condition that minimizes friction (and barreling) and assumes the stress state is axial compression. When friction can be neglected, the uniaxial compressive stress (flow stress) is related to the deformation force P by:

$$\sigma_f = \frac{P}{A} = \frac{4P}{\pi D^2} = \frac{4Ph_2}{\pi D_1^2 h_1} \qquad \text{(Eq 43)}$$

where the last term is obtained by substituting from Eq 42. In Eq 43, subscript 1 refers to the initial values of D and h, while subscript 2 refers to conditions at some subsequent value of specimen height, h. Equation 43 shows that the flow stress can be obtained directly from the load P and the instantaneous height (h_2), provided that friction can be neglected.

The true strain in the compression test is given by:

$$\varepsilon = \ln\left(\frac{h_1}{h_2}\right) = 2\ln\left(\frac{D_1}{D_2}\right) \qquad \text{(Eq 44)}$$

where either the displacement of the anvil or the diameter of the specimen can be used, whichever is more convenient.

Minimizing barreling of the compression specimen can be accomplished by minimizing friction between the ends of the specimen and the anvils. This is done by using an effective lubricant and machining concentric rings on the end of the specimen to retain the lubricant and keep it from being squeezed out. An extensive series of tests have shown what works best (Ref 30).

Figure 14 shows the true stress-true strain curve (flow curve) for an annealed Al-2Mg alloy. Stress and strain were calculated as described in the previous section. Note how the flow curve in compression agrees with that determined in a tensile test and how the compressive curves extend to much larger strains because there is no specimen necking. Figure 15 extends the strain over double the range of Fig. 14. Note that once beyond $\varepsilon > 0.5$, the curves begin to diverge depending on the effectiveness of the lubrication. The highest curve (greatest deviation from uniaxial stress) is for grooved anvils (platens) that dig in and prevent sidewise flow. The least friction is for the condition where a Teflon (E.I. DuPont de Nemours & Co., Inc., Wilmington, DE) film sprayed with Molykote (Dow Corning Corporation, Midland, MI) is placed between the anvil and the specimen.

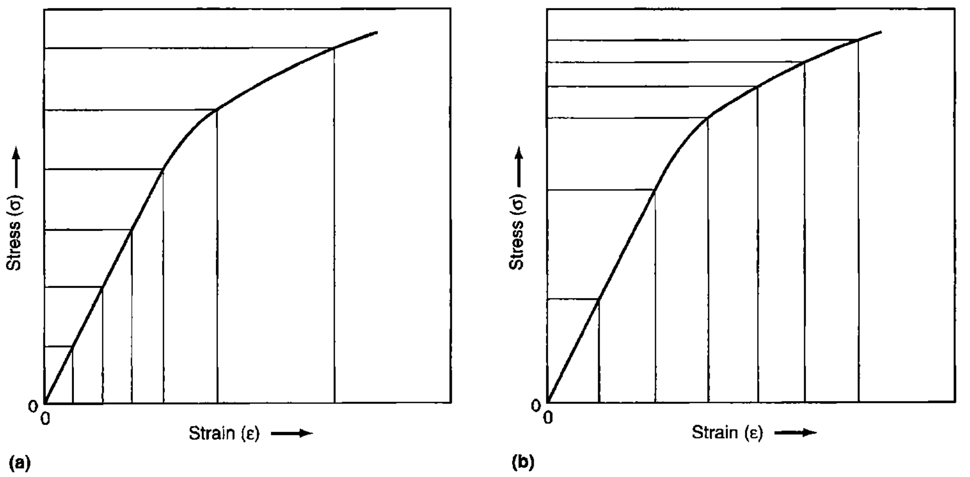

Fig. 17 Differences between constant stress increments and constant strain increments. (a) Equal stress increments result in strains of increasing increments. (b) Equal strain increments result in decreasing stress increments.

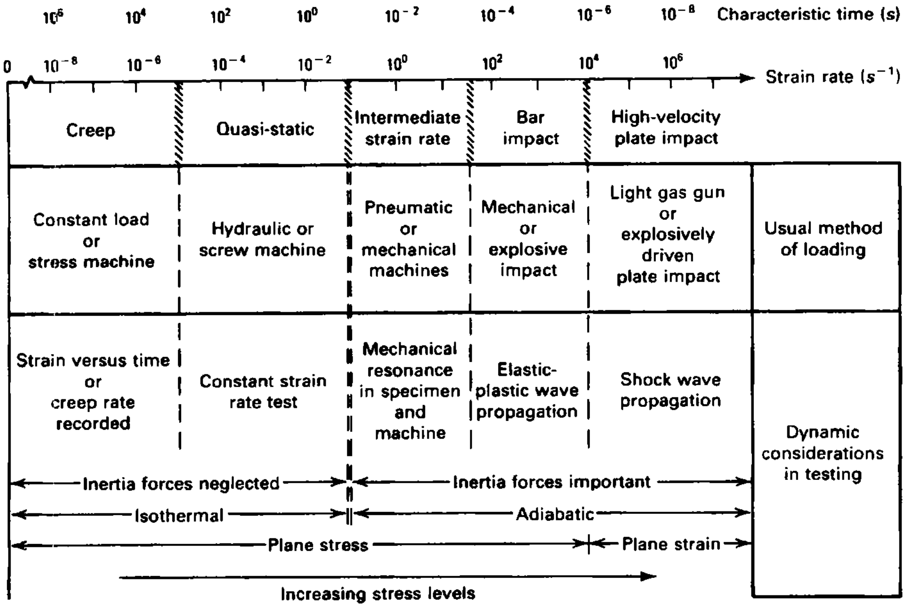

Fig. 18 Strain-rate ranges and associated experimental equipment, conditions, and consequences

Essentially no barreling occurs in room-temperature compression tests when Teflon film is placed between the anvil and the end of the specimen. Because the film will eventually tear, it is necessary to run the test incrementally and replace the film when an electrical signal indicates that there is no longer a continuous film.

Obviously, the need to run the test incrementally is inconvenient. A series of single-increment compression tests on a range of materials with strain-hardening exponents from $n = 0.08$ to 0.49 showed that lubricant conditions do not become significant until $\varepsilon > 0.5$ so long as $n > 0.15$. For strains $\varepsilon \leq 1.0$, a grooved specimen with molybdenum disulfide (MoS_2) grease lubricant gave consistently good results. Nearly as good results are achieved with smooth anvils and a spray coat of MoS_2 (Ref 30).

Another approach to minimize the effects of barreling is to remachine the specimens to their original diameter after some degree of deformation. This is costly and inconvenient and adds uncertainties to the results. For additional details on compression testing, see the article "Uniaxial Compression Testing" in *Mechanical Testing and Evaluation,* Volume 8 of the *ASM Handbook.*

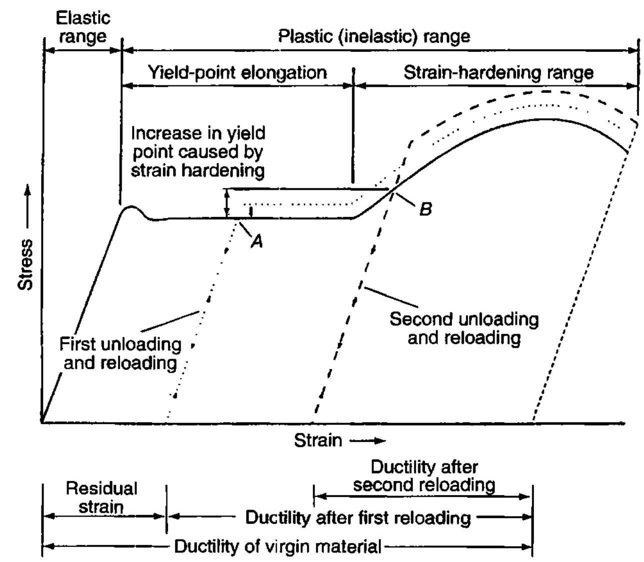

Fig. 19 Effects of prior tensile loading on stress-strain behavior; the graph is not to scale. The solid line represents the behavior of a virgin piece. The dotted line is a specimen that has been unloaded at A and then reloaded. The dashed line represents a second unloading at B. In each case the stress is based on the cross-sectional area of the specimen measured after the unloading.

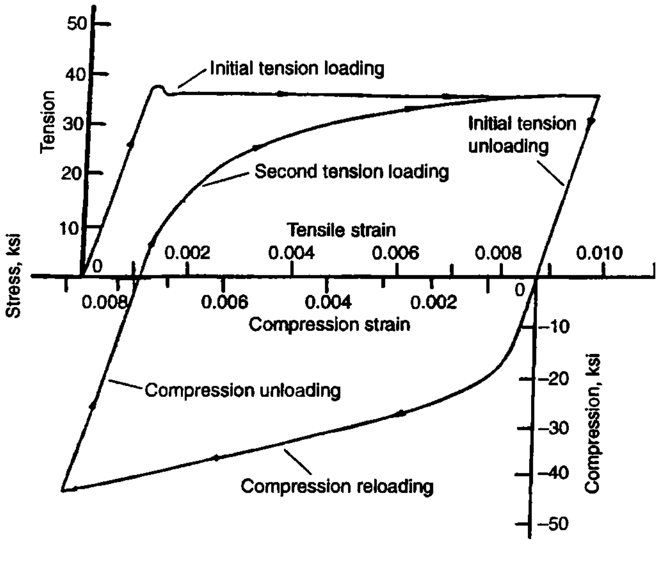

Fig. 20 An example of the Bauschinger effect and hysteresis loop in tension-compression-tension loading. The initial tension loading is to about 0.001 strain, followed by compression again to 0.001 strain.

Tangent Modulus Curves

The tangent modulus, E_t, is the slope of the stress-strain curve at any point on the curve.

$$E_t = \frac{dS}{de} \qquad \text{(Eq 45)}$$

Below the proportionality limit, E_t has the same value as E.

Figure 10 has a construction of $E_t = 1$ at the point where the strain was ε_u. The slope has the same units as the stress.

Many of the curves in the *Atlas* have the plot of the tangent modulus superimposed on the stress-strain curve. These curves have dual units along the x-axis, one set for strain and one set for E_t. Figure 16 is an example. The modulus of elasticity can be visually estimated on the linear segment of the stress-strain curve as slightly more than 280 MPa/4 $\times$ 0.001 = 70,000 MPa or 70 GPa (40 ksi/4 $\times$ 0.001 = 10,000 ksi, or 10 $\times$ 10^6 psi). This corresponds to the constant value (vertical line) on the tangent modulus curves up to the proportionality limit. At higher stress, the stress-strain curves flatten and the tangent modulus curves decrease in value.

Torsional Testing

Torsion tests can be carried out on most materials to determine mechanical properties such as modulus of elasticity in shear, shear yield strength, ultimate shear strength, modulus of rupture in shear, and ductility. The torsion test can also be conducted on full-size parts (shafts, axles, and pipes) and structures (beams and frames) to determine their response to torsional loading. In torsion testing, unlike tensile testing and compression testing, large strains can be applied before plastic instability occurs, and complications due to friction between the test specimen and dies do not arise.

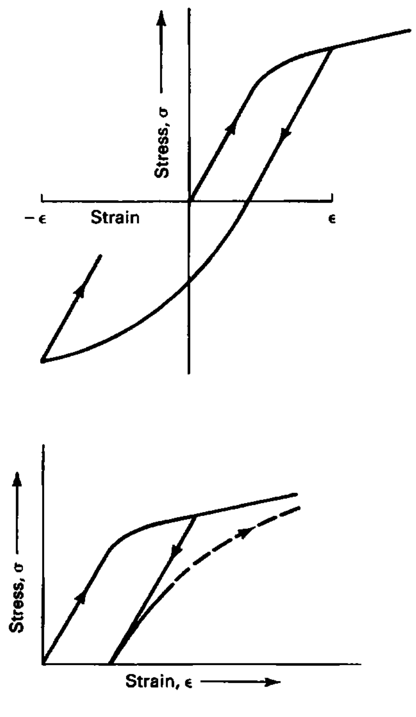

Fig. 21 Two types of hysteresis stress-strain loops resulting from Bauschinger effect in titanium alloys

Torsion tests are most frequently carried out on prismatic bars of circular cross section by applying a torsional moment about the longitudinal axis. The shear stress versus shear strain curve can be determined from simultaneous measurements of the torque and angle of twist of the test specimen over a predetermined gage length.

When converted from torque (in units of newton-meters or inch-pounds) and angular displacement (in degrees or radians) torsional stress-strain has the same units as engineering stress-strain, but the variance from "true" stress-strain is typically much less. On a cylindrical specimen that does not buckle, the difference is 5% or less from engineering to "true" stress-strain, even in the plastic (nonlinear) range.

There is evidence that torsion testing of hollow tubes is one of the better ways to determine the effects of strain, strain rate, and temperature on the flow stress of materials over the range of these variables usually encountered in the metal working process. Details on torsional testing and analysis can be found in the articles "Fundamental Aspects of Torsional Loading" and "Shear, Torsion, and Multiaxial Testing" in *Mechanical Testing and Evaluation*, Volume 8 of *ASM Handbook.*

Mechanical Testing Details

For credibility and repeatability, tests that are the basis of the stress-strain curves are conducted in accordance with some industry, national, or multinational standard. In the *Atlas,* when the source documentation cites a standard, it is so indicated in the caption. These standards provide insight to interpret the data.

Details of testing methods are found in *Mechanical Testing and Evaluation,* Volume 8 of *ASM Handbook.* Pertinent articles include:

- "Testing Machines and Strain Sensors"
- "Accreditation of Mechanical Testing Laboratories"
- "Mechanical Behavior under Tensile and Compressive Loads"
- "Stress-Strain Behavior in Bending"
- "Bend Testing"
- "Fundamental Aspects of Torsional Loading"
- "Uniaxial Tension Testing"
- "Uniaxial Compression Testing"
- "Hot Tension and Compression Testing"
- "Tension and Compression Testing at Low Temperatures"
- "Shear, Torsion, and Multiaxial Testing"

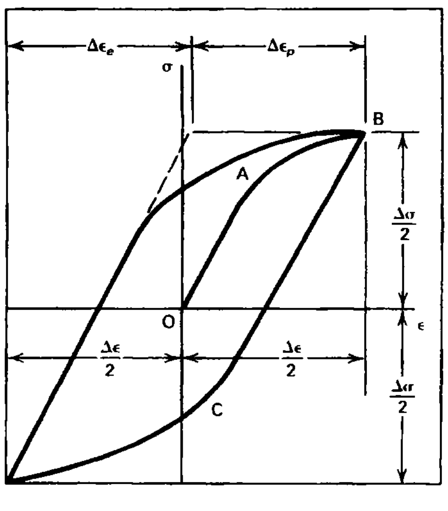

Fig. 22 Stress-strain loop for constant-strain cycling

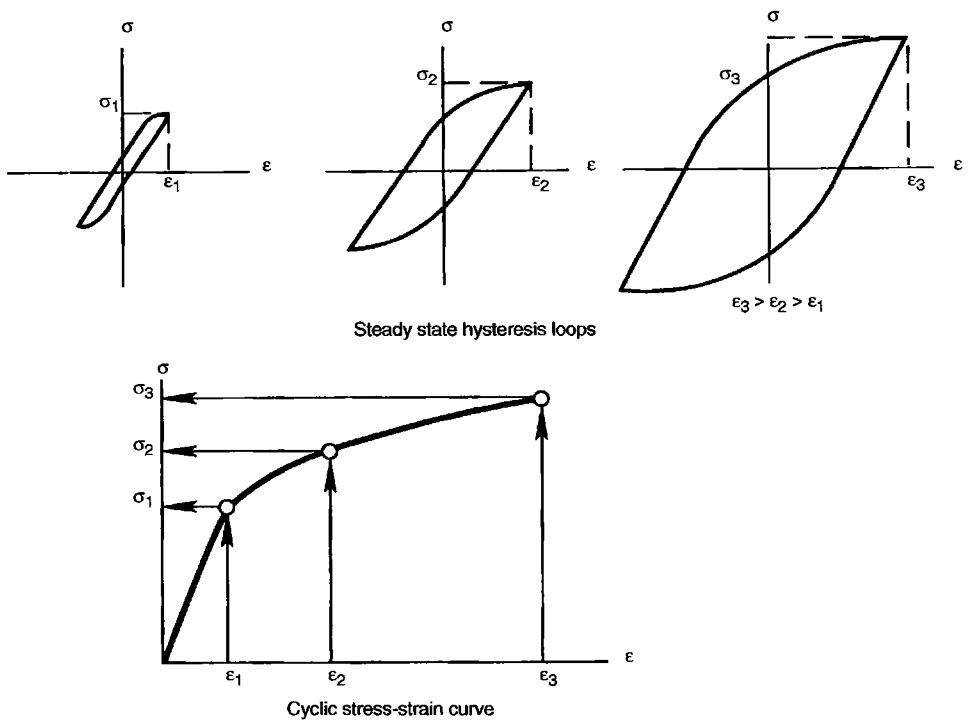

Fig. 23 Construction of cyclic stress-strain curve by joining tips of stabilized hysteresis loops

Test Variables

The condition of the test environment, composition, conditioning, size, shape, and history of the specimen are among the factors affecting the stress-strain data. These parameters are given to the extent that they are available.

Test Temperature. Relative to room-temperature (RT) tests, most materials become stronger, but less ductile, at lower temperatures, and more ductile, but weaker, at higher temperatures. There are anomalous behaviors such as blue brittleness. Carbon steels generally exhibit an increase in strength and a reduction of ductility and toughness at temperatures around 300 °C (570 °F). Because such temperatures produce a bluish temper color on the surface of the specimen, this problem has been called blue brittleness. Typically, brittleness is associated with cold-temperature behavior.

Speed of Test. ASTM E 8 (Ref 31) lists five ways of defining the speed of the test:

- Rate of straining the specimen, de/dt
- Rate of stressing the specimen, dS/dt
- Rate of the separation of the test machine heads during the test
- Elapsed time for completing part or all of the test
- Free-running cross-head speed (speed of machine heads when unloaded)

Strain Rate. Average strain rates for most tension tests range between 10^{-2} and 10^{-5} s^{-1}. Greater strain rates (10^{-1} and 10^{2} s^{-1}) are considered dynamic tests. For a specimen of initial gage length L_0 and deformed length L, the specific deformation rate is:

$$\frac{de}{dt} = \frac{1}{L_0}\frac{d(L - L_0)}{dt} \quad \text{(Eq 46)}$$

If the deformation occurs homogeneously throughout the specimen, then the specific deformation rate corresponds everywhere to the strain rate. However, if the deformation is nonhomogeneous, then the strain (and strain rate) varies the specimen length, and the specific deformation rate represents the spatial average strain rate. A well-known example of nonhomogeneous deformation is the propagation of deformation bands called Lüders bands.

Stress Rate. Figure 17 illustrates the differences in curves constructed from constant stress increments and constant strain increments.

Slow Speeds. Under relatively slow straining, most materials are assumed to transfer the heat generated by plastic deformation to their surroundings; that is, the straining is assumed to be isothermal (no change of temperature). The degree to which slow tension tests remain truly isothermal has been investigated (Ref 32). The flow stress, which is the uniaxial stress needed to continue plastic deformation of the material at a given stage of a test, is then assumed to depend only on strain and strain rate.

The strain-hardening parameter n has been defined. From Eq 26:

$$n = \frac{\varepsilon}{\sigma}\frac{d\sigma}{d\varepsilon} \quad \text{(Eq 47)}$$

In an analogous manner, the strain-rate sensitivity parameter m can be defined as:

$$m = \frac{\dot{\varepsilon}}{\sigma}\frac{d\sigma}{d\dot{\varepsilon}} \quad \text{(Eq 48)}$$

Both n and m are functions of strain and strain rate. m can be negative under some conditions. However, average values frequently are selected for these parameters, which are then treated as constants.

Values of n usually are between 0.1 and 0.5 for metals; they are determined from, but not identical to, strain-hardening rates. Values of

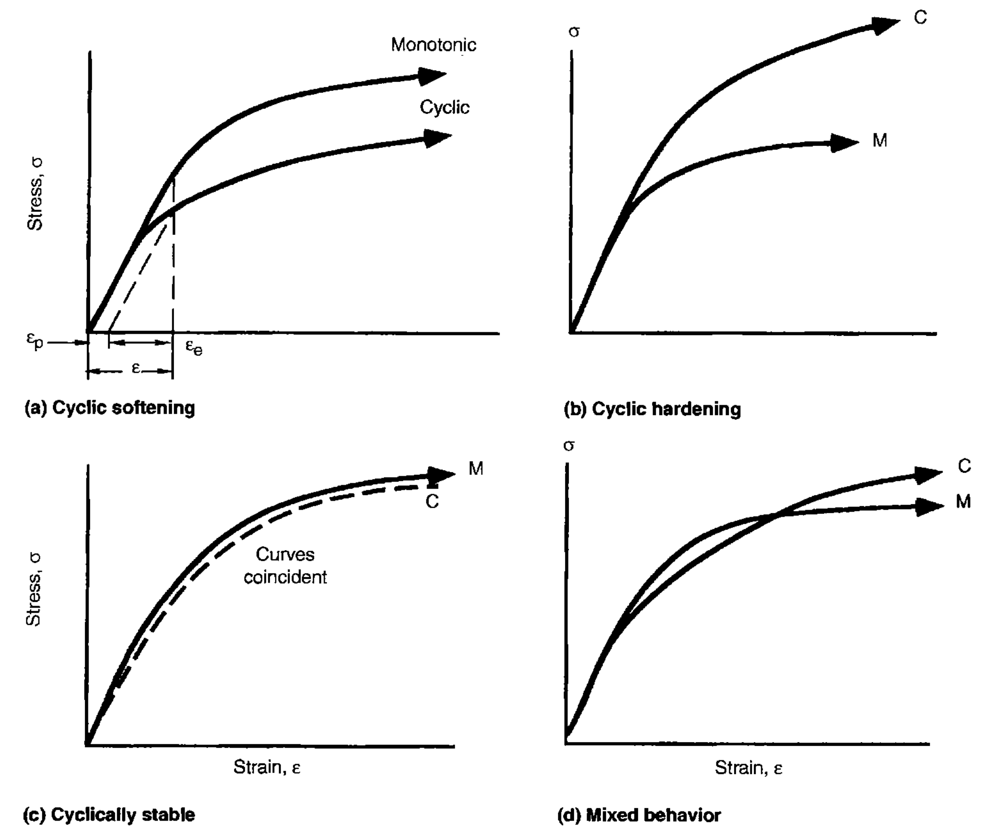

Fig. 24 Examples of various types of cyclic stress-strain

m for metals are usually much smaller than the corresponding *n* values ($m < 0.1$). *m* does increase with temperature. However, fine-grained metals have relatively large rate-sensitivity parameters ($m > 0.1$) under specific deformation conditions. Under such conditions, these materials can be deformed to extremely large strains and are called superplastic metals.

High Rate Testing. For extremely high rates of testing, it is commonly assumed that deformation occurs under adiabatic (no heat transfer) conditions. Plastic work is mostly (about 90%) converted to heat. The remainder is inelastically stored as changes in defect structure. In high-speed tests, this heat raises the temperature of the material. Consequently, the material properties are changed. This is another major complication in analyses of high-speed tests.

Consequences of testing over a wide spectrum of strain rates are summarized in Fig. 18 (Ref 33).

Hysteresis. If a specimen is loaded past its yield point and then unloaded, or loaded in reverse, subsequent testing on the specimen would result in a different pattern of behavior. Figure 19 shows this effect. The specimen is loaded initially to point A. The solid line represents the behavior of the virgin sample. If instead, the sample were unloaded at point A, the path of unloading is parallel to the initial load path (dotted line). There is some permanent deformation (residual strain), and the area is redetermined as A_2. When reloaded, the dotted line is retraced and the yield point is now higher due to strain hardening. If this unloading and reloading were done again at point B, the dashed line indicates the behavior.

Figure 19 illustrates the effect of stopping and restarting a test. It also points to a consideration when a test sample is machined from a failed part. If the testpiece were subjected to deformation prior to the failure, the properties obtained from the test should not be equated to the original material properties (Ref 34).

If the prior history of the test specimen includes compression, a hysteresis is present, know as the Bauschinger effect. This is illustrated in Fig. 20. The initial tensile loading is to about 1% strain. The specimen is unloaded and reloaded in compression to 1% strain (measured on the second scale on the *x*-axis). On unloading and reloading in tension, the shape of the stress-strain curve is significantly different than the original. Again the prior deformation of a test sample will affect its behavior (Ref 34). Figure 21 shows the two types of hysteresis possible in titanium alloys, one with load reversal, and one with load application, rest, and reapplication.

Nature of Loading. Figure 22 illustrates a stress-strain loop under controlled constant-strain cycling in a low-cycle fatigue test. During initial loading, the stress-strain curve is O-A-B, with yielding beginning about A. Upon unloading, yielding begins in compression at a lower stress C due to the Bauschinger effect. In reloading in tension, a hysteresis loop develops. The dimensions of this loop are described by its width $\Delta\varepsilon$ (the total strain range) and its height $\Delta\sigma$ (the stress range). The total strain range $\Delta\varepsilon$ consists of an elastic strain component $\Delta\varepsilon_e = \Delta\sigma/E$ and a plastic strain component $\Delta\varepsilon_p$. The width of the hysteresis loop depends on the level of cyclic strain. When the level of cyclic strain is small, the hysteresis loop becomes very narrow. For tests conducted under constant $\Delta\varepsilon$, the stress range $\Delta\sigma$ usually changes with an increasing number of cycles. Annealed materials undergo cyclic strain hardening so that $\Delta\sigma$ increases with the number of cycles and then levels off after about 100 strain cycles. The larger the value of $\Delta\varepsilon$, the greater the increase in stress range. Materials that are initially cold

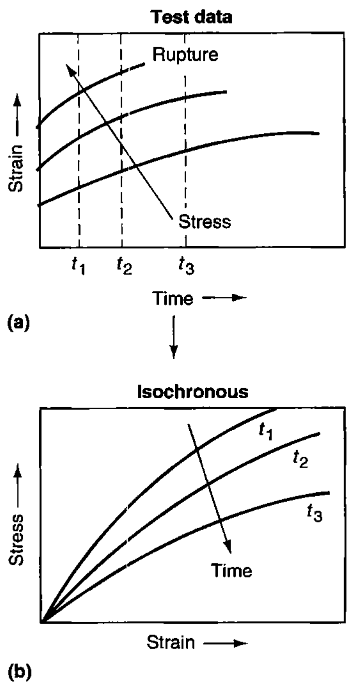

Fig. 25 Creep data (a) transferred to isochronous stress-strain curve (b)

worked undergo cyclic strain softening so that $\Delta\sigma$ decreases with increasing number of strain cycles. Thus, through cyclic hardening and softening, some intermediate strength level is attained that represents a steady-state condition (in which case the stress required to enforce the controlled strain does not vary significantly).

Monotonic. Some metals are cyclically stable, in which case their monotonic stress-strain behavior adequately describes their cyclic response.

Cyclic. For other materials the steady-state condition is usually achieved in about 20 to 40% of the total fatigue life in either hardening or softening materials. The cyclic behavior of metals is best described in terms of a stress-strain hysteresis loop, as illustrated in Fig. 22.

Changes in stress response of a metal occur relatively rapidly during the first several percent of the total reversals to failure. The metal, under controlled-strain amplitude, will eventually attain a steady-state stress response.

Now, to construct a cyclic stress-strain curve, one simply connects the locus of the points that represent the tips of the stabilized hysteresis loops from comparison specimen tests at several controlled-strain amplitudes (see Fig. 23).

In the particular example shown in Fig. 23, it was presumed that three companion specimens were tested to failure, at three different controlled-strain amplitudes. Failure of a specimen is defined, typically, as complete separation into two distinct pieces. Generally, the diameter of specimens are approximately 6 to 10 mm (0.25 to 0.375 in.). In actuality, there is a "propagation" period included in this definition of failure. Other definitions of failure appear in ASTM E 60.

The steady-state stress response, measured at approximately 50% of the life to failure, is thereby obtained. These stress values are then plotted at the appropriate strain levels to obtain the cyclic stress-strain curve. One would typically test approximately ten or more companion specimens. The cyclic stress-strain curve can be compared directly to the monotonic or tensile stress-strain curve to quantitatively assess cyclically induced changes in mechanical behavior. This is illustrated in Fig. 24. Note that 50% may not always be the life fraction where steady-state response is attained. Often it is left to the discretion of the interpreter as to where the steady-state cyclic stress-strain occurs. In any event, the criteria should be noted on the cyclic stress-strain curve for the material being tested (Ref 35).

The article "Fundamentals of Modern Fatigue Analysis for the Design" in *Fatigue and Fracture,* Volume 19 of *ASM Handbook* (Ref 35), provides more details on cyclic behavior of metals and was the basis for this section.

Isochronous Curves

Isochronous curves are included in this *Atlas,* although they are not simply stress-strain curves. The parameter of time is added to them. Mechanical tests can be performed as short-time static tests or long-term creep deformation tests. Data from the long-term tests are recorded as sets of strain as a function of time for different loads (stresses) for a given temperature. As the stress increases, this time to rupture is less as seen in Fig. 25(a). Collections of these data can be analyzed by holding one of the three variables (time, stress, and strain constant). From Fig. 25(a) (where stress is constant on each curve), values at constant time can be found in effect by constructing a vertical line, perpendicular to the time axis, that intersects the family of curves. Values at the intersection points form sets of stresses and strains at constant time that can be plotted on a linear coordinate system at these selected times to make the isochronous curves (Fig. 25b). These families of curves are plotted at a given temperature, since temperature is so significant to the creep behavior of an alloy.

Guide to the Curves in the Atlas

As much of the information about the test specimens that is available in the source and that is able to be abstracted in the caption is given with the curves that follow. The prime sources of all curves is given so further details may be gathered.

Parameters affecting the stress-strain behavior are:

- *Composition.* The compositions listed are intended as a guide to alloy identification. Nominal compositions have been added for this purpose, so this information is not necessarily from the source of the curve. If a more precise composition is given (listed to tenths or hundredths of a percent) in the source, this has been used.
- *Heat treatment and conditioning* are given in the style common to the alloy group. Temperature conversions are approximate.
- *Strain Rate of Test.* In some cases, the speed of the test head is given, which differs from the strain rate.
- *Temperature* of the test specimen is sometimes specified as being held for a set time prior to the test. Other times it is given in the source without qualification. At cryogenic temperatures, the stress-strain behavior of pure copper, brasses, bronzes, austenitic stainless steels, and some aluminum alloys exhibits a discontinuous yielding, and the curve appears serrated. Such behavior is indicated in the *Atlas* using a shaded envelope.
- *Orientation.* The orientation of the specimen relative to rolling or extruding direction is illustrated in Fig. 26 (Ref 36).
- *Specimen size and shape information* is provided to the extent found in the source documentation.

Units and Unit Conversions. The units on the left side and bottom of the curve are the units of the source document. The conversion of strain units on the curves is 1 ksi = 7 MPa. This conversion is used so that a common grid can be used. The more precise conversion is 1 ksi

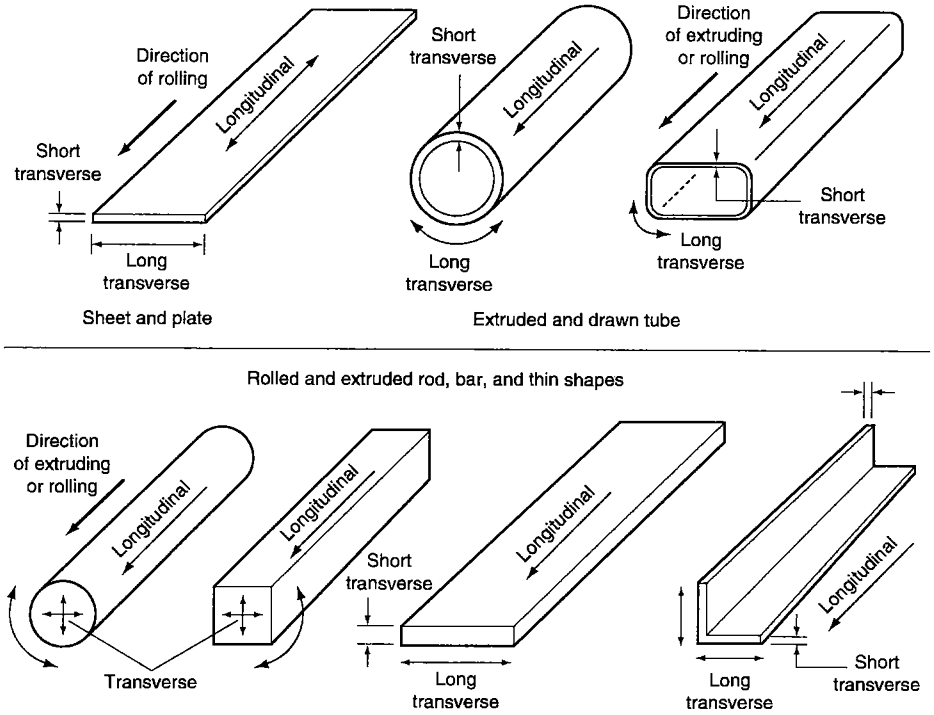

Fig. 26 Grain orientation in standard wrought forms of alloys. Source: Ref 36

= 6.894757 MPa. The converted stress in MPa can be multiplied by the correction factor of 6.894757/7.000000 = 0.98497 to obtain a more precise conversion.

Ramberg-Osgood Parameters. The Ramberg-Osgood Method is a method of modeling stress-strain curves. An equation (ideally a simple one) for the stress-strain curve is necessary for finding a quantitative expression for the available energy in fracture studies. The Ramberg-Osgood equation is useful:

$$\varepsilon = \frac{\sigma}{E} + \frac{\sigma^n}{F} \quad \text{(Eq 49)}$$

where n is (unfortunately) called the strain-hardening exponent and F is called the nonlinear modulus. This is said to be unfortunate because n is already commonly called the strain-hardening exponent (Eq 25), where it is, in fact the exponent of the strain. The Ramberg-Osgood parameter, n, is the reciprocal of the other n. The two can usually be distinguished by their values. The Ramberg-Osgood parameter, n, usually is between 2 and 40.

Equation 49 separates the total strain into a linear and a nonlinear part:

$$\varepsilon = \varepsilon_{\text{elastic}} + \varepsilon_{\text{plastic}} \quad \text{(Eq 50)}$$

There are other forms of the Ramberg-Osgood equation.

The total strain energy in a body (per unit thickness) equals the area under the load-displacement curve. The energy under the linear part of the stress-strain curves is discussed in the section "Resilience" in this article.

For applications where margins against ductile fracture must be quantified or where components are subjected to large plastic strains, elastic-plastic J-integral methods can be used to predict fracture conditions. Calculation of applied J values for cracked components requires knowledge of the strain-hardening capacity of the material in terms of the Ramberg-Osgood strain-hardening relationship.

MIL-HDBK-5, 1998 (Ref 37) presents an explanation of the method and uses the following expression for $\varepsilon_{\text{plastic}}$:

$$\varepsilon_{\text{plastic}} = 0.002(\sigma/\sigma_{0.2\text{YP}})^n \quad \text{(Eq 51)}$$

It further explains how material behavior can be modeled for computer codes using, E, n, and $\sigma_{0.2\text{YP}}$ where the exponential relationship is applicable.

Terms

Terms common to discussion of stress-strain curves, tensile testing, and material behavior under test included here (Ref 1, 2).

accuracy. (1) The agreement or correspondence between an experimentally determined value and an accepted reference value for the material undergoing testing. The reference value may be established by an accepted standard (such as those established by ASTM), or in some cases the average value obtained by applying the test method to all the sampling units in a lot or batch of the material may be used. (2) The extent to which the result of a calculation or the reading of an instrument approaches the true value of the calculated or measured quantity.

axial strain. Increase (or decrease) in length resulting from a stress acting parallel to the longitudinal axis of the specimen.

Bauschinger effect. The phenomenon by which plastic deformation increases yield strength in the direction of plastic flow and decreases it in other directions.

breaking stress. See *rupture stress.*

brittleness. A material characteristic in which there is little or no plastic (permanent) deformation prior to fracture.

chord modulus. The slope of the chord drawn between any two specific points on a stress-strain curve. See also *modulus of elasticity.*

compressive strength. The maximum compressive stress a material is capable of developing. With a brittle material that fails in compression by fracturing, the compressive strength has a definite value. In the case of ductile, malleable, or semiviscous materials (which do not fail in compression by a shattering fracture), the value obtained for compressive strength is an arbitrary value dependent on the degree of distortion that is regarded as effective failure of the material.

compressive stress, S_c. A stress that causes an elastic body to deform (shorten) in the direction of the applied load. Contrast with *tensile stress.*

creep. Time-dependent strain occurring under stress. The creep strain occurring at a diminishing rate is called primary or transient creep; that occurring at a minimum and almost constant rate, secondary or steady-rate creep; that occurring at an accelerating rate, tertiary creep.

creep test. A method of determining the extension of metals under a given load at a given temperature. The determination usually involves the plotting of time-elongation curves under constant load; a single test may extend over many months. The results are often expressed as the elongation (in millimeters or inches) per hour on a given gage length (e.g., 25 mm, or 1 in.).

cyclic loads. Loads that change value over time in a regular repeating pattern.

discontinuous yielding. The nonuniform plastic flow of a metal exhibiting a *yield point* in which plastic deformation is inhomogeneously distributed along the gage length. Under some circumstances, it may occur in metals not exhibiting a distinct yield point, either at the onset of or during plastic flow.

ductility. The ability of a material to deform plastically without fracturing.

elastic constants. The factors of proportionality that relate elastic displacement of a material to applied forces. See also *modulus of elasticity, shear modulus,* and *Poisson's ratio.*

elasticity. The property of a material whereby deformation caused by stress disappears upon the removal of the stress.

elastic limit. The maximum stress that a material is capable of sustaining without any permanent strain (deformation) remaining upon complete release of the stress. See also *proportional limit.*

elongation. (1) A term used in mechanical testing to describe the amount of extension of a testpiece when stressed. (2) In tensile testing, the increase in the gage length, measured after fracture of the specimen within the gage length, e_f, usually expressed as a percentage of the original gage length.

elongation, percent. The extension of a uniform section of a specimen expressed as percentage of the original gage length:

$$\text{Elongation, \%} = \frac{L_x - L_0}{L_0} \times 100$$

where L_0 is original gage length and L_x is final gage length.

engineering strain, *e*. A term sometimes used for average linear strain or conventional strain in order to differentiate it from *true strain.* In tension testing, it is calculated by dividing the change in the gage length by the original gage length.

engineering stress, *S*. A term sometimes used for conventional stress in order to differentiate it from *true stress.* In tension testing, it is calculated by dividing the load applied to the specimen by the original cross-sectional area of the specimen.

failure. Inability of a component or test specimen to fulfill its intended function.

fracture strength, S_f. The normal stress at the beginning of fracture, calculated from the load at the beginning of fracture during a tension test and the original cross-sectional area of the specimen.

gage length, L_0. The original length of that portion of the specimen over which strain or change of length is determined.

Hooke's Law. The law of springs, which states that the force required to displace (stretch) a spring is proportional to the displacement.

hysteresis (mechanical). The phenomenon of permanently absorbed or lost energy that occurs during any cycle of loading or unloading when a material is subjected to repeated loading.

load, *P*. In the case of mechanical testing, a force applied to a testpiece that is measured in units such as pound-force or newton.

Lüders lines. Elongated surface markings or depressions, often visible with the unaided eye, that form along the length of a tension specimen at an angle of approximately 45° to the loading axis. Caused by localized plastic deformation, they result from discontinuous (inhomogeneous) yielding. Also known as Lüders bands, Hartmann lines, Piobert lines, or stretcher strains.

maximum stress, S_{max}. The stress having the highest algebraic value in the stress cycle, tensile stress being considered positive and compressive stress negative. The *nominal stress* is used most commonly.

mechanical hysteresis. Energy absorbed in a complete cycle of loading and unloading within the elastic limit and represented by the closed loop of the stress-strain curves for loading and unloading.

mechanical properties. The properties of a material that reveal its elastic and inelastic behavior when force is applied or that involve the relationship between the intensity of the applied stress and the strain produced. The properties included under this heading are those that can be recorded by mechanical testing—for example, modulus of elasticity, tensile strength, elongation, hardness, and fatigue limit.

mechanical testing. The methods by which the *mechanical properties* of a metal are determined.

modulus of elasticity, *E*. The measure of rigidity or stiffness of a metal; the ratio of stress, below the proportional limit, to the corresponding strain. In terms of the stress-strain diagram, the modulus of elasticity is the slope of the stress-strain curve in the range of linear proportionality of stress to strain. Also known as Young's modulus. For materials that do not conform to *Hooke's law* throughout the elastic range, the slope of either the tangent to the stress-strain curve at the origin or at low stress, the secant drawn from the origin to any specified point on the stress-strain curve, or the chord connecting any two specific points on the stress-strain curve is usually taken to be the modulus of elasticity. In these cases, the modulus is referred to as the *tangent modulus, secant modulus,* or *chord modulus,* respectively.

modulus of resilience, U_R. The amount of energy stored in a material when loaded to its *elastic limit.* It is determined by measuring the area under the stress-strain curve up to the elastic limit. See also *strain energy.*

modulus of rigidity. See *shear modulus.*

modulus of rupture. Nominal stress at fracture in a bend test or torsion test. In bending, modulus of rupture is the bending moment at fracture (*Mc*) divided by the section modulus (*I*):

$$S_b = \frac{Mc}{I}$$

In torsion, modulus of rupture is the torque at fracture (*Tr*) divided by the polar section modulus (*J*):

$$S_s = \frac{Tr}{J}$$

modulus of toughness, U_T. The amount of work per unit volume done on a material to cause failure under static loading.

***m*-value.** See *strain-rate sensitivity.*

natural strain. See *true strain.*

necking. Reducing the cross-sectional area of metal in a localized area by stretching.

nominal strain. See *strain.*

nominal strength. See *ultimate strength.*

nominal stress. The stress at a point calculated on the net cross section by simple elasticity theory without taking into account the effect on the stress produced by stress raisers such as holes, grooves, fillets, and so forth.

normal stress. The stress component perpendicular to a plane on which forces act. Normal stress may be either tensile or compressive.

***n*-value.** See *strain-hardening exponent.*

offset. The distance along the strain coordinate between the initial portion of a stress-strain curve and a parallel line that intersects the stress-strain curve at a value of stress (commonly 0.2%) that is used as a measure of the *yield strength.* Used for materials that have no obvious *yield point.*

offset yield strength. The stress at which the strain exceeds by a specified amount (the *offset*) an extension of the initial proportional portion of the stress-strain curve. Expressed in force per unit area.

permanent set. The deformation or strain remaining in a previously stressed body after release of load.

plastic instability. The stage of deformation in a tensile test where the plastic flow becomes nonuniform and *necking* begins.

plasticity. The property that enables a material to undergo permanent deformation without rupture.

plastic strain. Dimensional change that does not disappear when the initiating stress is removed. Usually accompanied by some elastic deformation.

Poisson's ratio, ν. The absolute value of the ratio of transverse (lateral) strain to the corresponding axial strain resulting from uniformly distributed axial stress below the *proportional limit* of the material.

proof stress. The stress that will cause a specified small permanent set in a material.

proportional limit. The greatest stress a material is capable of developing without a deviation from straight-line proportionality between stress and strain. See also *elastic limit* and *Hooke's law.*

reduction in area. The difference between the original cross-sectional area of a tensile specimen and the smallest area at or after fracture as specified for the material undergoing testing.

secant modulus. The slope of the secant drawn from the origin to any specified point on the stress-strain curve. See also *modulus of elasticity.*

shear modulus, *G*. The ratio of shear stress to the corresponding shear strain for shear stresses below the proportional limit of the material. Values of shear modulus are usually determined by torsion testing. Also known as modulus of rigidity.

specimen. A test object, often of standard dimensions or configuration, that is used for destructive or nondestructive testing. One or more specimens may be cut from each unit of a sample.

strain. The unit of change in the size or shape of a body due to force. Also known as nominal strain. See also *engineering strain, linear strain,* and *true strain.*

strain energy. A measure of the energy absorption characteristics of a material determined by measuring the area under the stress-strain diagram.

strain hardening. An increase in hardness and strength caused by plastic deformation at temperatures below the recrystallization range. Also known as work hardening.

strain-hardening coefficient, *K*. See *strain-hardening exponent.*

strain-hardening exponent, *n*. The value n in the relationship $\sigma = K\varepsilon^n$, where σ is the *true stress,* ε is the *true strain,* and K, which is called the "strength coefficient," is equal to the true stress at a true strain of 1.0. The strain-hardening exponent, also called "n-value," is equal to the slope of the true-stress/true-strain curve up to maximum load, when plotted on log-log coordinates. The n-value relates to the ability of a material to be stretched in metalworking operations. The higher the n-value, the better the formability (stretchability).

strain rate, $\dot{\varepsilon}$. The time rate of straining for the usual tensile test. Strain as measured directly on the specimen gage length is used for determining strain rate. Because strain is dimensionless, the units of strain rate are reciprocal time.

strain-rate sensitivity (*m*-value). The increase in stress (σ) needed to cause a certain increase in plastic strain rate ($\dot{\varepsilon}$) at a given level of plastic strain (ε) and a given temperature (T).

$$m = \left(\frac{\Delta \log \sigma}{\Delta \log \dot{\varepsilon}} \right)_{\varepsilon T}$$

strength. The maximum nominal stress a material can sustain. Always qualified by the type of stress (tensile, compressive, or shear).

strength coefficient. See *strain-hardening exponent.*

stress. The intensity of the internally distributed forces or components of forces that resist a change in the volume or shape of a material that is or has been subjected to external forces. Stress is expressed in force per unit area and is calculated on the basis of the original dimensions of the cross section of the specimen. Stress can be either direct (tension or compression) or shear. See also *engineering stress, nominal stress, normal stress,* and *true stress.*

stress-strain curve. A graph in which corresponding values of stress and strain are plotted. Values of stress are usually plotted vertically (ordinates or y-axis) and values of strain horizontally (abscissas or x-axis). Also known as deformation curve and stress-strain diagram.

tangent modulus, E_T. The slope of the stress-strain curve at any specified point of the stress-strain curve. See also *modulus of elasticity.*

tensile strength, S_u. In tensile testing, the ratio of maximum load to original cross-sectional area. Also known as ultimate strength. Compare with *yield strength.*

tensile stress, *S*, σ. A stress that causes two parts of an elastic body, on either side of a typical stress plane, to pull apart. Contrast with *compressive stress.*

tensile testing. See *tension testing.*

tension. The force or load that produces elongation.

tension testing. A method of determining the behavior of materials subjected to uniaxial loading, which tends to stretch the metal. A longitudinal specimen of known length and diameter is gripped at both ends and stretched at a slow, controlled rate until rupture occurs. Also known as tensile testing.

transverse. Literally, "across," usually signifying a direction or plane perpendicular to the direction of working. In rolled plate or sheet, the direction across the width is often called long transverse, and the direction through the thickness, short transverse.

transverse strain. Linear strain in a plane perpendicular to the axis of the specimen.

true strain, ε. (1) The ratio of the change in dimension, resulting from a given load increment, to the magnitude of the dimension immediately prior to applying the load increment. (2) In a body subjected to axial force, the natural logarithm of the ratio of the gage length at the moment of observation to the original gage length. Also known as natural strain.

true stress, σ. The value obtained by dividing the load applied to a member at a given instant by the cross-sectional area over which it acts.

ultimate strength, S_u. The maximum stress (tensile, compressive, or shear) a material can sustain without fracture, determined by dividing maximum load by the original cross-sectional area of the specimen. Also known as nominal strength or maximum strength.

uniform strain. The strain occurring prior to the beginning of localization of strain (*necking*); the strain to maximum load in the tension test.

work hardening. See *strain hardening.*

von Mises criterion. The maximum distortion energy criterion that yielding will occur when the von Mises effective stress equals or exceeds the yield stress.

$$\bar{\sigma} \geq \sigma_{YP}$$

von Mises effective stress and strain. The effective stress ($\bar{\sigma}$) and effective strain ($\bar{\varepsilon}$) are given by:

$$\bar{\sigma} = \frac{1}{\sqrt{2}} [(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]^{1/2}$$

and

$$d\bar{\varepsilon} = \frac{\sqrt{2}}{3} [(d\varepsilon_1 - d\varepsilon_2)^2 + (d\varepsilon_2 - d\varepsilon_1)^2 + (d\varepsilon_3 - d\varepsilon_1)^2]^{1/2}$$

where 1, 2, and 3 indicate the principal axes.

yielding. Evidence of plastic deformation in structural materials. Also known as plastic flow or creep.

yield point. The first stress in a material, usually less than the maximum attainable stress, at which an increase in strain occurs without an increase in stress. Only certain metals—those that exhibit a localized, heterogeneous type of transition from elastic to plastic deformation—produce a yield point. If there is a decrease in stress after yielding, a distinction may be made between upper and lower yield points. The load at which a sudden drop in the flow curve occurs is called the upper yield point. The constant load shown on the flow curve is the lower yield point.

yield-point elongation. The amount of strain that is required to complete the yielding process. It is measured from the onset of *yielding* to the beginning of *strain hardening*.

yield strength, *YS* or S_y. The stress at which a material exhibits a specified deviation from proportionality of stress and strain. An offset of 0.2% is used for many metals. Compare with *tensile strength*.

yield stress. The stress level of highly ductile materials, such as structural steels, at which large strains take place without further increase in stress.

Young's modulus, *E*. See *modulus of elasticity*.

ACKNOWLEDGMENT

Portions of this article are adapted from G.E. Dieter, "Mechanical Behavior under Tensile and Compressive Loads," *Mechanical Testing and Evaluation*, Volume 8, *ASM Handbook*, 2000, p 99–108.

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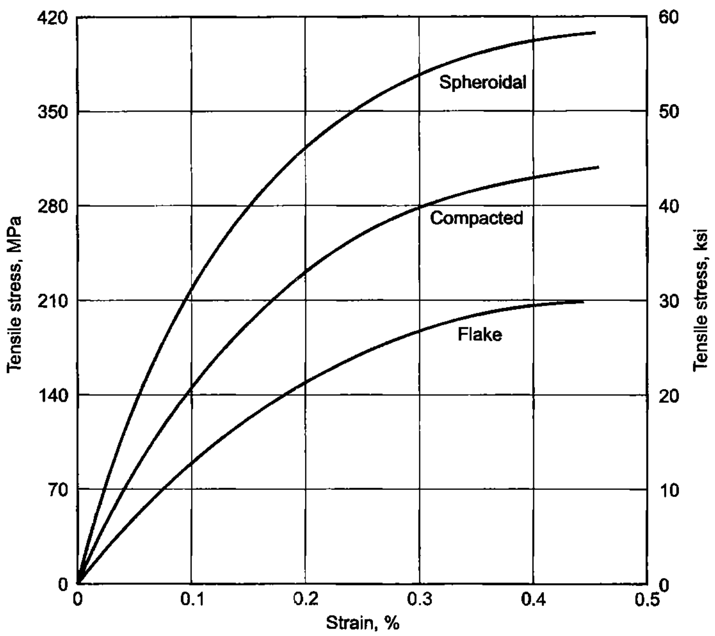
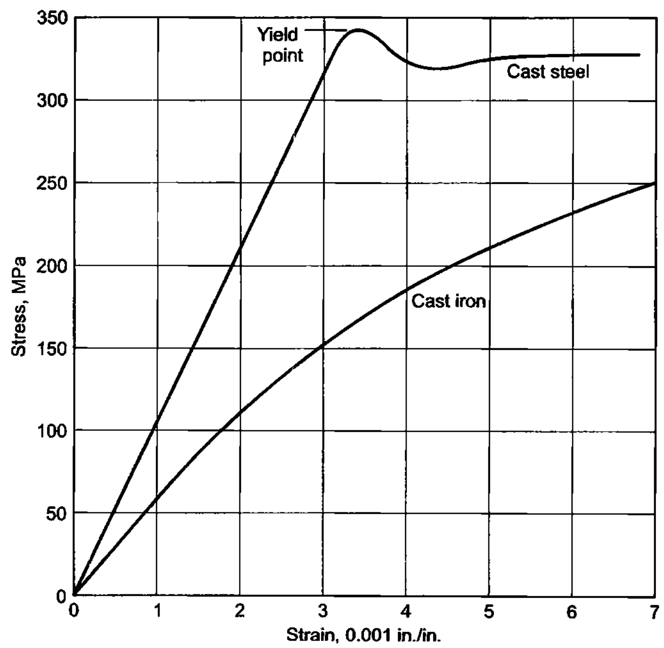
Ferrous Metals

Cast Iron (CI)



CI.001 Unclassified cast irons, influence of graphite morphology on stress-strain curves

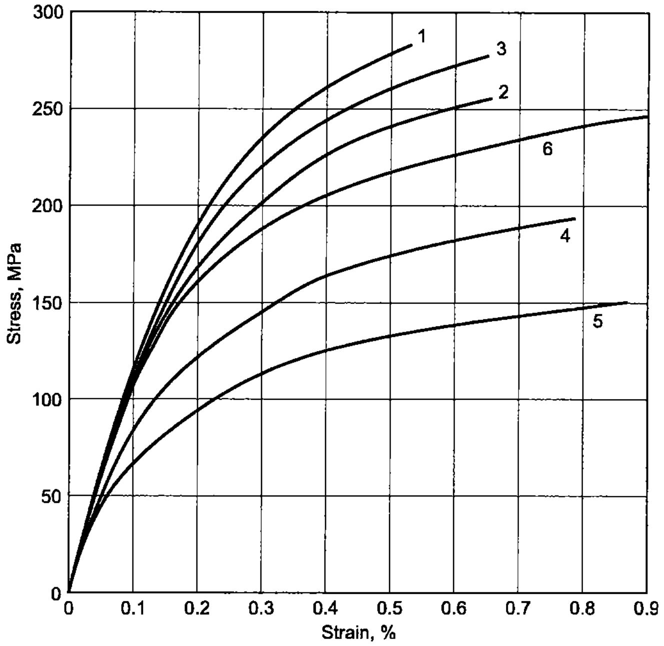
Source: D.M. Stefanescu, Classification and Basic Metallurgy of Cast Iron, *Properties and Selection: Irons, Steels, and High-Performance Alloys,* Vol 1, *ASM Handbook,* 1990, p 8



CI.002 Unclassified cast steel and cast iron, tensile stress-strain curves

Test direction: longitudinal. Cast steel: shows definite yield point; steel test bar diameter = 12.83 mm (0.505 in.); ultimate strength = 543 MPa. Cast iron: 25.4 mm (1 in.) cast bar, iron test bar diameter = 12.83 mm (0.0505 in.); ultimate strength = 315 MPa. Gage length = 51 mm (2 in.)

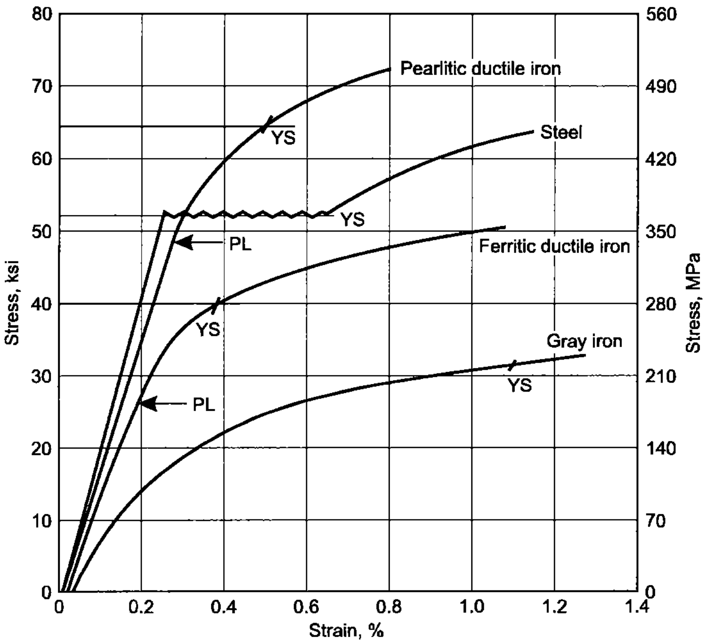
Source: G.N.J. Gilbert, Factors Relating to the Stress/Strain Properties of Cast Iron, *BCIRA J.,* Vol 6 (No. 6), April 1957, p 551



CI.003 Iron alloy casting, tensile stress-strain curves with effect of graphite

Test direction: longitudinal. In curves 1 through 5, the curvature increases as the amount of graphite in the iron increases. Curve 6 had graphite similar in quantity to curve 2, but it is coarser. Modulus of elasticity: curve 1, 145 GPa (21.1 psi × 10^6); curve 2, 116 GPa (16.9 psi × 10^6); curve 3, 123 GPa (17.9 psi × 10^6); curve 4, 103 GPa (14.9 psi × 10^6); curve 5, 84 GPa (12.2 psi × 10^6); curve 6, 115 GPa (16.7 psi × 10^6)

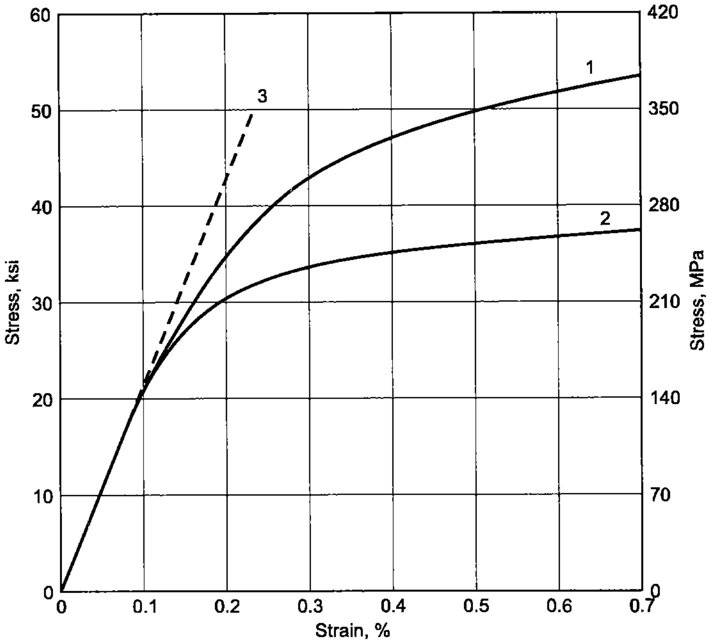
Source: G.N.J. Gilbert, Factors Relating to the Stress/Strain Properties of Cast Iron, *BCIRA J.*, Vol 6 (No. 6), April, 1957, p 553



CI.004 Unclassified cast irons and steels, stress-strain curves

Behavior of several irons compared to steel. 0.2% yield strength: pearlitic ductile iron, 455 MPa (66 ksi); steel, 372 MPa (54 ksi); ferritic ductile iron, 276 MPa (40 ksi); gray iron, 220 MPa (32 ksi). PL, proportionality limits

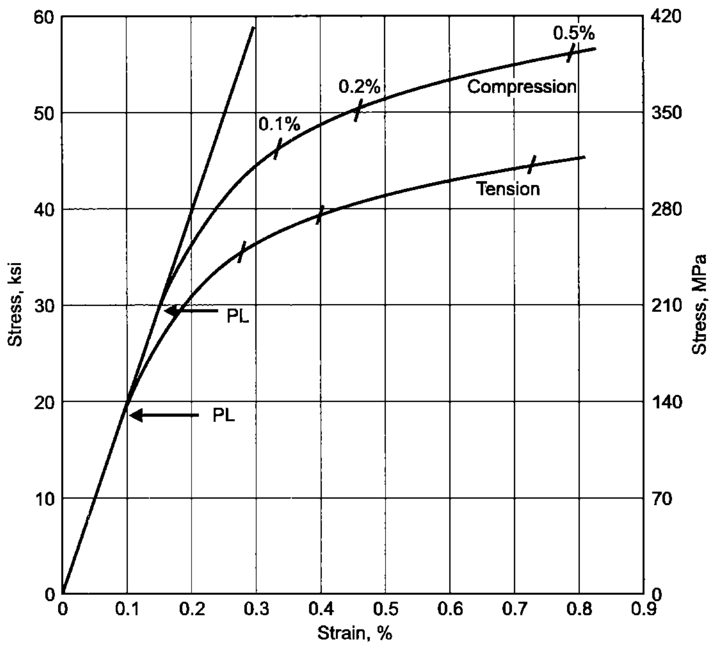
Source: Private communication with Lyle Jenkins



CI.005 Pearlitic and ferritic compacted graphite iron casting, typical tensile stress-strain curves

Curve 1: as-cast pearlitic; ultimate tensile strength = 410 MPa (59.5 ksi); elongation = 1.0%. Curve 2: ferritic; ultimate tensile strength = 320 MPa (46.4 ksi); elongation = 3.5%. Dashed curve (3) indicates modulus of elasticity, 144 GPa (20.9 × 10^6 psi).

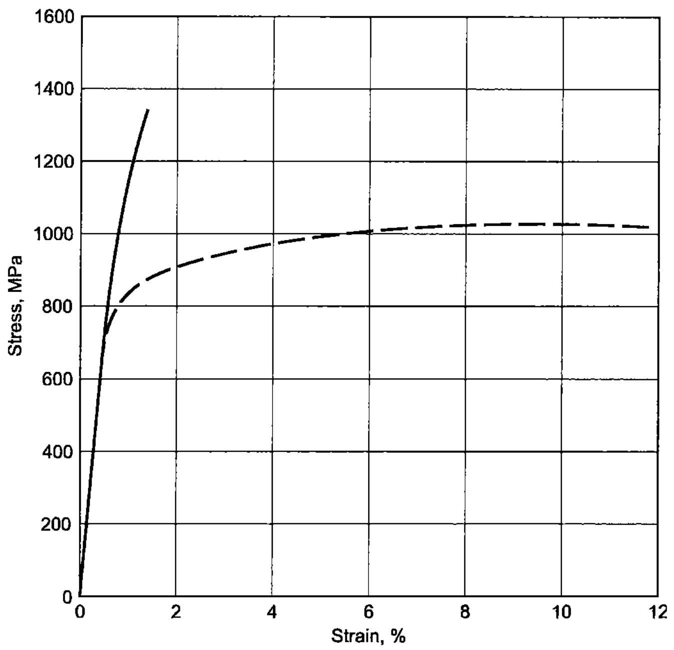
Source: C.F. Walton, Ed., *Iron Castings Handbook*, Iron Casting Society, 1981, p 382



CI.006 4.35 carbon equivalent compacted graphite iron casting, tensile and compressive stress-strain curves

0.1%, 0.2%, and 0.5% yield strengths are indicated. Proportionality limits (PL) are 201 MPa (29.1 ksi) in compression and 124 MPa (18 ksi) in tension.

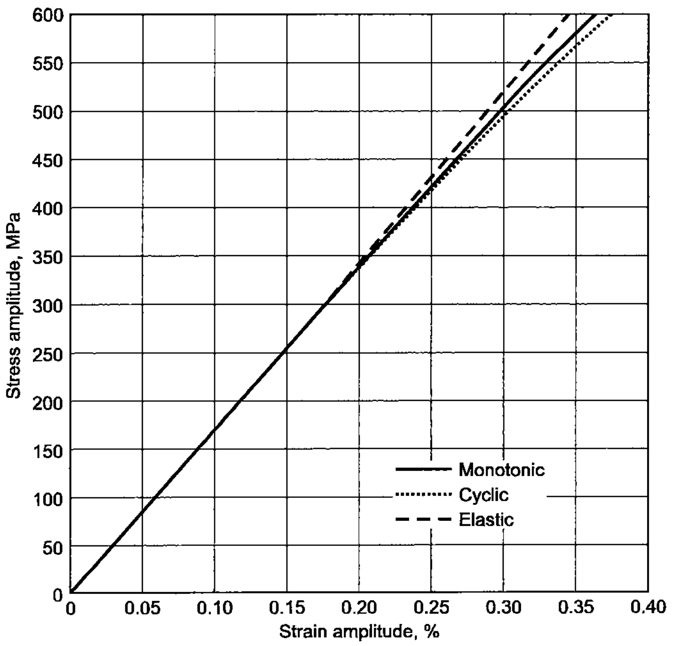
Source: G.F. Seargeant and E.R. Evans, The Production and Properties of Compacted Graphite Irons, *British Foundryman*, May 1978. As published in C.F. Walton, Ed., *Iron Castings Handbook*, Iron Casting Society, 1981, p 388



CI.007 Austempered ductile iron casting, stress-strain curves showing effect of matrix structure

Solid curve for austempered ductile iron, 300 °C, 1 h, with lower bainitic matrix structures. Dashed curve for austempered ductile iron, 375 °C, 1 h, with upper bainitic matrix structures

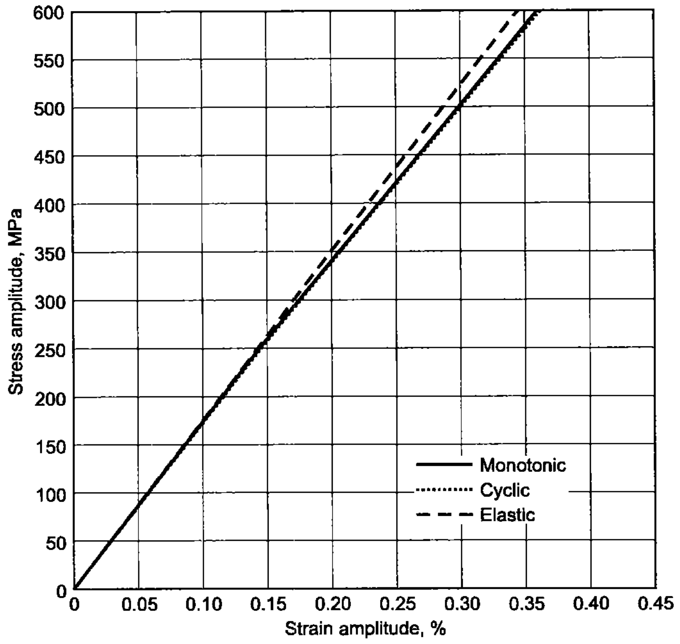
Source: P.A Blackmore and R.A. Harding, "The Effects of Metallurgical Process Variables on the Properties of ADI's," p 117–134; *J. Heat Treat.*, Vol 3 (No. 4), p 320–325. As published in *Structural Alloys Handbook*, Vol 1, CINDAS/Purdue University, 1994, p 25



CI.008 Austempered ductile iron casting, monotonic and cyclic stress-strain curves

Casting size = 25 × 45 mm. Austempered ductile iron (ADI), BCIRA Interim Grade 1200/1, high strength. Austempered 310 °C, 3 h. Monotonic curve (solid line): strength coefficient, $K = 26{,}425.7$; strain-hardening exponent, $n = 0.45$. Cyclic curve (dotted line): strength coefficient, $K' = 11{,}389.7$; strain-hardening exponent, $n' = 0.37$. Elastic line (dashed): slope (modulus of elasticity) = 173.6 GPa (25.18×10^6 psi). Composition: Fe-3.59C-2.15Si-0.29Mn-0.012S-0.010P-0.056Mg-0.80Ni-0.03Cr-0.027Sn-0.09Mo

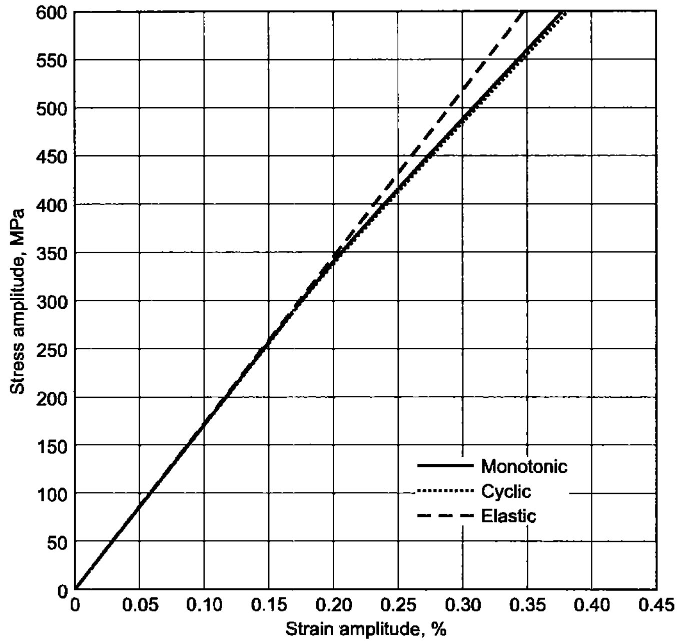
Source: M.J.D. Frier, "Strain Life Data and Stress/Strain Data for Austempered Ductile Irons—Tests of the High-Strength Grade," Report 1820, British Cast Iron Research Association (BCIRA), 1991, p 3



CI.009 Austempered ductile cast iron bar, monotonic and cyclic stress-strain curves

Bar diameter = 22 mm. Austempered ductile iron (ADI), BCIRA Interim Grade 1200/1, high strength. Austempered 325 °C, 3 h. Monotonic curve (solid line): strength coefficient, K = 22,486; strain-hardening exponent, n = 0.42. Cyclic curve (dotted line): strength coefficient, K' = 18,588.7; strain-hardening exponent, n' = 0.40. Elastic line (dashed): slope (modulus of elasticity) = 173.2 GPa. Composition: Fe-3.65C-2.16Si-0.47Mn-0.015S-0.010P-0.056Mg-0.58Ni-0.02Cr-0.027Sn-0.07Cu

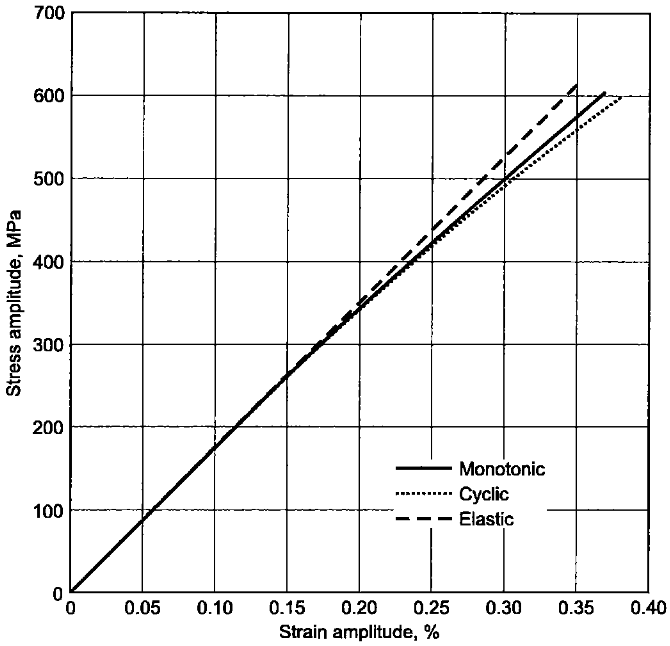
Source: I.S. Matharu, M.J.D. Frier, and K. Shelby, "Strain-Life Fatigue Data and Stress/Strain Data for Austempered Ductile Irons," Report 1813, British Cast Iron Research Association (BCIRA), 1990, p 226



CI.010 Austempered ductile iron casting, monotonic and cyclic stress-strain curves

Casting size = 25 × 45 mm. Austempered ductile iron (ADI), BCIRA Interim Grade 950/6, high strength. Austempered 375 °C, 2.5 h. Monotonic curve (solid line): strength coefficient, K = 6049.1; strain-hardening exponent, n = 0.28. Cyclic curve (dotted line): strength coefficient, K' = 5190.4; strain-hardening exponent, n' = 0.27. Elastic line (dashed): slope (modulus of elasticity) = 174.6 GPa. Composition: Fe-3.67C-2.08Si-0.30Mn-0.014S-0.014P-0.057Mg-0.77Ni-0.03Cr-0.028Sn-0.08Cu

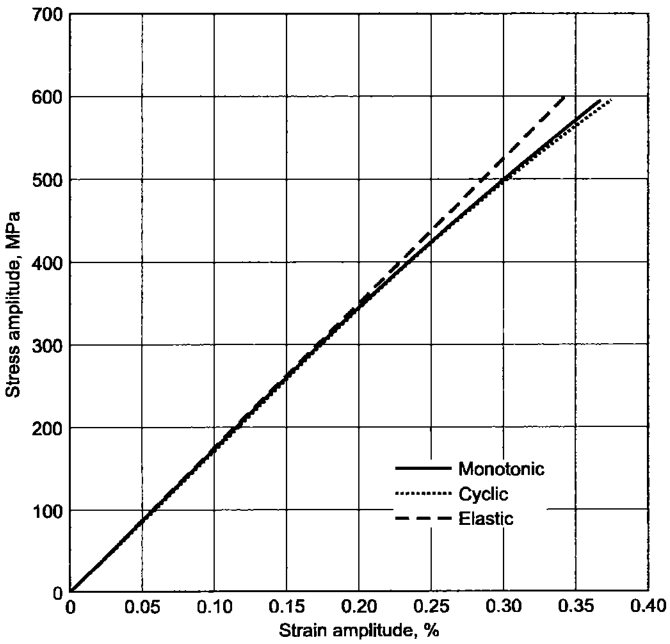
Source: I.S. Matharu, M.J.D. Frier, and K. Shelby, "Strain-Life Fatigue Data and Stress/Strain Data for Austempered Ductile Irons," Report 1813, British Cast Iron Research Association (BCIRA), 1990, p 226



CI.011 Austempered ductile cast iron bar, monotonic and cyclic stress-strain curves

Bar diameter = 22 mm. Austempered ductile iron (ADI), BCIRA Interim Grade 950/6, high strength. Austempered 375 °C, 1.25 h. Monotonic curve (solid line): strength coefficient, K = 28,769.7; strain-hardening exponent, n = 0.46. Cyclic curve (dotted line): strength coefficient, K' = 12,075.7; strain-hardening exponent, n' = 0.37. Elastic line (dashed): slope (modulus of elasticity) = 173.9 GPa. Composition: Fe-3.73C-2.21Si-0.47Mn-0.020S-0.011P-0.059Mg-0.55Ni-0.03Cr-0.027Sn-0.08Cu

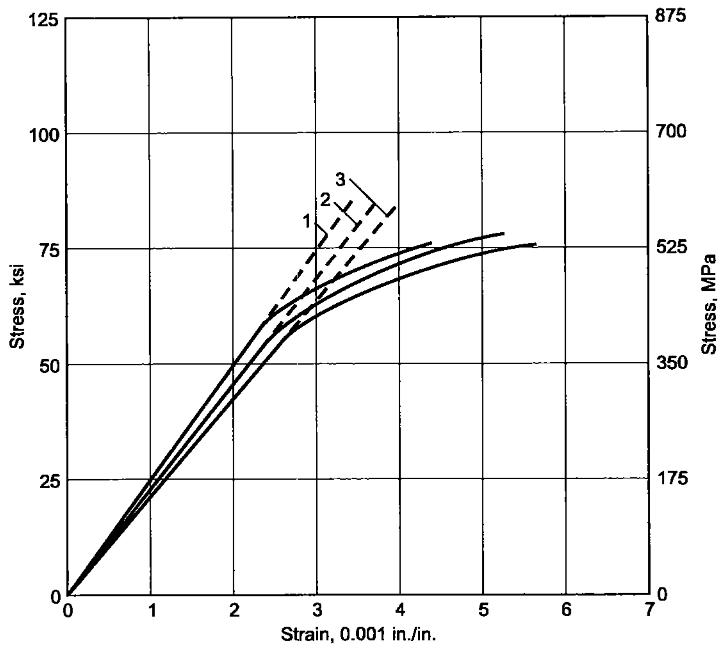
Source: I.S. Matharu and M.J.D. Frier, "Strain-Life Fatigue Data and Stress/Strain Data for Austempered Ductile Irons—A Preliminary Report," Report 1795, British Cast Iron Research Association (BCIRA), 1990, p 53



CI.012 Austempered ductile cast iron bar, monotonic and cyclic stress-strain curves

Bar diameter = 22 mm. Austempered ductile iron (ADI), BCIRA Interim Grade 950/6, high strength. Austempered 350 °C, 1 h. Monotonic curve (solid line): strength coefficient, K = 11,647.1; strain-hardening exponent, n = 0.36. Cyclic curve (dotted line): strength coefficient, K' = 8887.6; strain-hardening exponent, n' = 0.33. Elastic line (dashed): slope (modulus of elasticity) = 174.1 GPa. Composition: Fe-3.68C-2.22Si-0.40Mn-0.020S-0.012P-0.056Mg-0.54Ni-0.02Cr-0.027Sn-0.07Cu

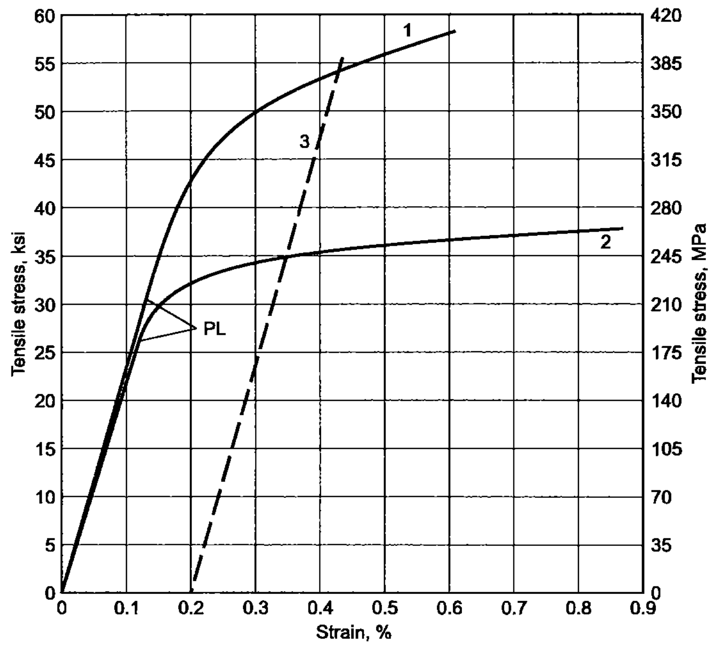
Source: I.S. Matharu and M.J.D. Frier, "Strain-Life Fatigue Data and Stress/Strain Data for Austempered Ductile Irons—A Preliminary Report," Report 1795, British Cast Iron Research Association (BCIRA), 1990, p 53



CI.013 3.60–3.90% carbon ductile casting, tensile stress-strain curves

Modulus of elasticity varies from the maximum 150 GPa (21.7×10^6 psi) (curve 1) to the minimum 159 GPa (23.0×10^6 psi) (curve 3), with an average of 157 GPa (22.7×10^6 psi) (curve 2), based on 40 tests

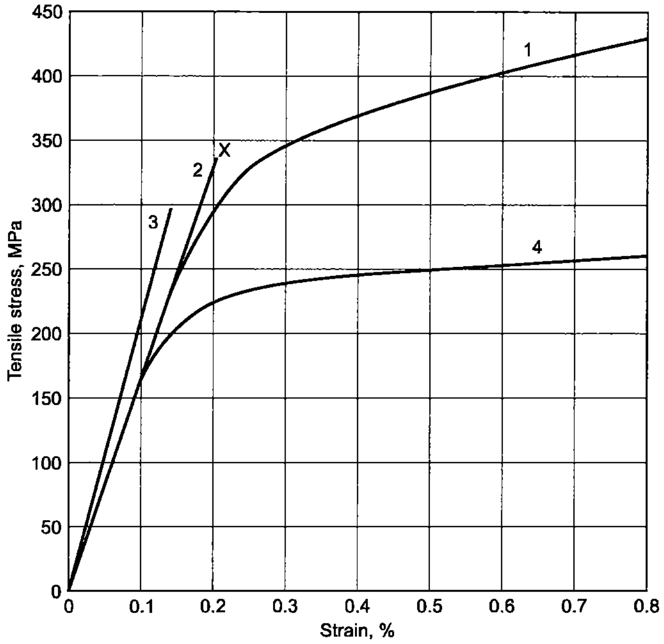
Source: Nodular Iron, *Properties and Selection of Metals,* Vol 1, 8th ed., *Metals Handbook,* American Society for Metals, 1961, p 386



CI.014 Pearlitic and ferritic ductile iron casting, typical tensile stress-strain curves

Curve 1: as-cast pearlitic, ultimate tensile strength = 745 MPa (108 ksi). Curve 2: annealed ferritic, ultimate tensile strength = 400 MPa (58 ksi). Curve 3 (dashed): 0.2% offset yield strength. PL, limits of proportionality

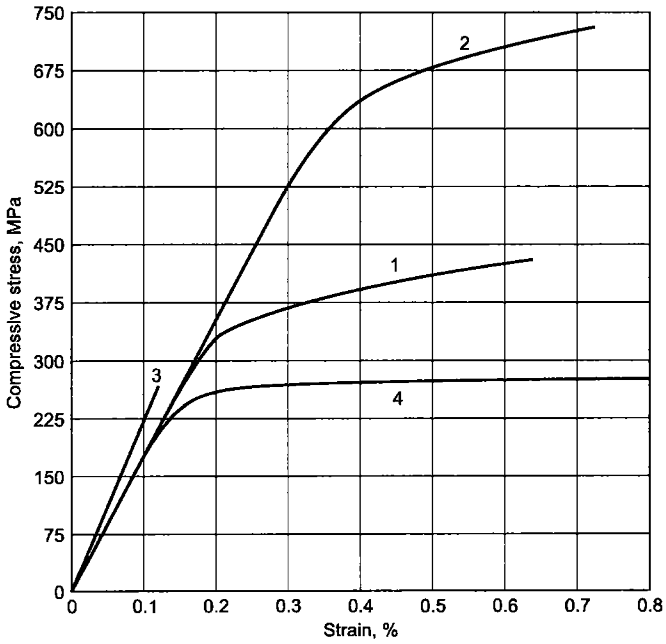
Source: G.N.J. Gilbert, Behavior of Cast Irons under Stress, *Engineering Properties and Performance of Modern Iron Castings,* British Cast Iron Research Association (BCIRA), 1970, p 41. As published in C.F. Walton, Ed., *Iron Castings Handbook,* Iron Casting Society, 1981, p 335



CI.015 Ductile iron alloy casting, tensile stress-strain curves

Test direction: longitudinal. Iron test specimen: 28.65 mm diam × 76.2 mm gage length (1.128 in. diam × 3 in. gage length). Steel test specimen: 37.922 mm diam × 76.2 mm gage length (1.493 in. diam × 3 in. gage length). Curve 1: as-cast pearlitic nodular iron; 0.1% proof stress = 349 MPa. Curve 2: high-silicon nodular iron failed in elastic region at X. Curve 3: En 4 steel; yield strength = 316 MPa. Curve 4: annealed ferritic nodular iron; 0.1% proof stress = 232 MPa. Composition: Curves 1 and 4, Fe-3.66C-1.8Si-0.41Mn-0.012S-0.025P-0.76Ni-(1 = 0.064Mg, 4 = 0.063Mg); curve 2, Fe-2.62C-6.14Si-0.35Mn-0.014S-0.021P-0.78Ni-0.051Mg-0.006Ce; curve 3, Fe-0.23C-0.56Mn-0.044S-0.027P

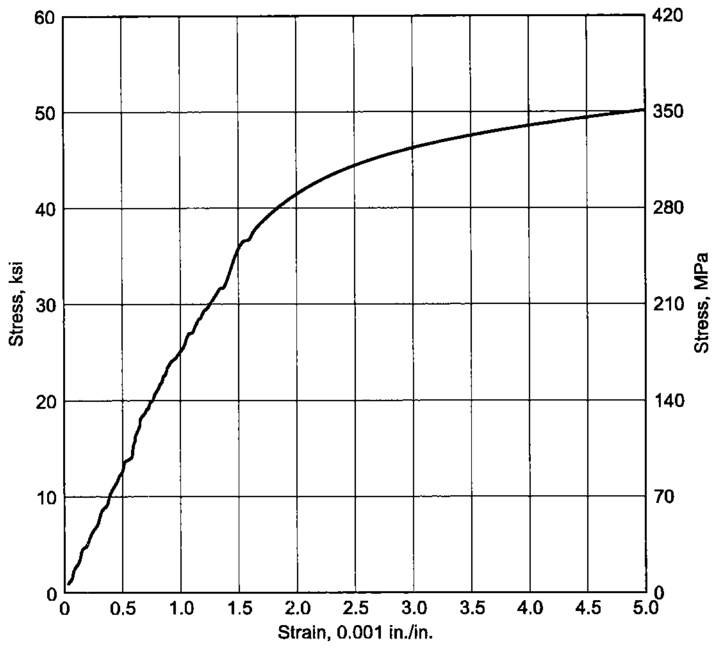
Source: G.N.J. Gilbert, The Stress/Strain Properties of Nodular Cast Irons in Tension and Compression, *BCIRA J.*, Vol 12 (No. 2), March 1964, p 179



CI.016 Ductile iron casting, compressive stress-strain curves

Test direction: longitudinal. Iron test specimen: 28.65 mm diam × 76.2 mm gage length (1.128 in. diam × 3 in. gage length). Steel test specimen: 37.922 mm diam × 76.2 mm gage length (1.493 in. diam × 3 in. gage length). Curve 1: as-cast pearlitic nodular iron; 0.1% proof stress = 398 MPa. Curve 2: high-silicon nodular iron, 0.1% proof stress = 676 MPa. Curve 3: En 4 steel; yield strength = 283 MPa. Curve 4: annealed ferritic nodular iron; 0.1% proof stress = 264 MPa. Composition: Curves 1 and 4, Fe-3.66C-1.8Si-0.41Mn-0.012S-0.025P-0.76Ni-(1 = 0.064Mg, 4 = 0.063Mg); curve 2, Fe-2.62C-6.14Si-0.35Mn-0.014S-0.021P-0.78Ni-0.051Mg-0.006Ce; curve 3, Fe-0.23C-0.56Mn-0.044S-0.027P

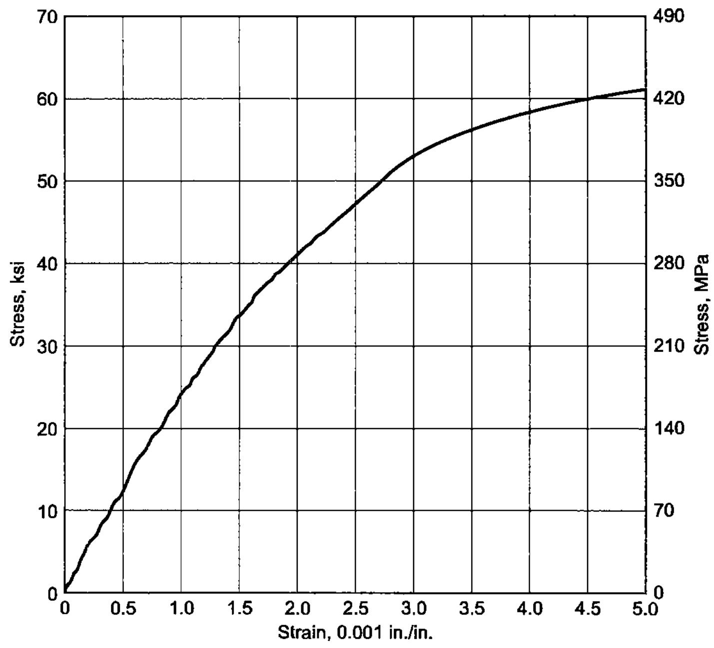
Source: G.N.J. Gilbert, The Stress/Strain Properties of Nodular Cast Irons in Tension and Compression, *BCIRA J.*, Vol 12 (No. 2), March 1964, p 185



CI.017 Ferritic ductile iron bar, uniaxial tensile stress-strain curve

Bar diameter = 12.827 mm (0.505 in.). Samples primarily ferritic with 5–10% pearlite. Test bars machined to ASTM A 536, Fig 6. Test was stress controlled at 345 MPa/min (50 ksi/min). Typical yield strength = 324 MPa (47 ksi); ultimate strength = 496 MPa (72 ksi); elongation = 16%. Composition: Fe-3.599C-2.753Si-0.193Mn-0.033P-0.014S

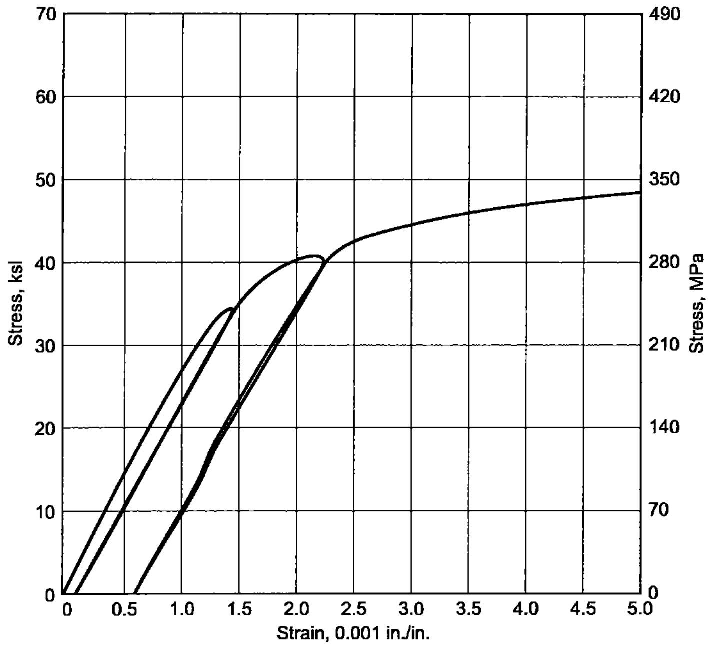
Source: K.E. Metzloff, H.W. Kwon, L.Y. Fang, and C.R. Loper, Jr., Service Modulus: A Method for Accurate Determination of Young's Modulus and Yield Strength in Ductile Iron, *AFS Trans.*, Vol 104, 1996, p 723



CI.018 Pearlitic ductile iron bar, uniaxial tensile stress-strain curve

Bar diameter = 12.827 mm (0.505 in.). Samples primarily pearlitic with 90–95% pearlite. Test bars machined to ASTM A 536, Fig 6. Test was stress controlled at 345 MPa/min (50 ksi/min). Typical yield strength = 400 MPa (58 ksi); ultimate strength = 738 MPa (107 ksi); elongation = 7.5%. Composition: Fe-3.684C-2.422Si-0.469Mn-0.028P-0.015S-0.349Cu

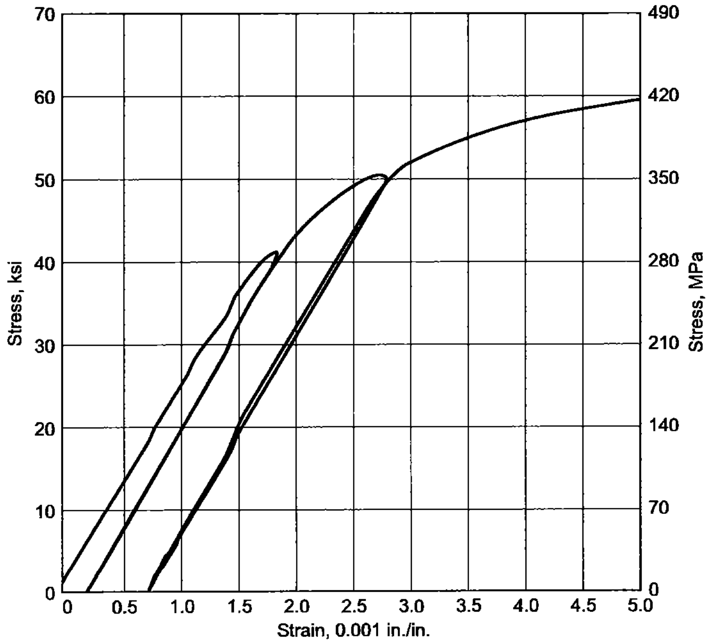
Source: K.E. Metzloff, H.W. Kwon, L.Y. Fang, and C.R. Loper, Jr., Service Modulus: A Method for Accurate Determination of Young's Modulus and Yield Strength in Ductile Iron, *AFS Trans.*, Vol 104, 1996, p 723



CI.019 Ferritic ductile iron bar, uniaxial tensile stress-strain curves

Bar diameter = 12.827 mm (0.505 in.). Samples primarily ferritic with 5–10% pearlite. Test bars machined to ASTM A 536, Fig 6. Test was stress controlled at 345 MPa/min (50 ksi/min). Typical yield strength (YS) = 324 MPa (47 ksi); ultimate strength = 496 MPa (72 ksi); elongation = 16%. Sample loaded to 70% YS, unloaded to 91 kg (200 lb), loaded to 85% YS, unloaded to 91 kg (200 lb), loaded to failure. Composition: Fe-3.599C-2.753Si-0.193Mn-0.033P-0.014S

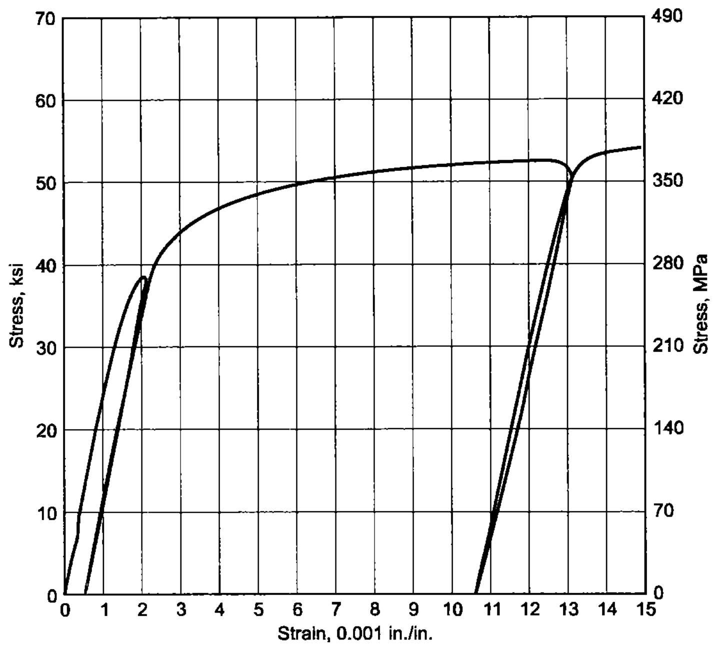
Source: K.E. Metzloff, H.W. Kwon, L.Y. Fang, and C.R. Loper, Jr., Service Modulus: A Method for Accurate Determination of Young's Modulus and Yield Strength in Ductile Iron, *AFS Trans.*, Vol 104, 1996, p 724



CI.020 Pearlitic ductile iron bar, uniaxial tensile stress-strain curves

Bar diameter = 12.827 mm (0.505 in.). Samples primarily pearlitic with 90–95% pearlite. Test bars machined to ASTM A 536, Fig 6. Test was stress controlled at 345 MPa/min (50 ksi/min). Typical yield strength = 400 MPa (58 ksi); ultimate strength = 738 MPa (107 ksi); elongation = 7.5%. Sample loaded to 70% YS, unloaded to 91 kg (200 lb), loaded to 85% YS, unloaded to 91 kg (200 lb), loaded to failure. Composition: Fe-3.684C-2.422Si-0.469Mn-0.028P-0.015S-0.349Cu

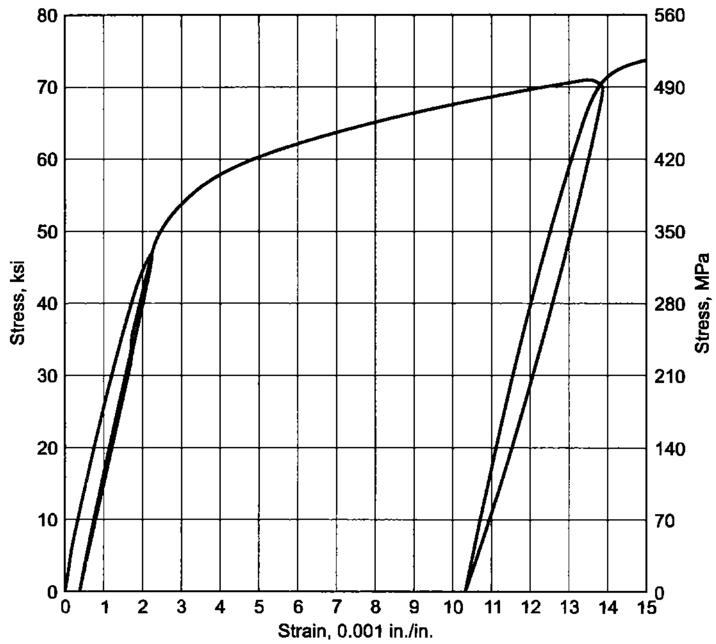
Source: K.E. Metzloff, H.W. Kwon, L.Y. Fang, and C.R. Loper, Jr., Service Modulus: A Method for Accurate Determination of Young's Modulus and Yield Strength in Ductile Iron, *AFS Trans.*, Vol 104, 1996, p 725



CI.021 Ferritic ductile iron bar, uniaxial tensile stress-strain curves

Bar diameter = 12.827 mm (0.505 in.). Samples primarily ferritic with 5–10% pearlite. Test bars machined to ASTM A 536, Fig 6. Test was stress controlled at 345 MPa/min (50 ksi/min). Typical yield strength = 324 MPa (47 ksi); ultimate strength = 496 MPa (72 ksi); elongation = 16%. Sample loaded to 80% YS, unloaded to 91 kg (200 lb), loaded to 1% strain, unloaded to 91 kg (200 lb), loaded to failure. Composition: Fe-3.599C-2.753Si-0.193Mn-0.033P-0.014S

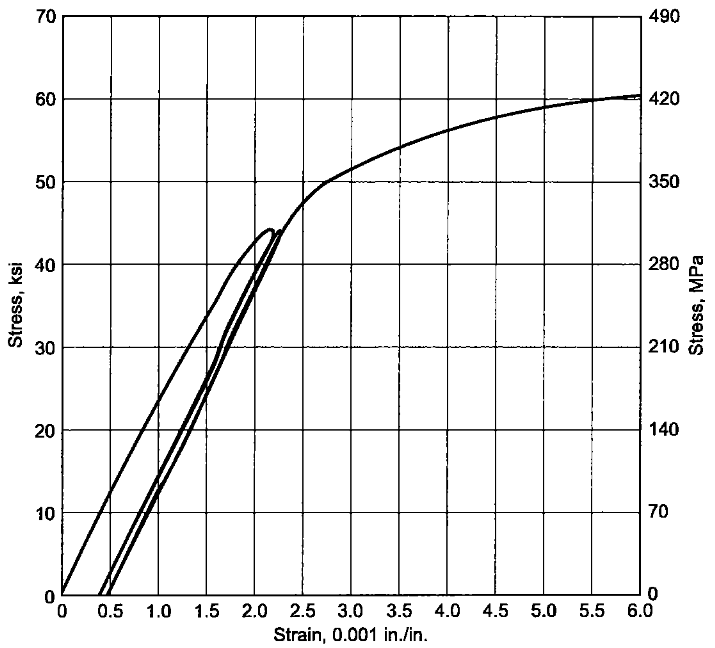
Source: K.E. Metzloff, H.W. Kwon, L.Y. Fang, and C.R. Loper, Jr., Service Modulus: A Method for Accurate Determination of Young's Modulus and Yield Strength in Ductile Iron, *AFS Trans.*, Vol 104, 1996, p 726



CI.022 Pearlitic ductile bar, uniaxial tensile stress-strain curves

Bar diameter = 12.827 mm (0.505 in.). Samples primarily pearlitic with 90–95% pearlite. Test bars machined to ASTM A 536, Fig 6. Test was stress controlled at 345 MPa/min (50 ksi/min). Typical yield strength = 400 MPa (58 ksi); ultimate strength = 738 MPa (107 ksi); elongation = 7.5%. Sample loaded to 80% YS, unloaded to 91 kg (200 lb), loaded to 1% strain, unloaded to 91 kg (200 lb), loaded to failure. Composition: Fe-3.684C-2.422Si-0.469Mn-0.028P-0.015S-0.349Cu

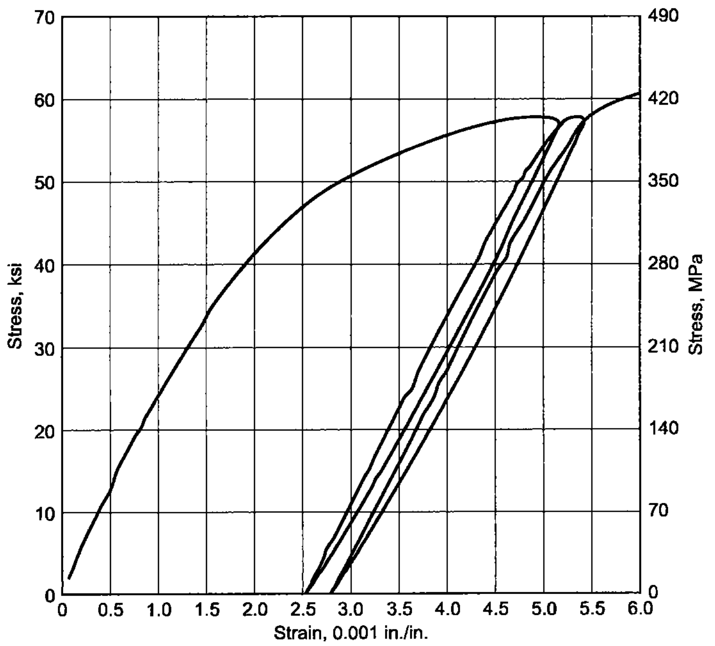
Source: K.E. Metzloff, H.W. Kwon, L.Y. Fang, and C.R. Loper, Jr., Service Modulus: A Method for Accurate Determination of Young's Modulus and Yield Strength in Ductile Iron, *AFS Trans.*, Vol 104, 1996, p 726



CI.023 Pearlitic ductile iron bar, uniaxial tensile stress-strain curves

Bar diameter = 12.827 mm (0.505 in.). Samples primarily pearlitic with 90–95% pearlite. Test bars machined to ASTM A 536, Fig 6. Test was stress controlled at 345 MPa/min (50 ksi/min). Typical yield strength = 400 MPa (58 ksi); ultimate strength = 738 MPa (107 ksi); elongation = 7.5%. Sample loaded to 75% YS, unloaded to 91 kg (200 lb), loaded to 75% YS, unloaded to 91 kg (200 lb), loaded to failure. Composition: Fe-3.684C-2.422Si-0.469Mn-0.028P-0.015S-0.349Cu

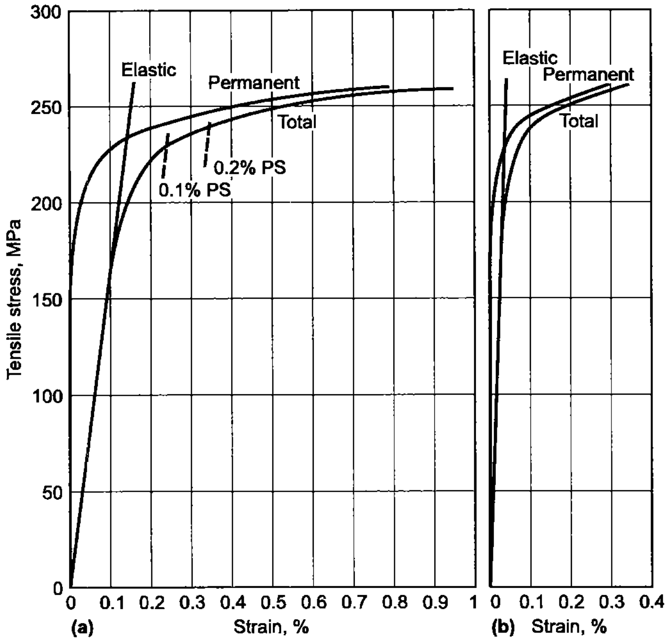
Source: K.E. Metzloff, H.W. Kwon, L.Y. Fang, and C.R. Loper, Jr., Service Modulus: A Method for Accurate Determination of Young's Modulus and Yield Strength in Ductile Iron, *AFS Trans.*, Vol 104, 1996, p 727



CI.024 Pearlitic ductile iron bar, uniaxial tensile stress-strain curves

Bar diameter = 12.827 mm (0.505 in.). Samples primarily pearlitic with 90–95% pearlite. Test bars machined to ASTM A 536, Fig 6. Test was stress controlled at 345 MPa/min (50 ksi/min). Typical yield strength = 400 MPa (58 ksi); ultimate strength = 738 MPa (107 ksi); elongation = 7.5%. Sample loaded to 100% YS, unloaded to 91 kg (200 lb), loaded to 100% YS, unloaded to 91 kg (200 lb), loaded to failure. Composition: Fe-3.684C-2.422Si-0.469Mn-0.028P-0.015S-0.349Cu

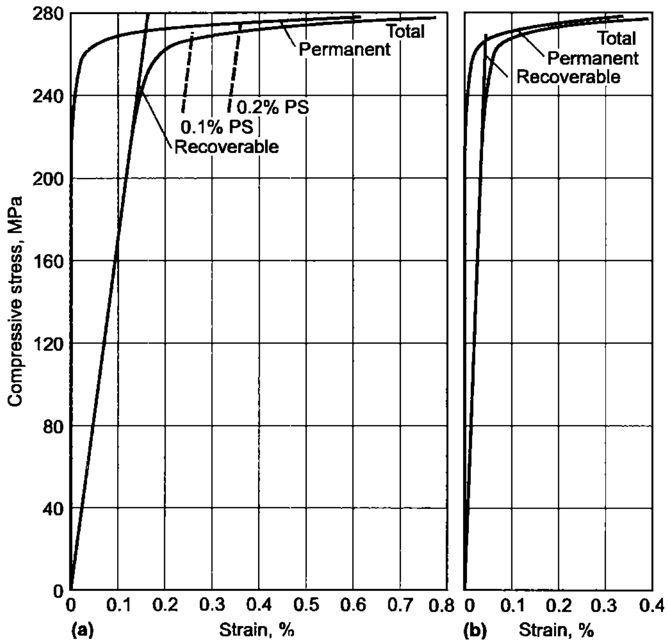
Source: K.E. Metzloff, H.W. Kwon, L.Y. Fang, and C.R. Loper, Jr., Service Modulus: A Method for Accurate Determination of Young's Modulus and Yield Strength in Ductile Iron, *AFS Trans.*, Vol 104, 1996, p 727



CI.025 Ferritic ductile iron casting, longitudinal tensile stress-strain curves (a) with lateral contraction (b)

Test specimen size = 28.651 mm diam × 76.2 mm gage length (1.128 in. diam × 3 in. gage length). Permanent strain remains when sample unloaded. Total strain is permanent plus recoverable. 0.1% proof stress (PS) = 232 MPa; 0.2% proof stress = 242 MPa. Composition: Fe-3.66C-1.8Si-0.41Mn-0.012S-0.025P-0.76Ni-0.064Mg

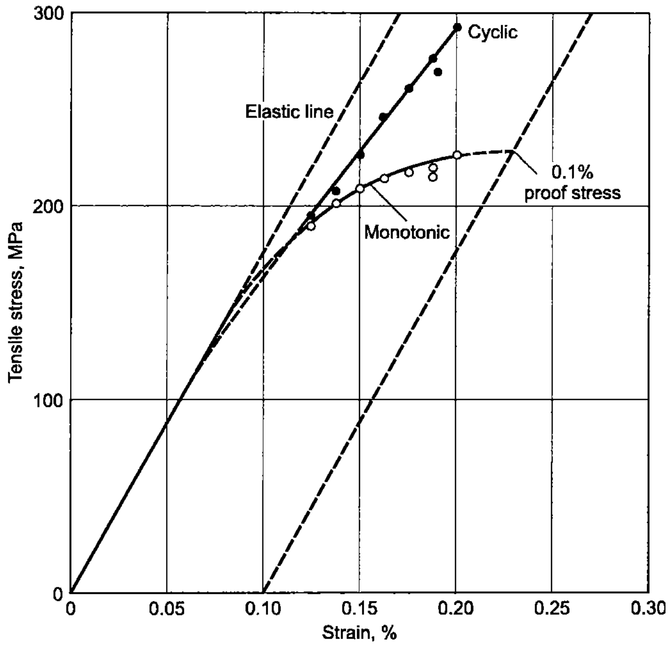
Source: G.N.J. Gilbert, The Stress/Strain Properties of Nodular Cast Irons in Tension and Compression, *BCIRA J.*, Vol 12 (No. 2), March 1964, p 177



CI.026 Ferritic ductile iron casting, longitudinal compressive stress-strain curves (a) with lateral expansion (b)

Test specimen size = 28.651 mm diam × 76.2 mm gage length (1.128 in. diam × 3 in. gage length). Permanent strain remains when sample unloaded. Total strain is permanent plus recoverable. 0.1% proof stress (PS) = 266 MPa; 0.2% proof stress = 267 MPa. Composition: Fe-3.66C-1.8Si-0.41Mn-0.012S-0.025P-0.76Ni-0.064Mg

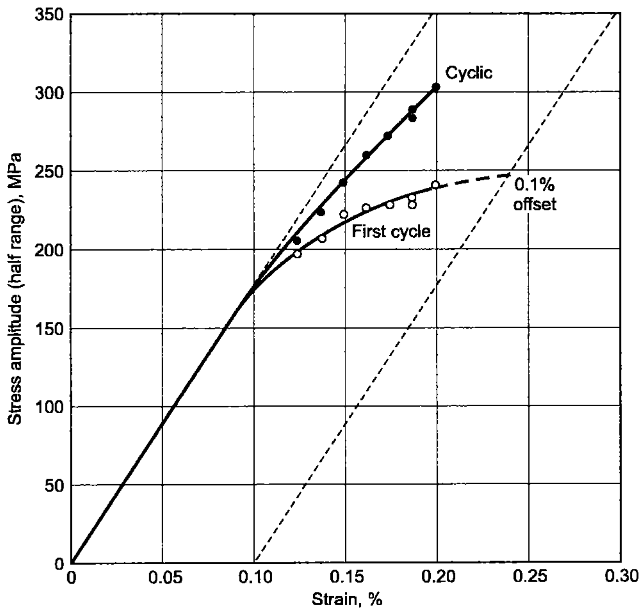
Source: G.N.J. Gilbert, The Stress/Strain Properties of Nodular Cast Irons in Tension and Compression, *BCIRA J.*, Vol 12 (No. 2), March 1964, p 182



CI.027 Ferritic nodular ductile iron casting, tensile monotonic and cyclic stress-strain curves

Curves based on the first cycle of loading and cycle tests carried out at less than 0.1% strain. The stress values are raised by strain hardening. Modulus of elasticity = 177 GPa. Composition: Fe-3.51C-2.07Si-0.32Mn-0.022S-0.017P-0.046Mg

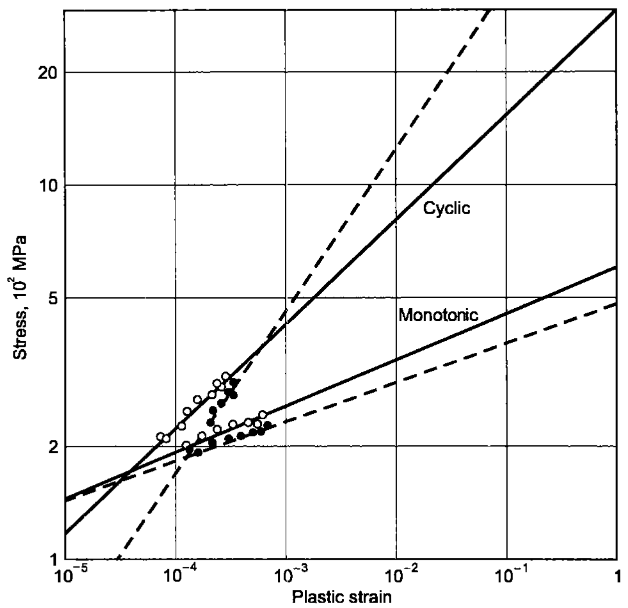
Source: G.N.J. Gilbert, "The Stress/Strain Properties and Fatigue Properties of a Ferritic and a Pearlitic Nodular Cast Iron Tested under Strain Control," Report 1586, British Cast Iron Research Association (BCIRA), 1984



CI.028 Ferritic nodular ductile iron casting, stress amplitude-strain curve for monotonic and cyclic loading

Curves based on the first cycle of loading and a cycle at approximately half the fatigue life using the stress amplitudes (half stress range). Composition: Fe-3.51C-2.07Si-0.32Mn-0.022S-0.017P-0.046Mg

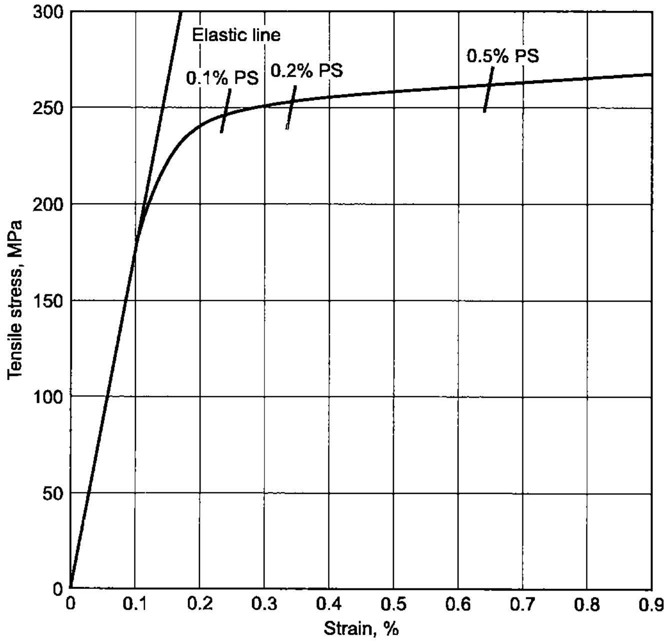
Source: G.N.J. Gilbert, "The Stress/Strain Properties and Fatigue Properties of a Ferritic and a Pearlitic Nodular Cast Iron Tested under Strain Control," Report 1586, British Cast Iron Research Association (BCIRA), 1984



CI.029 Ferritic nodular ductile iron casting, log stress-log plastic strain curve for monotonic and cyclic loading

Work-hardening behavior shown for monotonic and cyclic loading based on maximum stress (dashed curve) and stress amplitude (solid curve) at approximately half the fatigue life. Half fatigue life is used to define cyclic stress-strain curve because fatigue behavior does not stabilize for these irons. Composition: Fe-3.51C-2.07Si-0.32Mn-0.022S-0.017P-0.046Mg

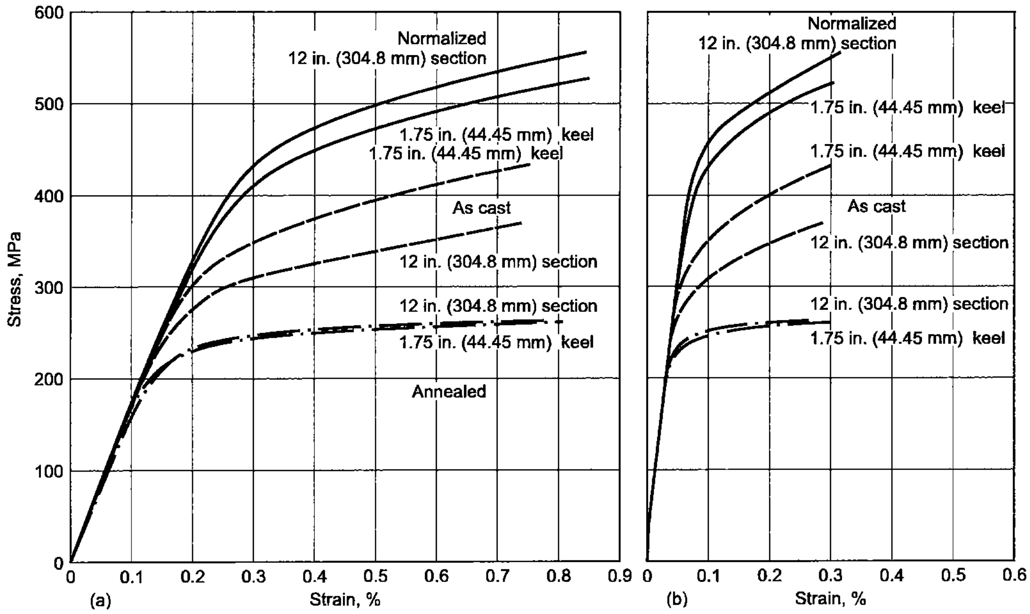
Source: G.N.J. Gilbert, "The Stress/Strain Properties and Fatigue Properties of a Ferritic and a Pearlitic Nodular Cast Iron Tested under Strain Control," Report 1586, British Cast Iron Research Association (BCIRA), 1984



CI.030 Ferritic nodular ductile iron casting, tensile stress-strain curve

Test direction: longitudinal. Proof stress (PS): 0.1%, 246 MPa; 0.2%, 253 MPa; 0.5%, 263 MPa. Ultimate tensile strength = 400 MPa; elongation = 26.5%; hardness = 134 HB (10/3000). Composition: Fe-3.42C-2.11Si-0.31Mn-0.014S-0.007P-0.061Mg

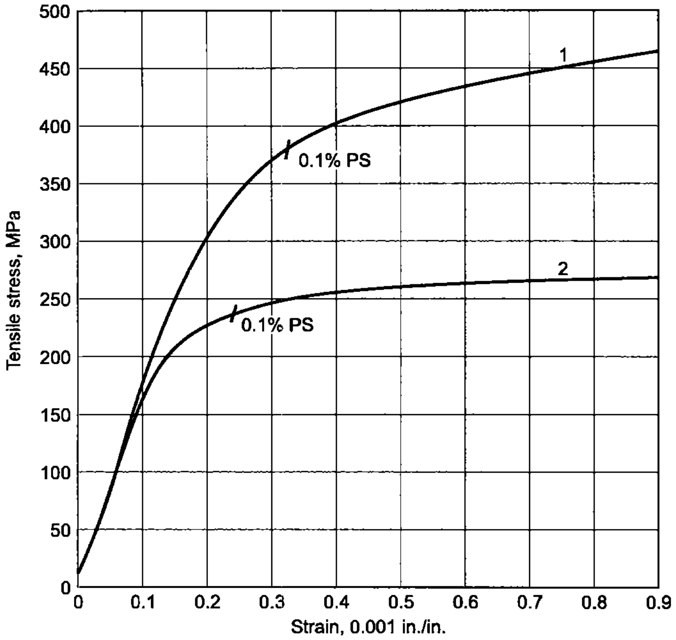
Source: G.N.J. Gilbert and M.J.D. Frier, "The Stress/Strain Properties of a Pearlitic and a Nodular Cast Iron Cyclically Loaded between Equal and Opposite Strain Limits in Tension and Compression," Report 1579, British Cast Iron Research Association (BCIRA), 1984



CI.031 Recarburized steel ductile casting, longitudinal tensile stress-total strain curves (a) with lateral contraction (b)

Comparison is made between 44.45 mm (1.75 in.) keel test blocks and 304.8 mm diam × 50.8 mm (12 in. diam × 2 in.) castings; 50.8 mm (2 in.) square test specimens cut from the latter. As-cast pearlitic nodular iron, normalized pearlitic, and annealed ferritic nodular iron are shown for each size. Composition: Fe-3.52C-1.76Si-0.29Mn-0.026S-0.020P-0.92Ni-0.062Mg

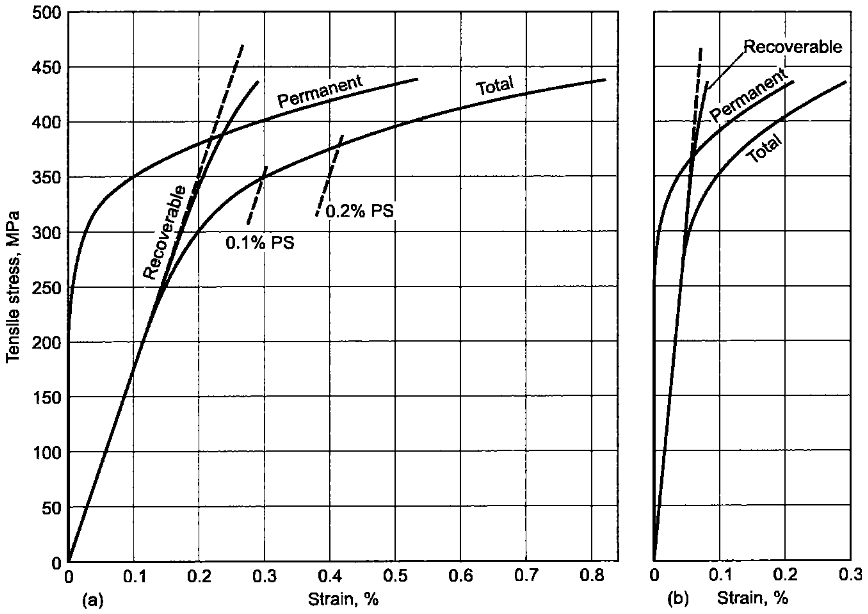
Source: G.N.J. Gilbert, The Effect of Section Size on the Stress-Strain Properties of Nodular Cast Iron, *BCIRA J.*, Vol 12 (No. 6), Nov 1964, p 766



CI.032 Nodular ductile iron casting, typical tensile stress-strain curves at 20 °C

Curve 1: nodular iron; ultimate strength = 695 MPa; 0.1% proof stress = 378 MPa. Curve 2: nodular iron, ultimate strength = 402 MPa; 0.1% proof stress = 238 MPa. Allowable design stress is significantly less than the proof stress.

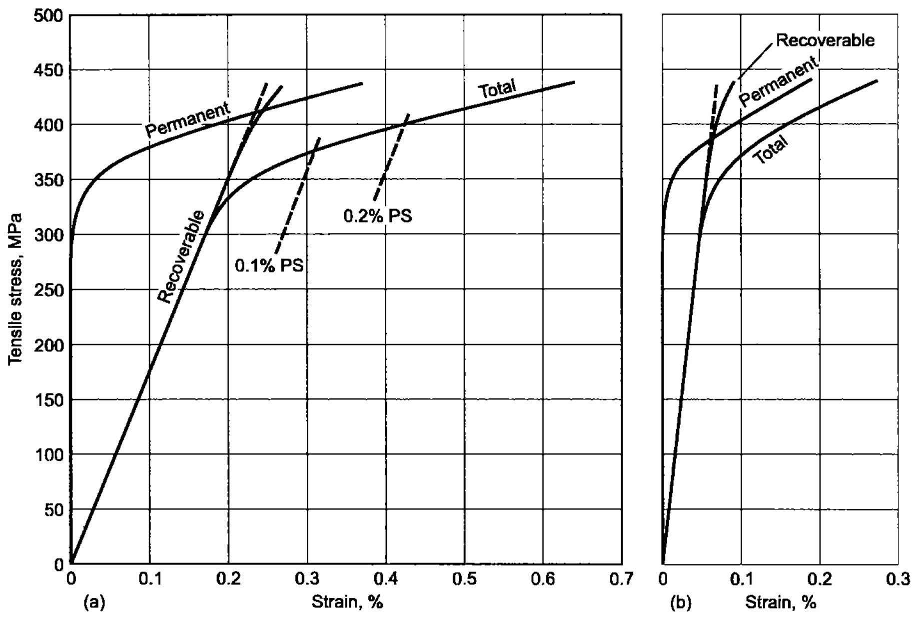
Source: "Stress/Strain Behaviour of Nodular and Malleable Cast Irons," Broadsheet 157-2, British Cast Iron Research Association (BCIRA), 1981



CI.033 Pearlitic nodular ductile iron casting, longitudinal tensile stress-strain curves (a) with lateral contraction (b)

Test specimen size = 28.651 mm diam × 76.2 mm gage length (1.128 in. diam × 3 in. gage length). Permanent strain remains when sample unloaded. Total strain is permanent plus recoverable. 0.1% proof stress (PS) = 347 MPa; 0.2% proof stress = 374 MPa. Composition: Fe-3.66C-1.8Si-0.41Mn-0.012S-0.025P-0.76Ni-0.063Mg

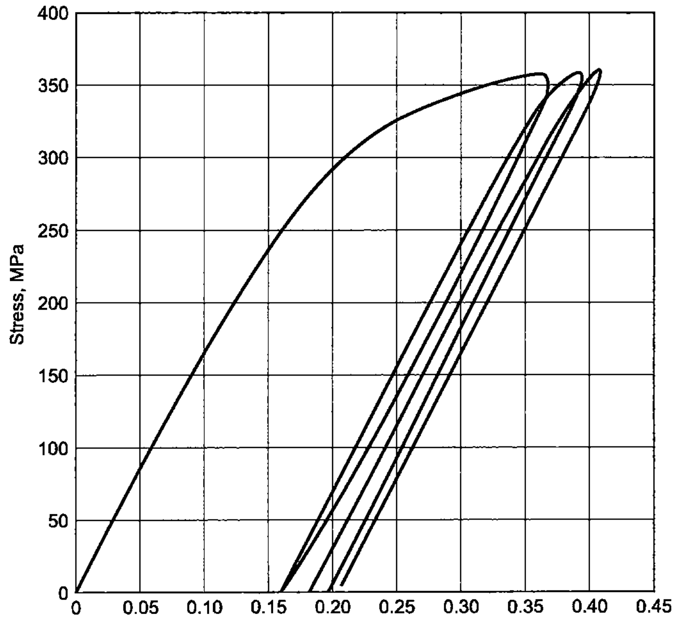
Source: G.N.J. Gilbert, The Stress/Strain Properties of Nodular Cast Irons in Tension and Compression, *BCIRA J.*, Vol 12 (No. 2), March 1964, p 175



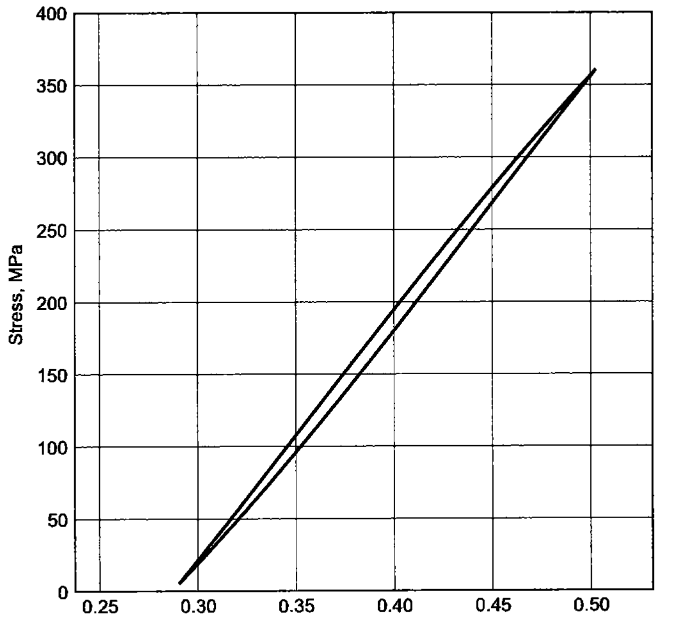
CI.034 Pearlitic ductile iron casting, longitudinal compressive stress-strain curves (a) with lateral expansion (b)

Test specimen size = 28.651 mm diam × 76.2 mm gage length (1.128 in. diam × 3 in. gage length). Permanent strain remains when sample unloaded. Total strain is permanent plus recoverable. 0.1% proof stress (PS) = 377 MPa; 0.2% proof stress = 398 MPa. Composition: Fe-3.66C-1.8Si-0.41Mn-0.012S-0.025P-0.76Ni-0.063Mg

Source: G.N.J. Gilbert, The Stress/Strain Properties of Nodular Cast Irons in Tension and Compression, *BCIRA J.*, Vol 12 (No. 2), March 1964, p 180



(a)

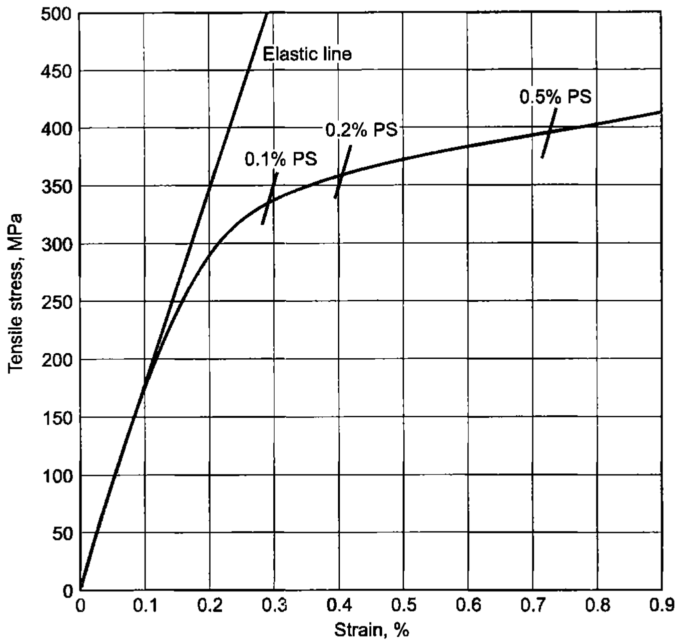


(b)

CI.035 Pearlitic nodular ductile iron casting, tensile stress-strain curves

Test direction: longitudinal. (a) Beginning of cycling in tension to 350 MPa. (b) Behavior of same sample after 128 cycles to 350 MPa. 0.2% proof stress = 358 MPa; ultimate tensile strength = 659 MPa. Composition: Fe-3.42C-2.11Si-0.31Mn-0.014S-0.007P-0.061Mg

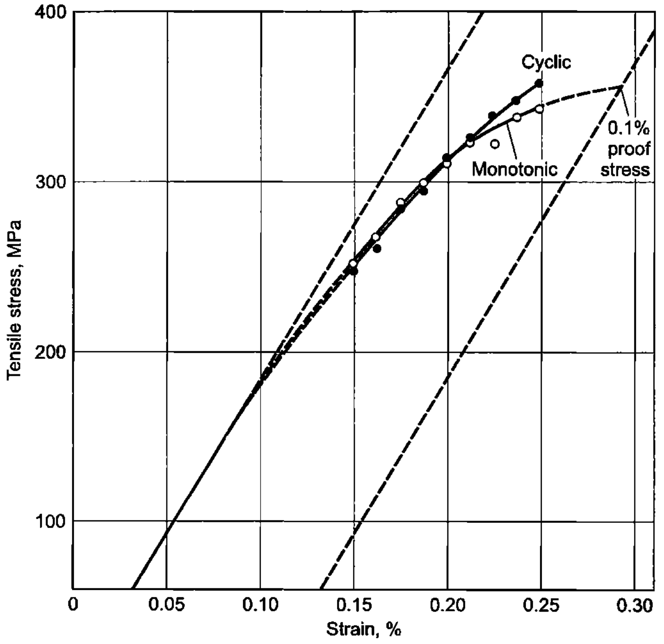
Source: G.N.J. Gilbert and M.J.D. Frier, "The Stress/Strain Properties of a Pearlitic and a Nodular Cast Iron Cyclically Loaded between Equal and Opposite Strain Limits in Tension and Compression," Report 1579, British Cast Iron Research Association (BCIRA), 1984



CI.036 Pearlitic nodular ductile iron casting, tensile stress-strain curves

Test direction: longitudinal. Proof stress (PS): 0.1%, 355 MPa; 0.2%, 358 MPa; 0.5%, 395 MPa. Ultimate tensile strength = 659 MPa; elongation = 6.5%; hardness = 219 HB (10/3000). Composition: Fe-3.42C-2.11Si-0.31Mn-0.014S-0.007P-0.061Mg

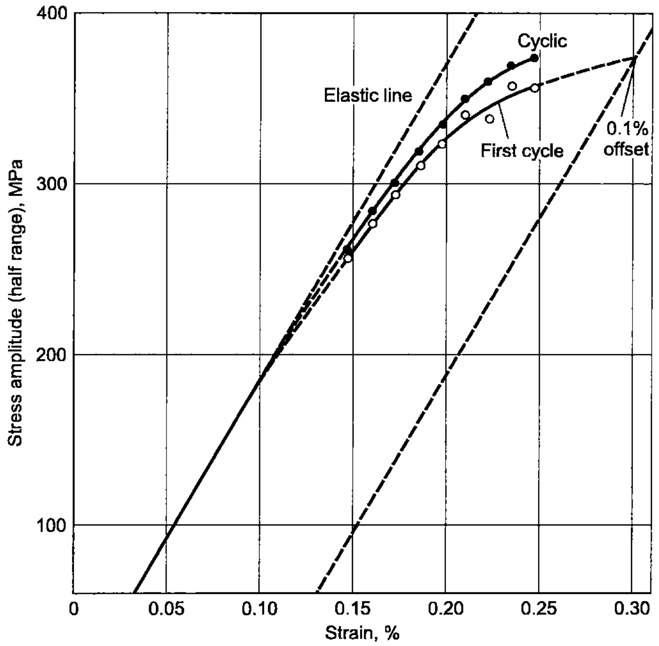
Source: G.N.J. Gilbert and M.J.D. Frier, "The Stress/Strain Properties of a Pearlitic and a Nodular Cast Iron Cyclically Loaded between Equal and Opposite Strain Limits in Tension and Compression," Report 1579, British Cast Iron Research Association (BCIRA), 1984



CI.037 Pearlitic nodular ductile iron casting, tensile monotonic and cyclic stress-strain curves

Curves based on the first cycle of loading and cycle tests carried out at less than 0.1% strain. Strain hardening only contributes a slight increase in raising tensile stress level. Composition: Fe-3.64C-2.25Si-0.38Mn-0.010S-0.019P-0.044Mg

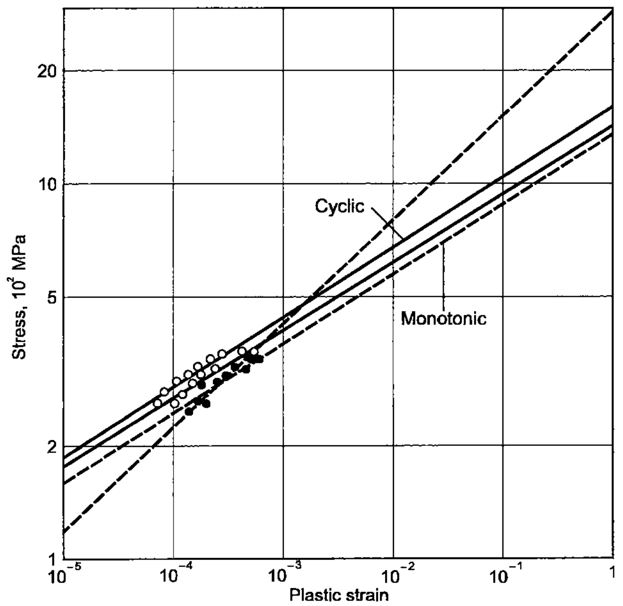
Source: G.N.J. Gilbert, "The Stress/Strain Properties and Fatigue Properties of a Ferritic and a Pearlitic Nodular Cast Iron Tested under Strain Control," Report 1586, British Cast Iron Research Association (BCIRA), 1984



CI.038 Pearlitic nodular ductile iron casting, stress amplitude-strain curves for monotonic and cyclic loading

Curves based on the first cycle of loading and a cycle at approximately half the fatigue life using the stress amplitudes (half stress range). Modulus of elasticity = 183 GPa. Composition: Fe-3.64C-2.25Si-0.38Mn-0.010S-0.019P-0.044Mg

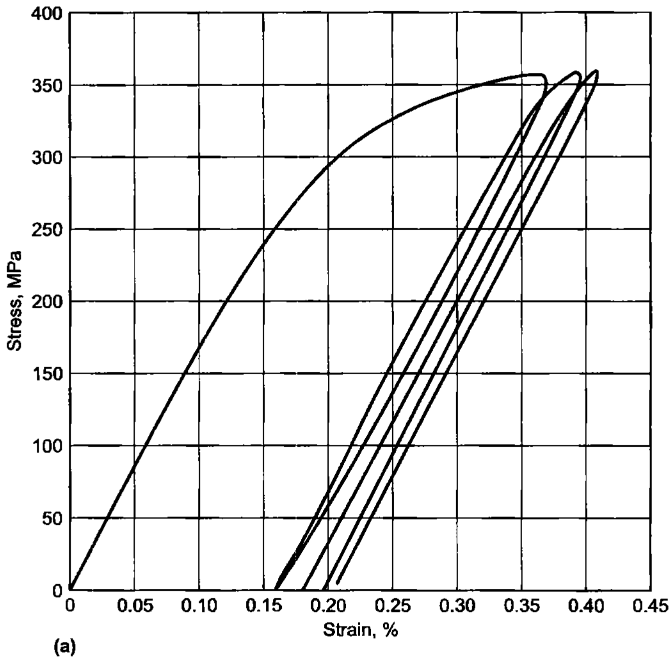
Source: G.N.J. Gilbert, "The Stress/Strain Properties and Fatigue Properties of a Ferritic and a Pearlitic Nodular Cast Iron Tested under Strain Control," Report 1586, British Cast Iron Research Association (BCIRA), 1984



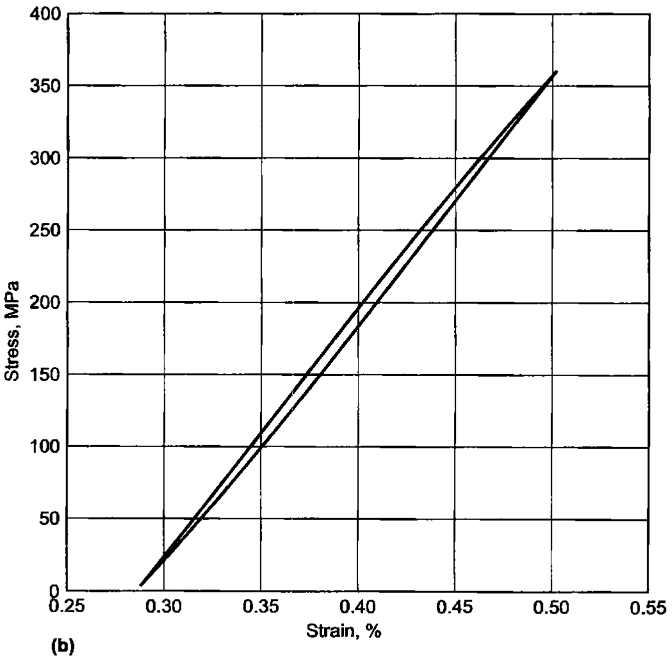
CI.039 Pearlitic nodular ductile iron casting, log stress-log plastic strain curve for monotonic and cyclic loading

Work-hardening behavior shown for monotonic and cyclic loading based on maximum stress (dashed curve) and stress amplitude (solid curve) at approximately half the fatigue life. Half fatigue life is used to define cyclic stress-strain curve because fatigue behavior does not stabilize for these irons. Composition: Fe-3.64C-2.25Si-0.38Mn-0.010S-0.019P-0.044Mg

Source: G.N.J. Gilbert, "The Stress/Strain Properties and Fatigue Properties of a Ferritic and a Pearlitic Nodular Cast Iron Tested under Strain Control," Report 1586, British Cast Iron Research Association (BCIRA), 1984



(a)

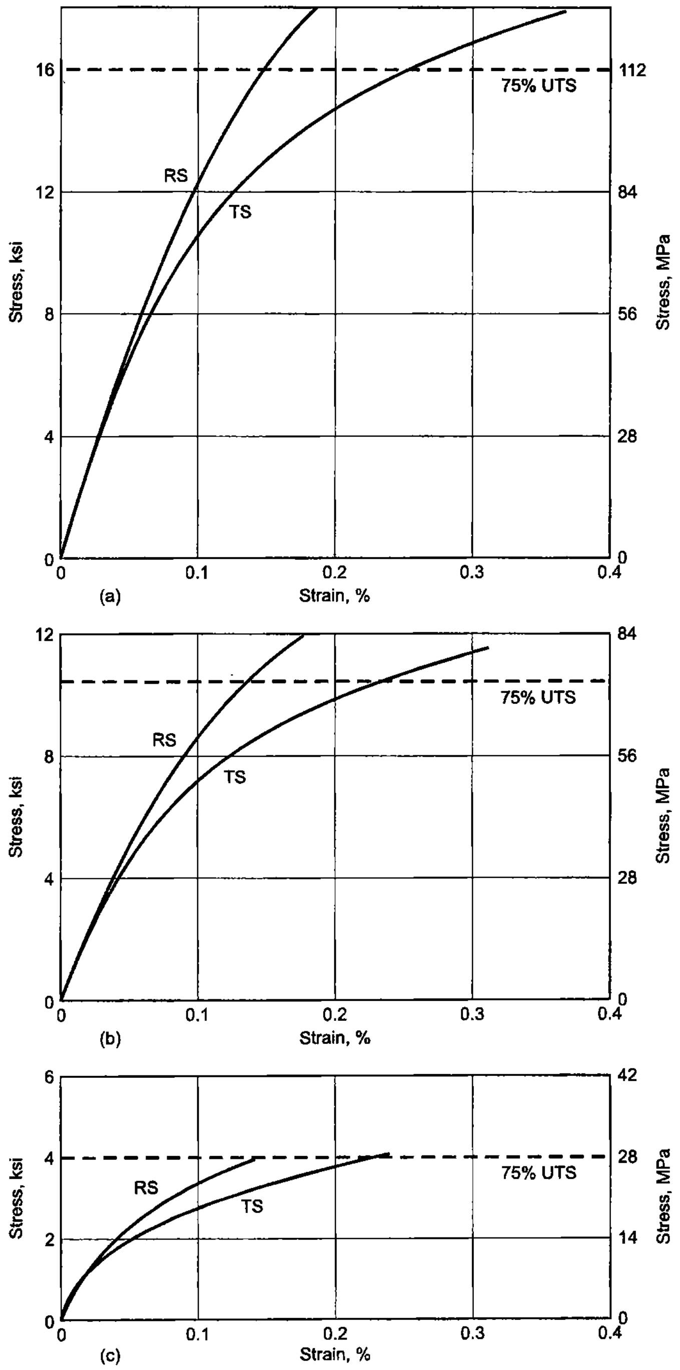


(b)

CI.040 Ductile iron casting, cyclic stress-strain curves

(a) The first several cycles in tension to 350 MPa.
(b) 128 cycles in tension to 350 MPa. Composition: Fe-3.45C-2.18Si-0.33Mn-0.012S-0.004P-0.048Mg

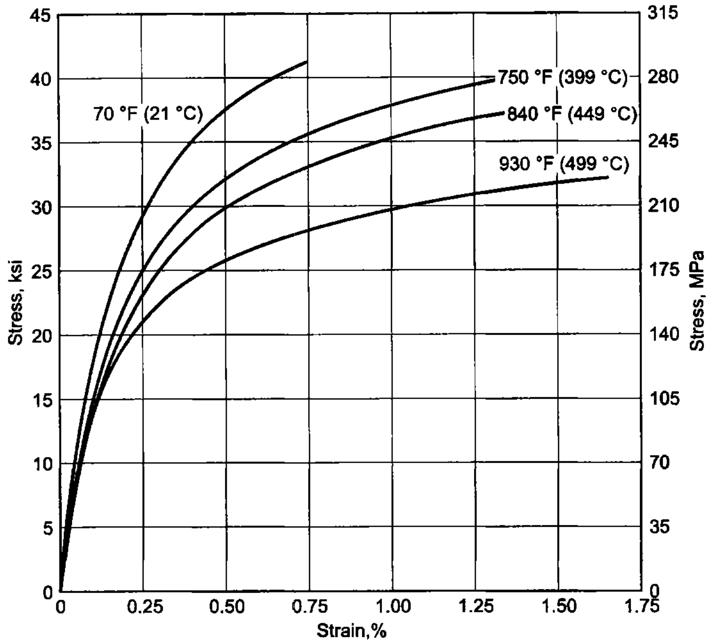
Source: G.N.J. Gilbert, "The Cyclic Stress/Strain Properties of a Ferritic Nodular Iron Tested under Completely Reversed Loading and under Tensile Loading," Report 1534, British Cast Iron Research Association (BCIRA), 1983



CI.041 Gray iron casting, tensile stress-strain curves showing effect of graphite form

TS, total strain; RS, recoverable strain; UTS, 75% ultimate tensile strength. (a) Compacted graphite. (b) Type A graphite. (c) Widmanstätten graphite

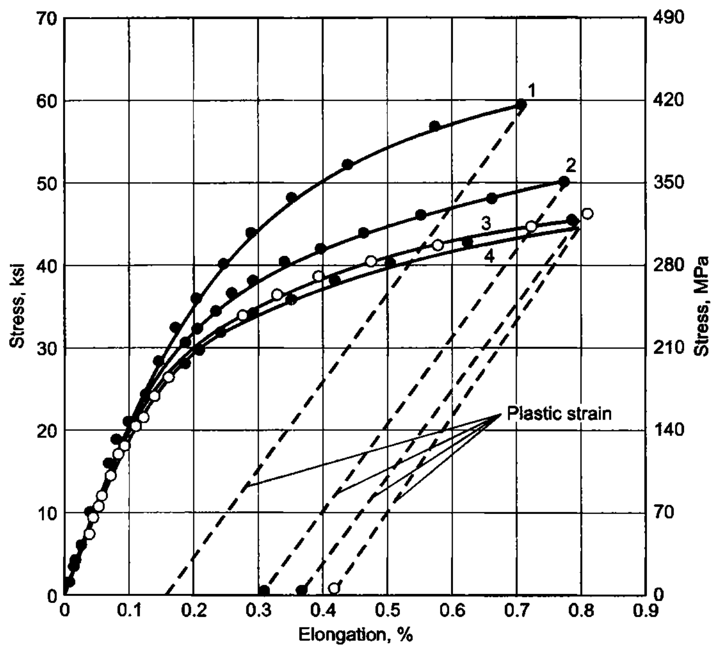
Source: R.E. Maringer, "Damping Capacity of Materials," Report RSIC-508, Battelle Memorial Institute, Redstone Scientific Information Center, Redstone Arsenal, Jan 1966, AD 640465. As published in *Structural Alloys Handbook*, Vol 1, CINDAS/Purdue University, 1994, p 20



CI.042 Gray iron casting, stress-strain curves to fracture at room and elevated temperatures

Composition: Fe-3.19C-(CC-0.85)-1.66Si- 0.91Mn-0.077P-0.089S

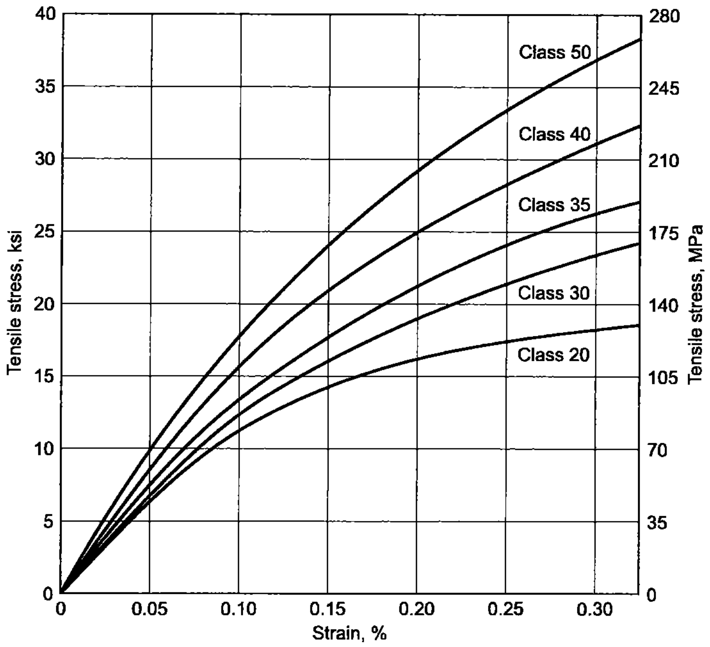
Source: C.F. Walton, *Gray and Ductile Iron Castings Handbook,* Gray and Ductile Iron Founders' Society, 1965. As published in *Structural Alloys Handbook,* Vol 1, CINDAS/Purdue University, 1994, p 20



CI.043 Pearlitic gray iron casting, stress-strain curves showing effect of section size

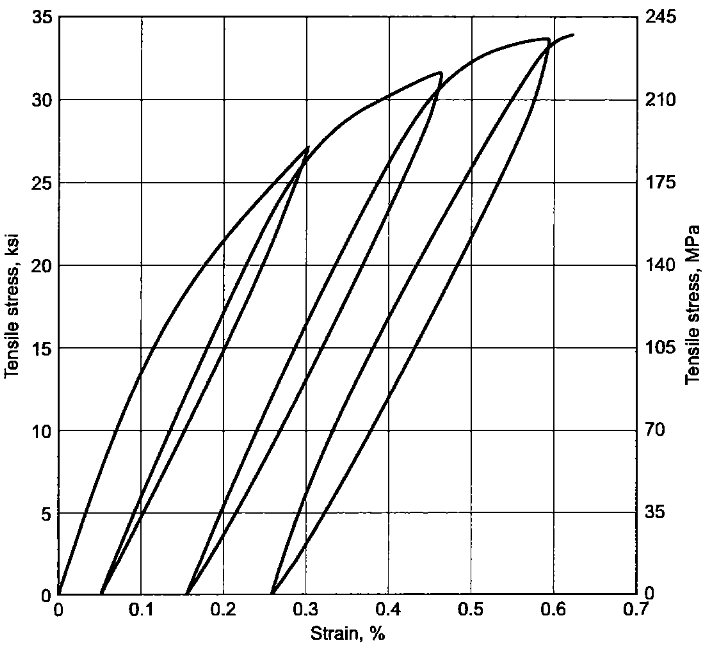
Casting thickness: curve 1, 12.7 mm (0.5 in.); curve 2, 25.4 mm (1 in.); curve 3, 152.4 mm (6 in.); curve 4, 76.2 mm (3 in.). Dashed lines indicate plastic strain.

Source: C.F. Walton, *Gray and Ductile Iron Castings Handbook,* Gray and Ductile Iron Founders' Society, Aug 1971. As published in *Structural Alloys Handbook,* Vol 1, CINDAS/Purdue University, 1994, p 20



CI.044 Class 20 to 50 gray iron casting, tensile stress-strain curves

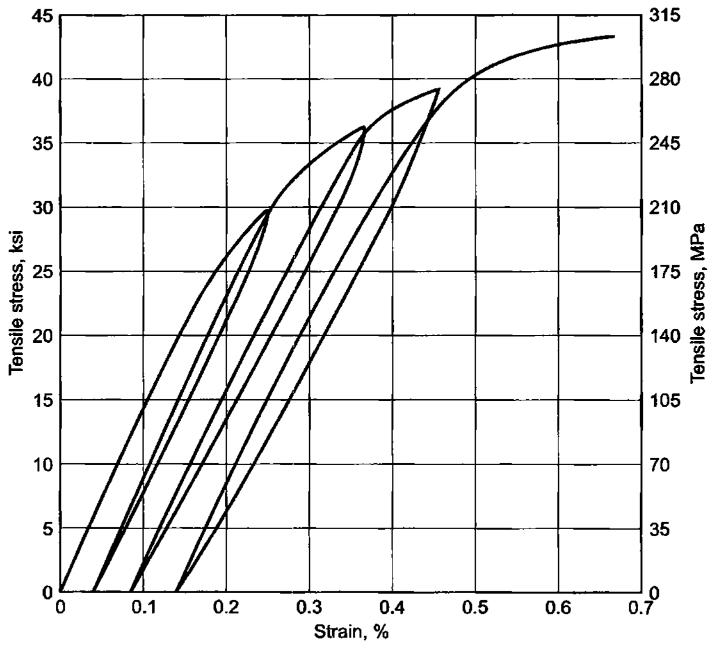
Source: J.L. Herron, R.A. Flinn, and P.K. Trojan, Research for the article: Mechanical Properties of Gray Iron, *Iron Castings Handbook,* C.F. Walton, Ed., Iron Casting Society, 1981, p 211



CI.045 Class 30 gray iron casting, cyclic tensile stress-strain curves

Permanent deformation results from removal and reapplication of load.

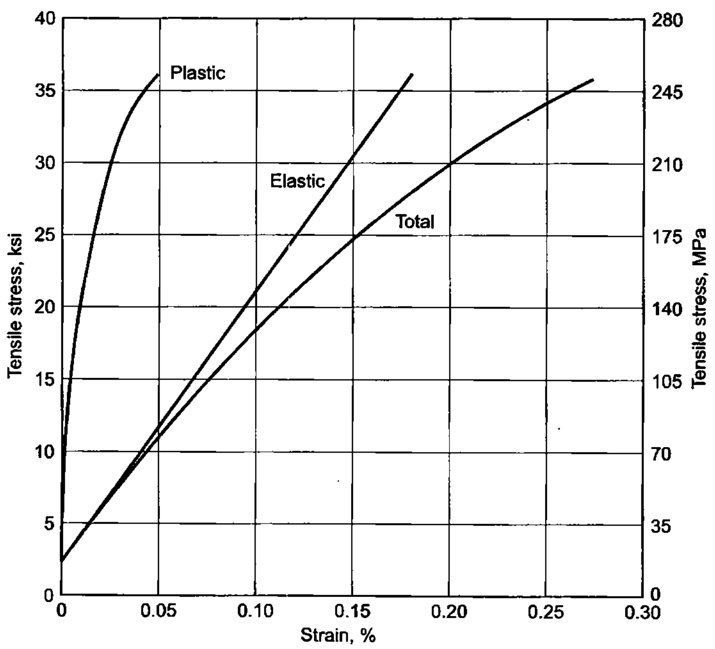
Source: J.L. Herron, R.A. Flinn, and P.K. Trojan, Research for the article: Mechanical Properties of Gray Iron, *Iron Castings Handbook,* C.F. Walton, Ed., Iron Casting Society, 1981, p 229



CI.046 Class 40 gray iron casting, cyclic tensile stress-strain curves

Permanent deformation results from removal and reapplication of load.

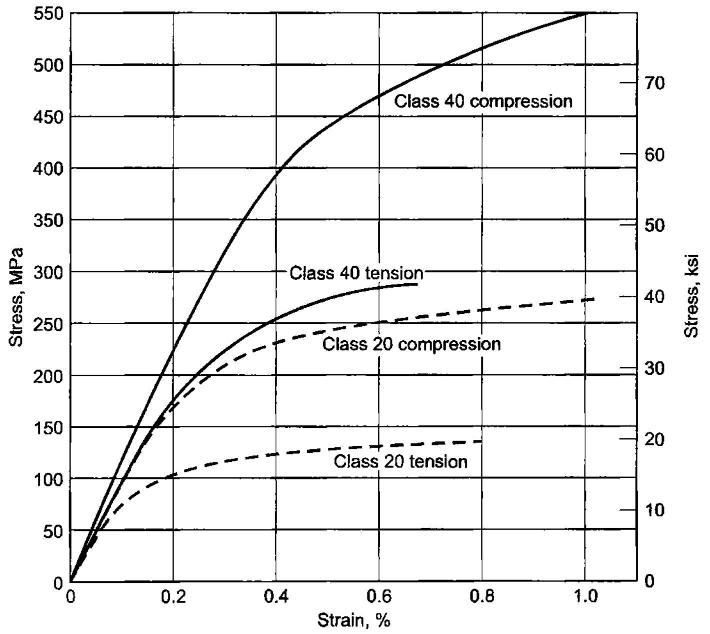
Source: J.L. Herron, R.A. Flinn, and P.K. Trojan, Research for the article: Mechanical Properties of Gray Iron, *Iron Castings Handbook,* C.F. Walton, Ed., Iron Casting Society, 1981, p 229



CI.047 Pearlite gray iron casting, tensile stress-strain curves

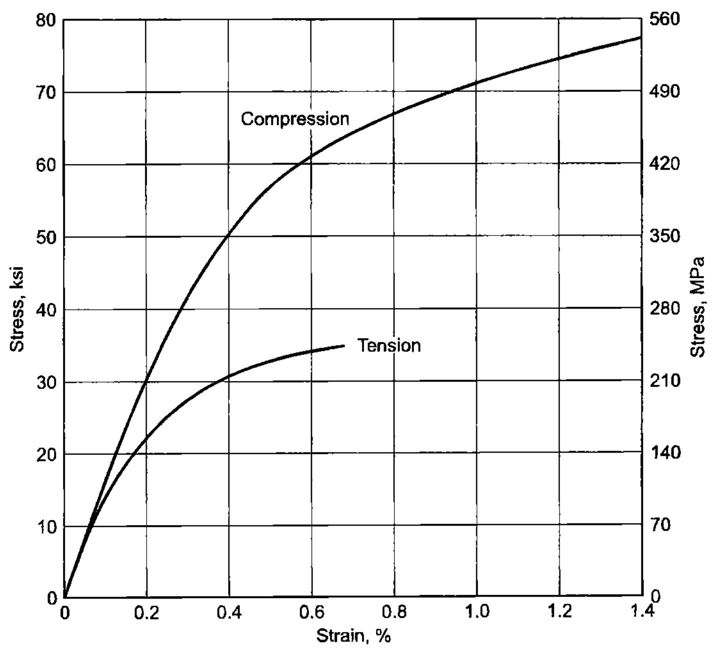
Total strain is composed of plastic and elastic portions.

Source: J.W. Grant, Comprehensive Mechanical Tests of Two Pearlite Gray Irons, *J. Res. BCIRA,* Vol 3, April 1951, p 861–875. Adapted from C.F. Walton, Ed., *Iron Castings Handbook,* Iron Casting Society, 1981, p 228



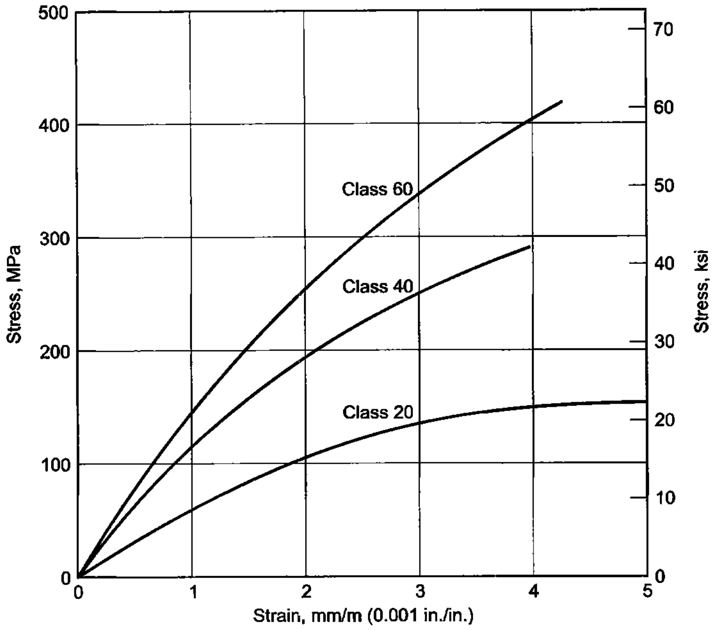
CI.048 Class 20 and 40 gray iron casting, tensile and compressive stress-strain curves

Source: J.L. Herron, R.A. Flinn, and P.K. Trojan, Research for the article: Mechanical Properties of Gray Iron, *Iron Castings Handbook*, C.F. Walton, Ed., Iron Casting Society, 1981, p 235



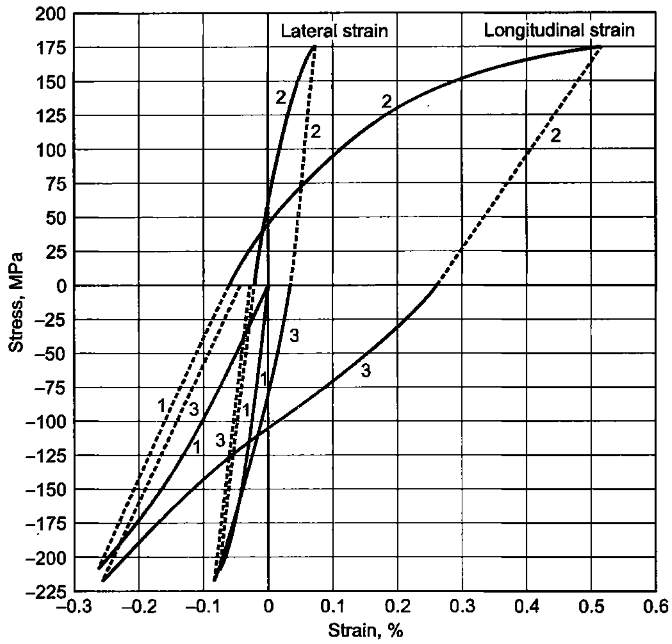
CI.049 Class 35 gray iron casting, tensile and compressive stress-strain curves

Source: J.L. Herron, R.A. Flinn, and P.K. Trojan, Research for the article: Mechanical Properties of Gray Iron, *Iron Castings Handbook*, C.F. Walton, Ed., Iron Casting Society, 1981, p 234



CI.050 Class 20, 40, and 60 gray iron casting, typical tensile stress-strain curves

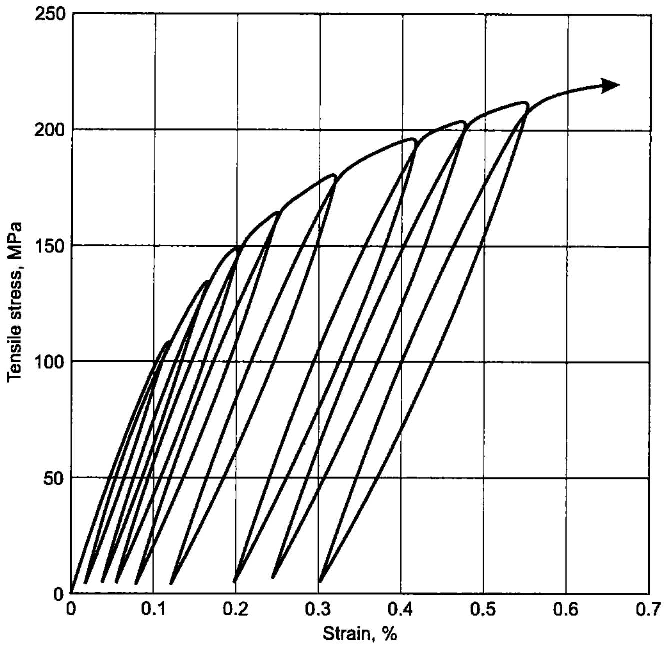
Source: Gray Iron, *Properties and Selection: Irons, Steels, and High-Performance Alloys,* Vol 1, *ASM Handbook,* 1990, p 20



CI.051 Gray iron casting, tensile and compressive longitudinal and lateral stress-strain curves

Progression of test follows numbers 1–3 (solid line 1 to dashed line 1 to solid line 2 to dashed line 2, etc.). Solid lines are load applications; dashed lines are relaxations. These are relatively high stresses. Composition: Fe-3.2C-2.19Si-0.56Mn-0.031S-0.046P

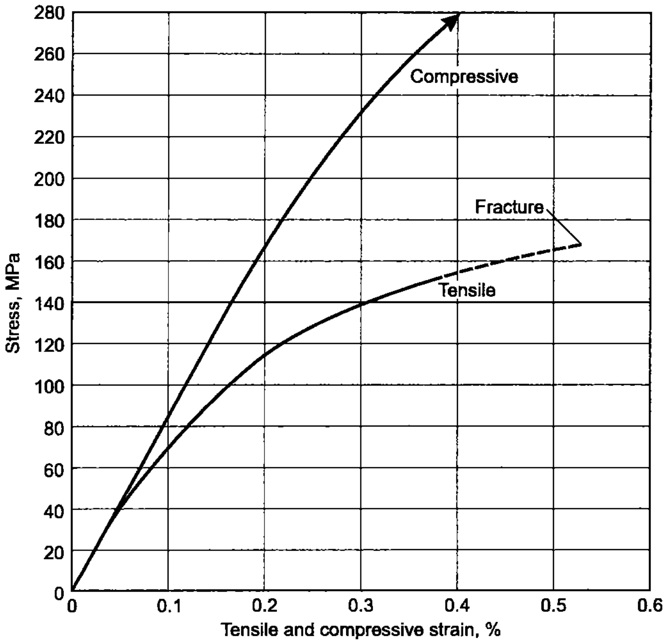
Source: G.N.J. Gilbert, Stress/Strain Properties of Cast Iron and Poisson's Ratio in Tension and Compression, *BCIRA J.,* Vol 9 (No. 3), May 1961, p 351



CI.052 Flake graphite, gray iron casting, tensile stress-strain curves with cyclic loading to increasing stress levels

Ultimate strength = 230 MPa. Permanent deformation increases with increasing stress levels.

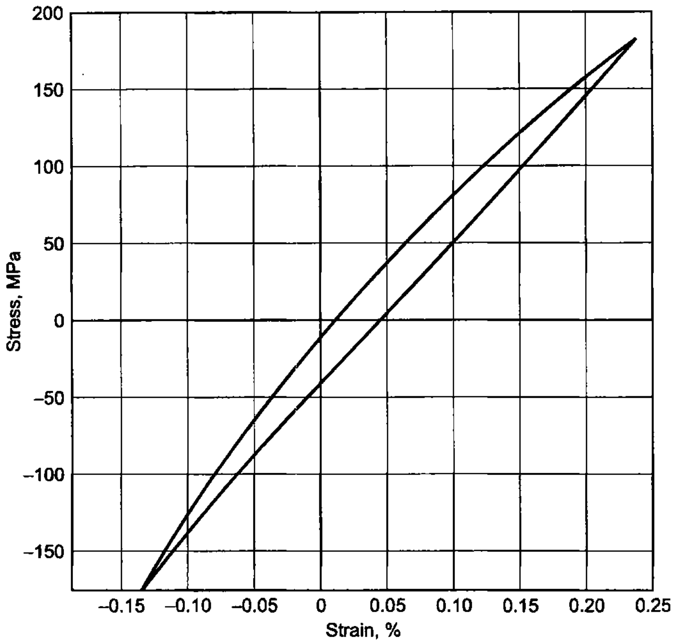
Source: "Stress/Strain Behaviour of Flake Graphite Cast Irons," Broadsheet 157-1, British Cast Iron Research Association (BCIRA), 1977



CI.053 Flake graphite, gray iron casting, comparison of tensile and compressive stress-strain curves

Compressive strength ≃ 600 MPa

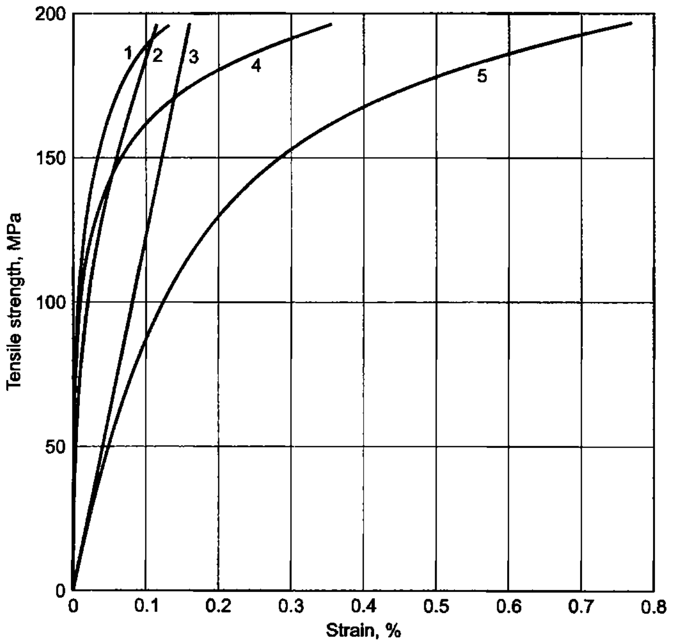
Source: "Stress/Strain Behaviour of Flake Graphite Cast Irons," Broadsheet 157-1, British Cast Iron Research Association (BCIRA), 1977



CI.054 Flake graphite, gray iron casting, cyclic stress-strain curves

Stress-strain curves for cycles 129–132 with loads varying ±175 MPa. The hysteresis loop advances to the right as the number of cycles increase.

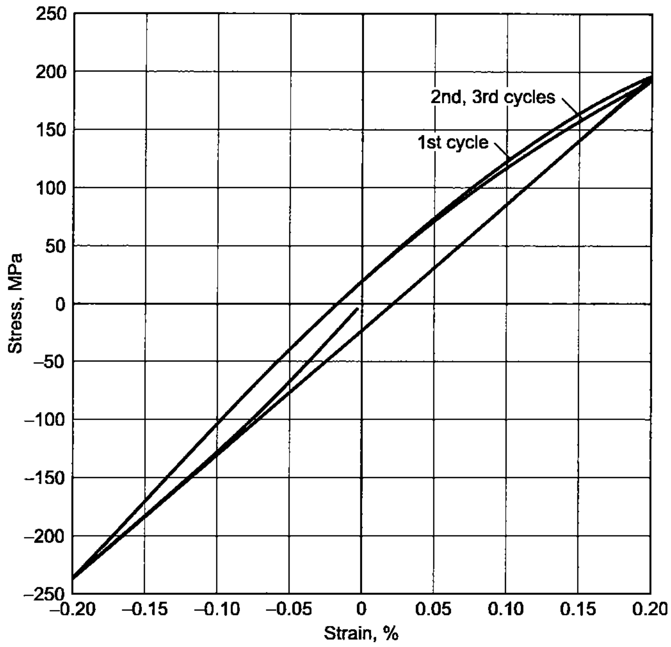
Source: G.N.J. Gilbert and S.D. Kemp, "The Cyclic Stress/Strain Properties of a Flake Graphite Cast Iron—A Progress Report," Report 1384, British Cast Iron Research Association (BCIRA), July 1980



CI.055 Gray iron casting, components of total stress-strain curves

Considering iron as a composite, the total strain 5, can be thought of consisting of the 1, plastic matrix; 2, voids with recoverable deformation; 3, elastic matrix; 4, voids with permanent deformation. Iron can be considered having a steel-like matrix with volume changes occurring in the spaces occupied by graphite. Iron tensile strength = 213 MPa

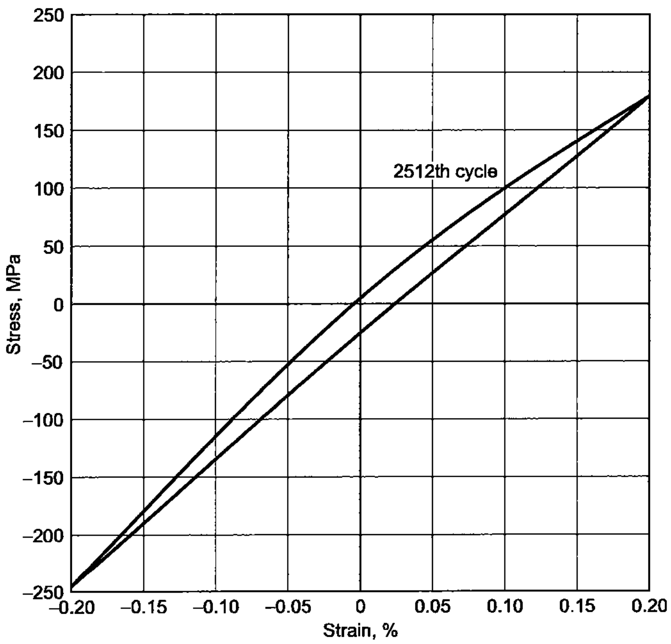
Source: G.N.J. Gilbert, "The Cyclic Stress/Strain Properties and Fatigue Properties of a Flake Graphite Cast Iron Tested under Strain Control—A Detailed Study," Report 1621, British Cast Iron Research Association (BCIRA), 1985



CI.056 Gray iron casting, cyclic stress-strain curves

Curves for first three cycles to ±0.20% strain. Composition: Fe-3.13C-2.15Si-0.35Mn-0.025S-0.086P

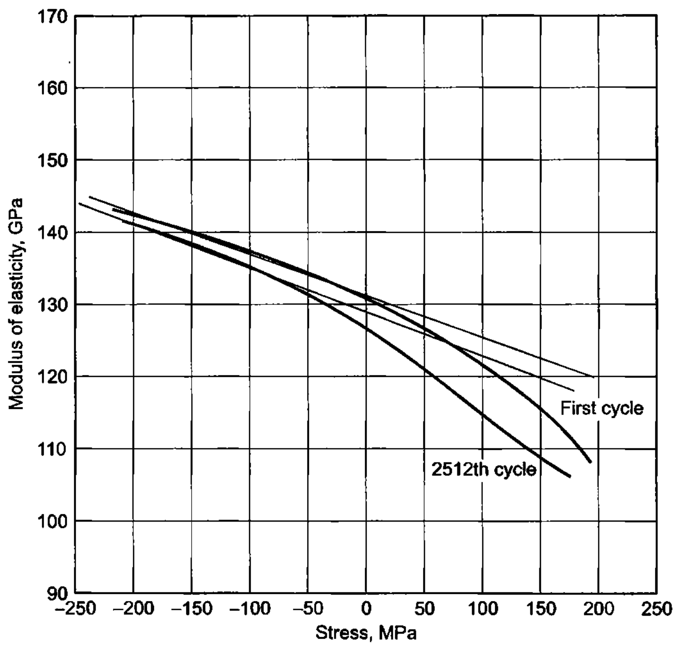
Source: G.N.J. Gilbert, "The Cyclic Stress/Strain Properties and Fatigue Properties of a Flake Graphite Cast Iron Tested under Strain Control—A Detailed Study," Report 1621, British Cast Iron Research Association (BCIRA), 1985



CI.057 Gray iron casting, cyclic stress-strain curves

Curve for 2512th cycle to ±0.20% strain. (Fatigue failure occurred at 3769 cycles.) Composition: Fe-3.13C-2.15Si-0.35Mn-0.025S-0.086P

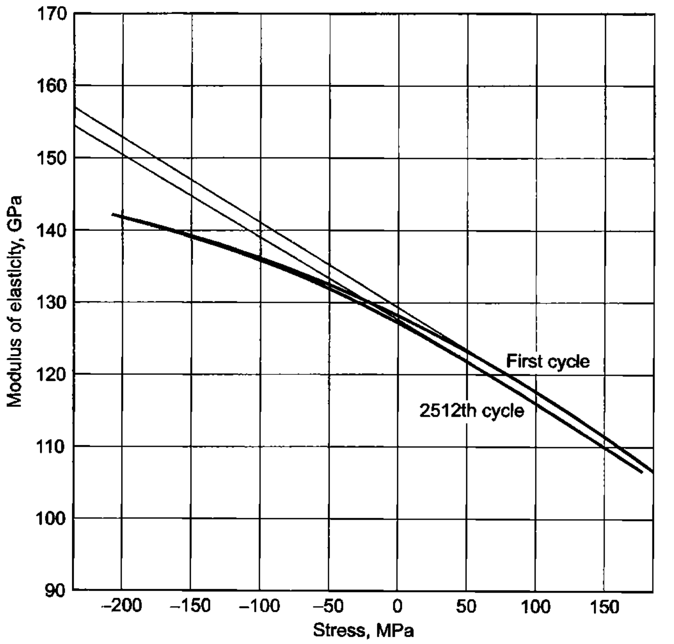
Source: G.N.J. Gilbert, "The Cyclic Stress/Strain Properties and Fatigue Properties of a Flake Graphite Cast Iron Tested under Strain Control—A Detailed Study," Report 1621, British Cast Iron Research Association (BCIRA), 1985



CI.058 Gray iron casting, modulus of elasticity-stress curves

Modulus of elasticity (*E*) for compression of first and 2512th cycle. At maximum compressive stress (0.0020 strain controlled) first cycle, $E = 144.95$ GPa; 2512th cycle, $E = 144.20$ GPa

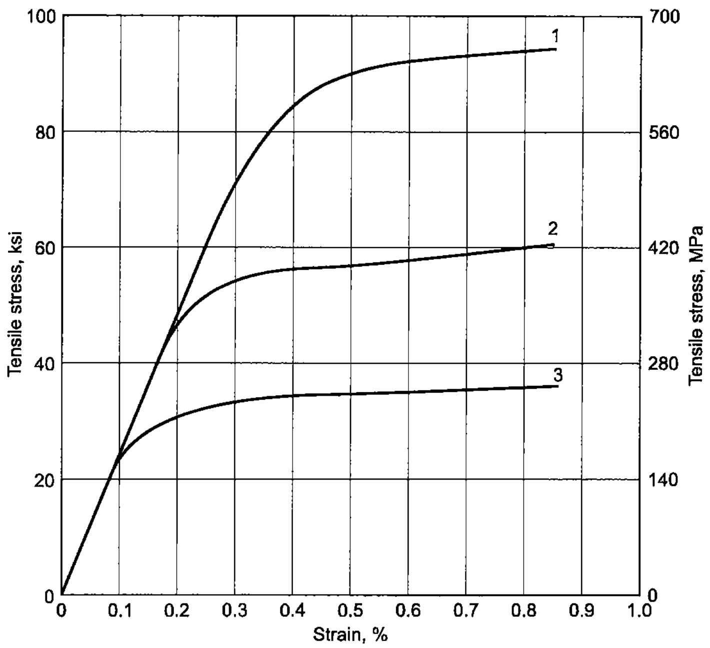
Source: G.N.J. Gilbert, "The Cyclic Stress/Strain Properties and Fatigue Properties of a Flake Graphite Cast Iron Tested under Strain Control—A Detailed Study," Report 1621, British Cast Iron Research Association (BCIRA), 1985



CI.059 Gray iron casting, modulus of elasticity-stress curves

Modulus of elasticity (*E*) for tension of first and 2512th cycle. At maximum tensile stress (0.0020 strain controlled) first cycle, $E = 157.62$ GPa; 2512th cycle, $E = 155.62$ GPa.

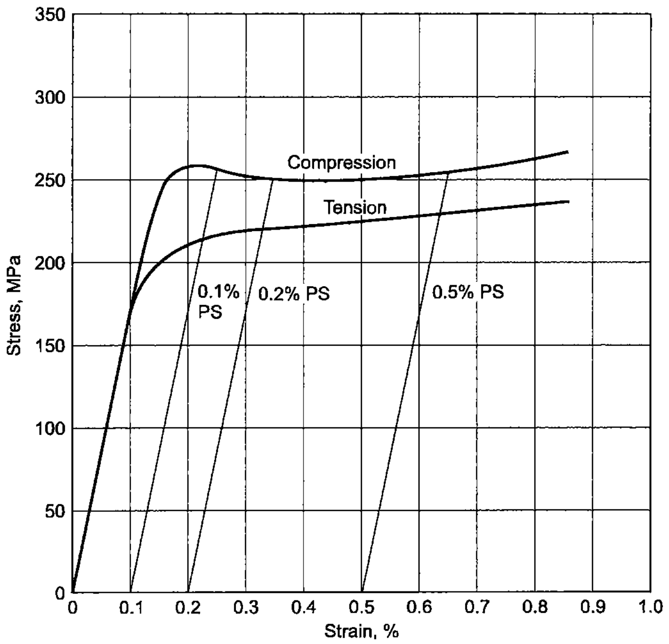
Source: G.N.J. Gilbert, "The Cyclic Stress/Strain Properties and Fatigue Properties of a Flake Graphite Cast Iron Tested under Strain Control—A Detailed Study," Report 1621, British Cast Iron Research Association (BCIRA), 1985



CI.060 Pearlitic and ferritic malleable iron casting, typical tensile stress-strain curves

Typical curves obtained from machined cast-to-shape test bars. Curve 1, pearlitic, oil quenched; curve 2, pearlitic, air quenched; curve 3, ferritic

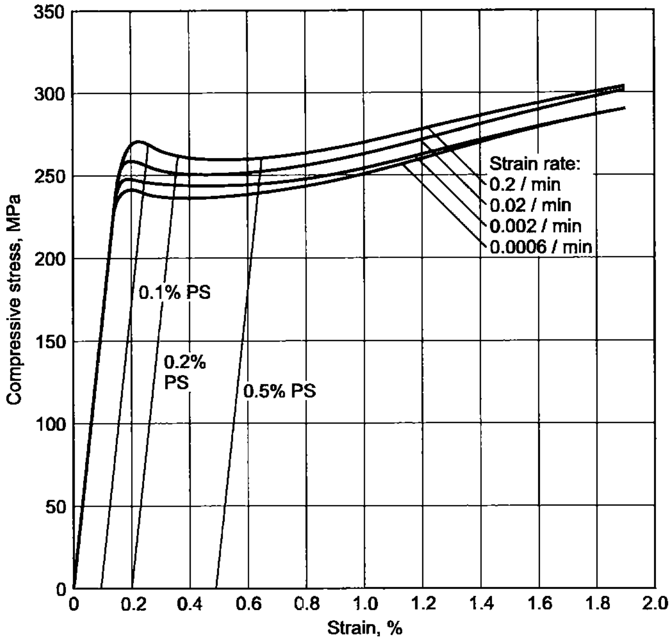
Source: L.W.L. Smith and G.N.J. Gilbert, "The Tensile Properties of Blackheart and Pearlitic Malleable Irons—A Progress Report," Report 1363, British Cast Iron Research Association (BCIRA), Jan 1980, p 49–62. As published in C.F. Walton, Ed., *Iron Castings Handbook*, Iron Casting Society, 1981, p 304



CI.061 Blackheart malleable iron casting, tensile and compressive stress-strain curves

Produced at 980 °C, fast cooled to 760 °C, slow cooled to 700 °C. Specimens were as-cast to shape. Tested at strain rate of 0.01/min. 0.2% proof stress (PS): tensile, 346 MPa; compressive, 284 MPa. Compressive PS at 0.2% is slightly less than at 0.1%. Composition: Fe-2.46C-1.40Si-0.46Mn-0.178S-0.034P-0.0032B-0.001Al-0.038Cr

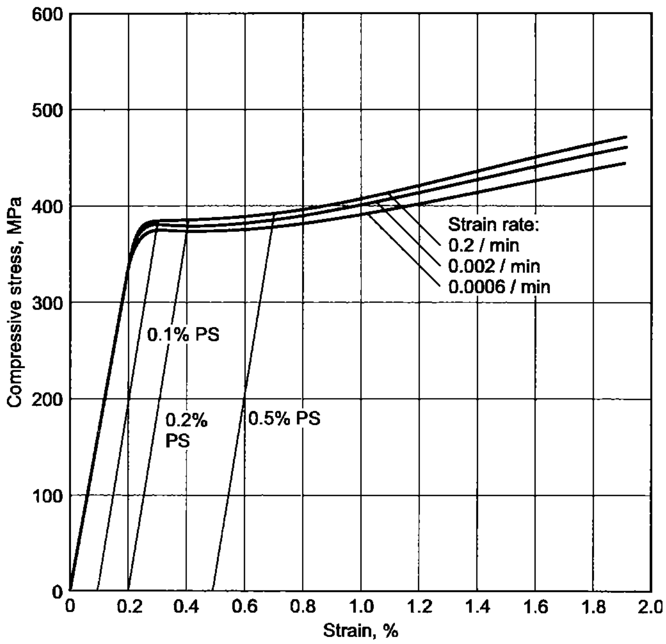
Source: L.W. Smith, "The Effect of Strain Rate on the Compressive Stress/Strain Properties of Malleable Irons," Report 1508, British Cast Iron Research Association (BCIRA), 1983, p 32



CI.062 Blackheart malleable iron casting, compressive stress-strain curves with effect of strain rate

Produced at 980 °C, fast cooled to 760 °C, slow cooled to 700 °C. Specimens were as-cast to shape. Tested at strain rates shown. 0.2% proof stresses (PS) vary from 236–261 MPa. Composition: Fe-2.46C-1.40Si-0.46Mn-0.178S-0.034P-0.0032B-0.001Al-0.038Cr

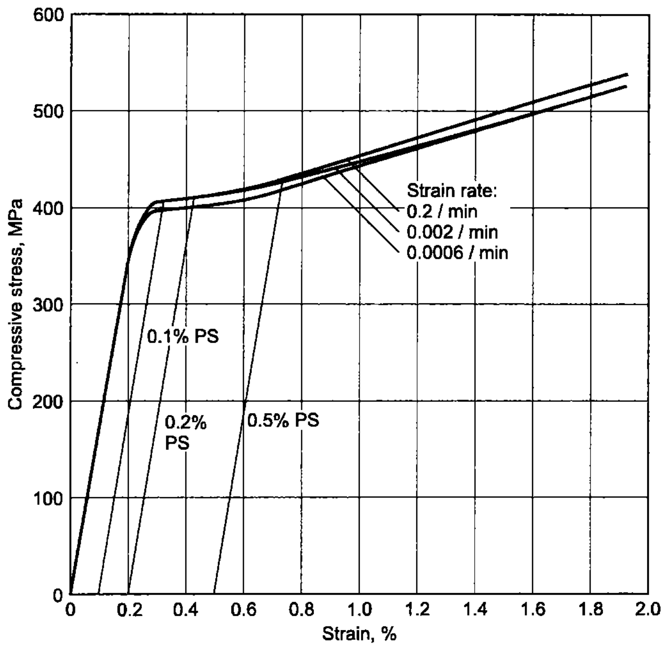
Source: L.W. Smith, "The Effect of Strain Rate on the Compressive Stress/Strain Properties of Malleable Irons," Report 1508, British Cast Iron Research Association (BCIRA), 1983, p 35



CI.063 Pearlitic malleable iron casting, compressive stress-strain curves with effect of strain rate

Annealed, 870 °C, air quenched, tempered, 700 °C, 6 h, 600 °C, 4 h. Specimens were as-cast to shape. Tested at strain rates shown. 0.2% proof stresses (PS) vary from 375–393 MPa. Composition: Fe-2.51C-1.43Si-0.50Mn-0.201S-0.039P-0.0031B-0.015Al-0.040Cr

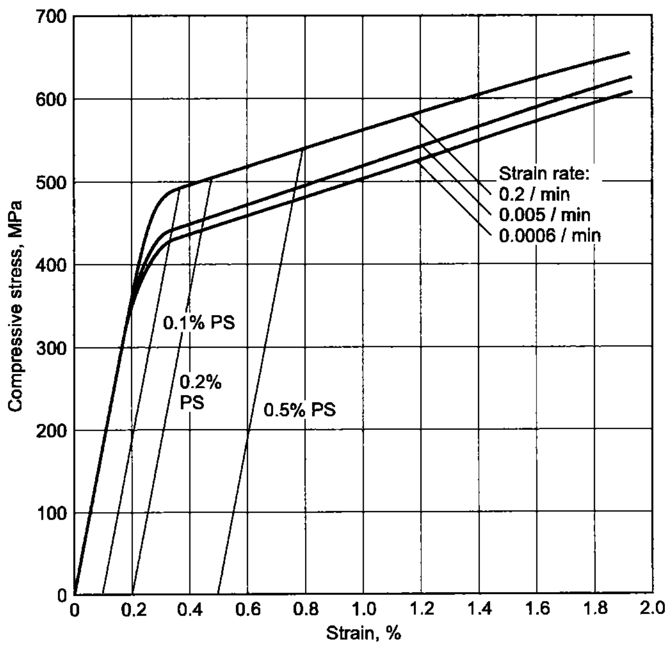
Source: L.W. Smith, "The Effect of Strain Rate on the Compressive Stress/Strain Properties of Malleable Irons," Report 1508, British Cast Iron Research Association (BCIRA), 1983, p 36



CI.064 Pearlitic malleable iron casting, compressive stress-strain curves with effect of strain rate

Annealed, 870 °C, air quenched, tempered, 700 °C, 6 h. Specimens were as-cast to shape. Tested at strain rates shown. 0.2% proof stresses (PS) vary from 398–410 MPa. Composition: Fe-2.44C-1.54Si-0.50Mn-0.180S-0.039P-0.0036B-0.020Al-0.048Cr

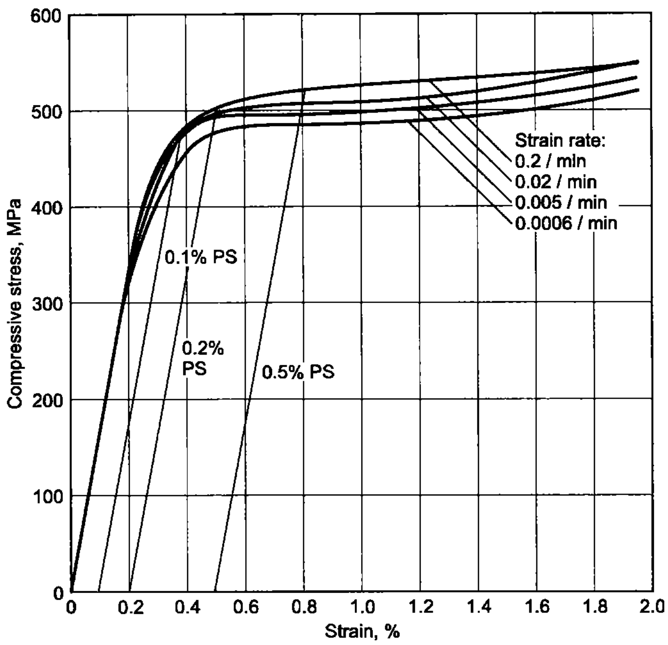
Source: L.W. Smith, "The Effect of Strain Rate on the Compressive Stress/Strain Properties of Malleable Irons," Report 1508, British Cast Iron Research Association (BCIRA), 1983, p 36



CI.065 Pearlitic malleable iron casting, compressive stress-strain curves with effect of strain rate

Annealed, 870 °C, air quenched, reheated to 640 °C in 1.5 h, tempered, 640 °C, 4 h. Specimens were as-cast to shape. Tested at strain rates shown. 0.2% proof stresses (PS) vary from 439–502 MPa. Composition: Fe-2.41C-1.37Si-0.50Mn-0.192S-0.034P-0.0035B-0.041Cr

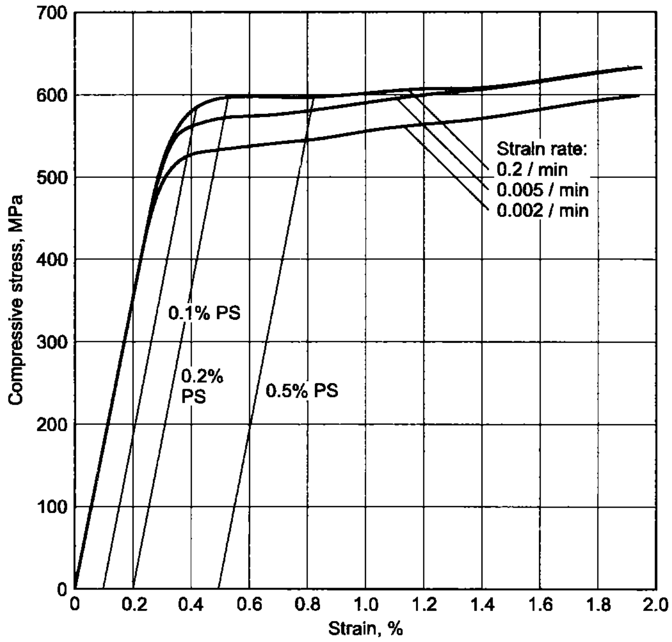
Source: L.W. Smith, "The Effect of Strain Rate on the Compressive Stress/Strain Properties of Malleable Irons," Report 1508, British Cast Iron Research Association (BCIRA), 1983, p 36



CI.066 Pearlitic malleable iron casting, compressive stress-strain curves with effect of strain rate

Annealed, 840 °C, oil quenched, tempered, 680 °C, 2 h. Specimens were as-cast to shape. Tested at strain rates shown. 0.2% proof stresses (PS) vary from 468–502 MPa. Composition: Fe-2.46C-1.40Si-0.51Mn-0.206S-0.043P-0.0032B-0.040Cr

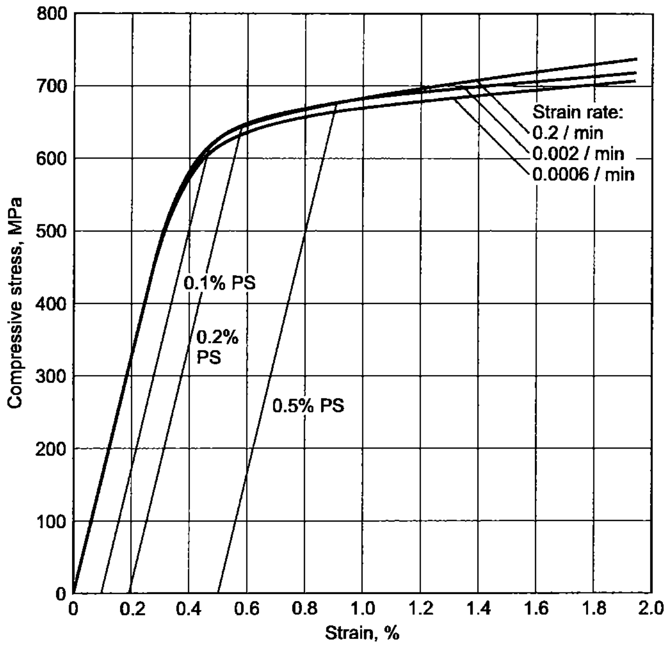
Source: L.W. Smith, "The Effect of Strain Rate on the Compressive Stress/Strain Properties of Malleable Irons," Report 1508, British Cast Iron Research Association (BCIRA), 1983, p 32



CI.067 Pearlitic malleable iron casting, compressive stress-strain curves with effect of strain rate

Annealed, 840 °C, oil quenched, tempered, 650 °C, 2 h. Specimens were as-cast to shape. Tested at strain rates of 0.0006–0.20/min; three curves shown for clarity. 0.2% proof stresses (PS) vary from 530–599 MPa. Composition: Fe-2.43C-1.35Si-0.50Mn-0.213S-0.042P-0.0035B-0.040Cr

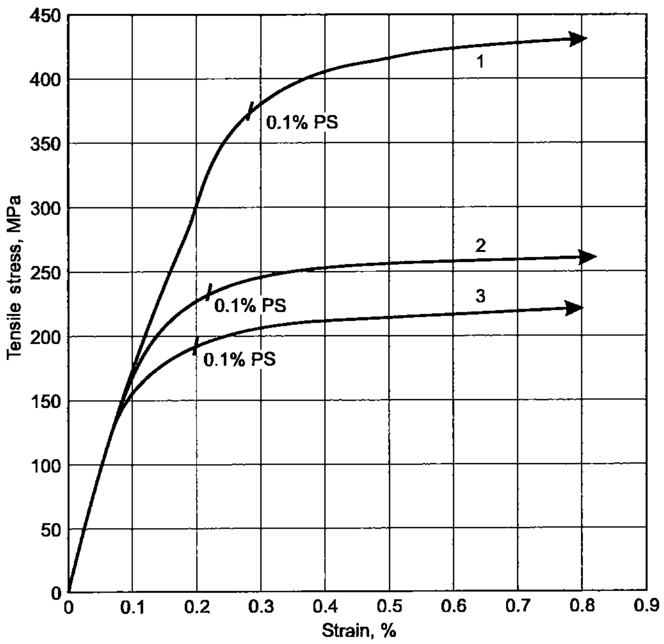
Source: L.W. Smith, "The Effect of Strain Rate on the Compressive Stress/Strain Properties of Malleable Irons," Report 1508, British Cast Iron Research Association (BCIRA), 1983, p 37



CI.068 Pearlitic malleable iron casting, compressive stress-strain curves with effect of strain rate

Air quenched and tempered malleable iron was reheated to 870 °C, oil quenched, tempered, 600 °C, 2.5 h. Specimens were as-cast to shape. Tested at strain rates of 0.0006–0.20/min; three curves shown for clarity. 0.2% proof stresses (PS) vary from 625–644 MPa. Composition: Fe-2.58C-1.45Si-0.53Mn-0.218S-0.032P-0.0031B-0.043Cr

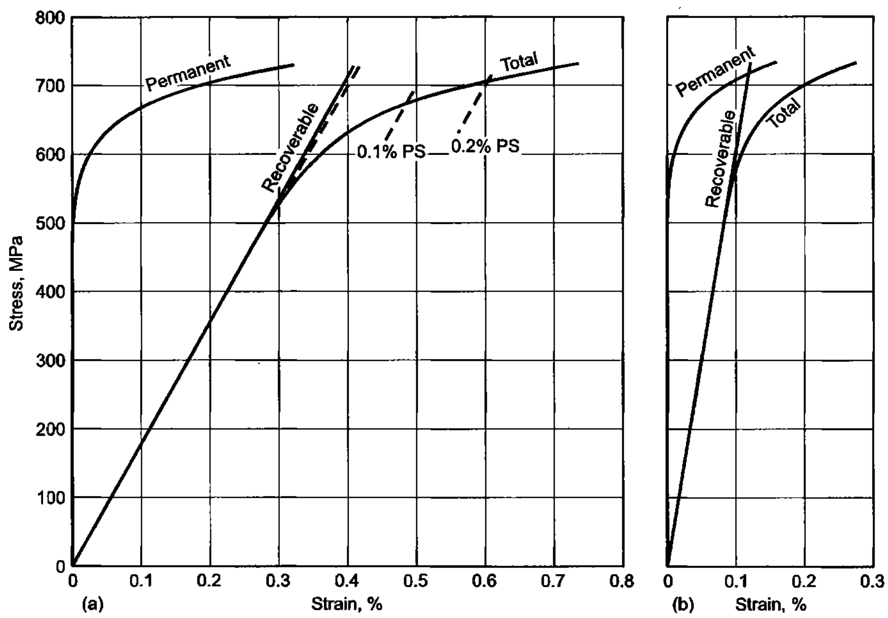
Source: L.W. Smith, "The Effect of Strain Rate on the Compressive Stress/Strain Properties of Malleable Irons," Report 1508, British Cast Iron Research Association (BCIRA), 1983, p 39



CI.069 Malleable iron casting, typical tensile stress-strain curves at 20 °C

Curve 1: pearlitic malleable iron, ultimate strength = 564 MPa; 0.1% proof stress (PS) = 377 MPa. Curve 2: whiteheart malleable iron, ultimate strength = 425 MPa; 0.1% proof stress = 233 MPa. Curve 3: ferritic malleable iron, ultimate strength = 324 MPa, 0.1% proof stress = 193 MPa. Allowable design stress is significantly less than the proof stress.

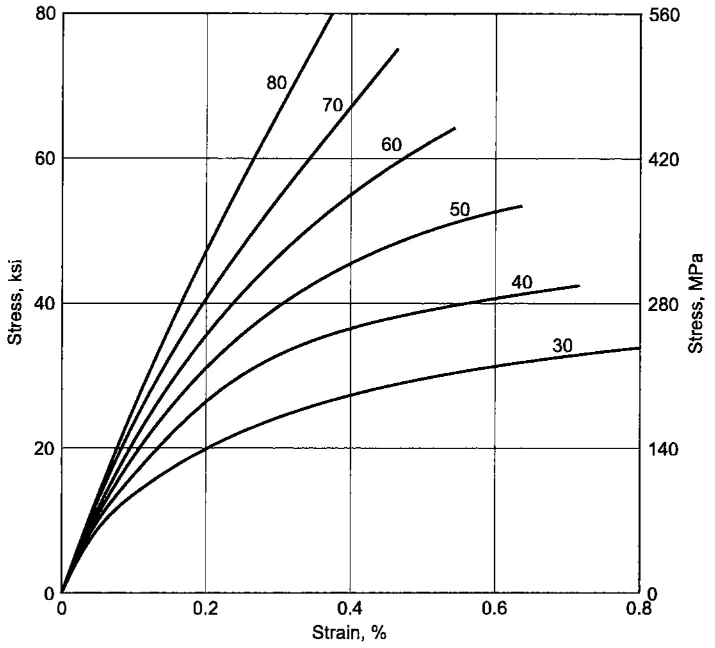
Source: "Stress/Strain Behaviour of Nodular and Malleable Cast Irons," Broadsheet 157-2, British Cast Iron Research Association (BCIRA), 1981



CI.070 High-silicon nodular graphite iron casting, longitudinal compressive stress-strain curves (a) with lateral expansion (b)

Test specimen size = 28.651 mm diam × 76.2 mm gage length (1.128 in. diam × 3 in. gage length). Permanent strain remains when sample unloaded. Total strain is permanent plus recoverable. 0.1% proof stress (PS) = 676 MPa; 0.2% proof stress = 707 MPa. Composition: Fe-2.62C-6.14Si-0.35Mn-0.014S-0.021P-0.78Ni-0.051Mg-0.006Ce

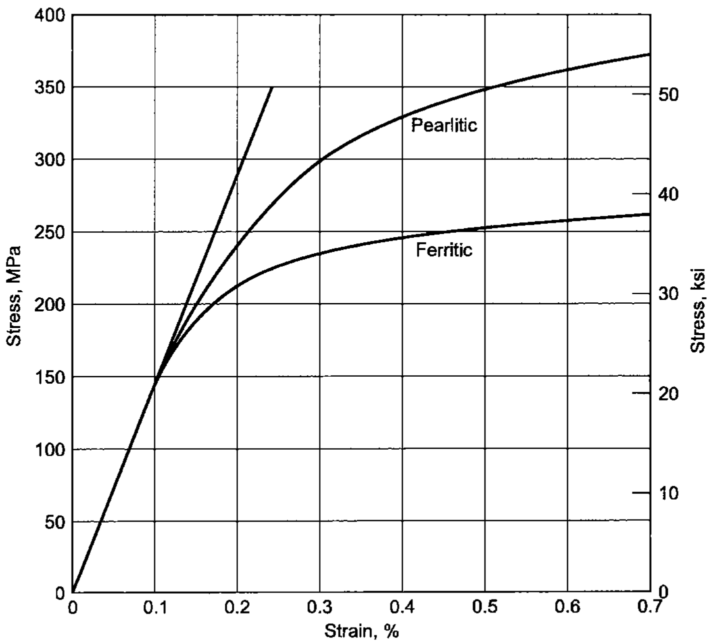
Source: G.N.J. Gilbert, The Stress/Strain Properties of Nodular Cast Irons in Tension and Compression, *BCIRA J.*, Vol 12 (No. 2), March 1964, p 183



CI.071 Nickel alloy iron casting, tensile stress-strain curves

Various classes of nickel cast irons

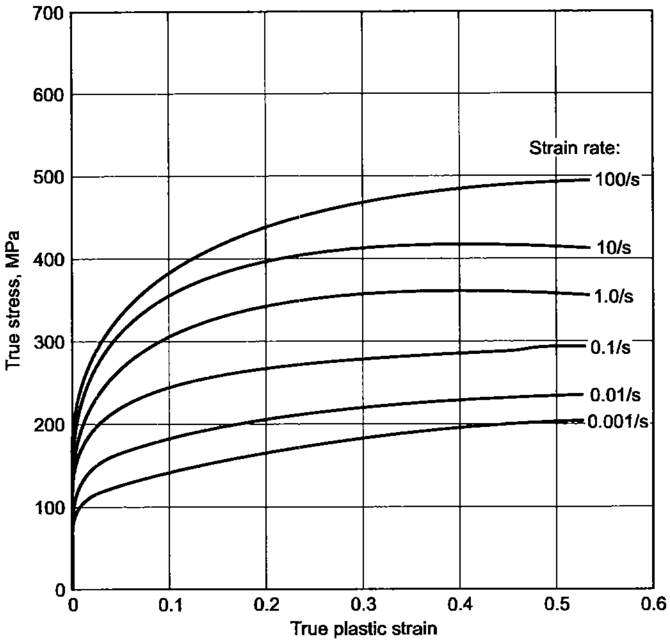
Source: "Engineering Properties and Applications of Nickel Cast Irons," International Nickel Co. As published in *Structural Alloys Handbook,* Vol 1, CINDAS/Purdue University, 1994, p 7



CI.072 Pearlitic and ferritic compacted graphite iron casting, typical stress-strain curves

Modulus of elasticity = 144 GPa. Pearlitic iron: tensile strength = 410 MPa (59.5 ksi); elongation = 1%. Ferritic iron: tensile strength = 320 MPa (46.5 ksi); elongation = 3.5%

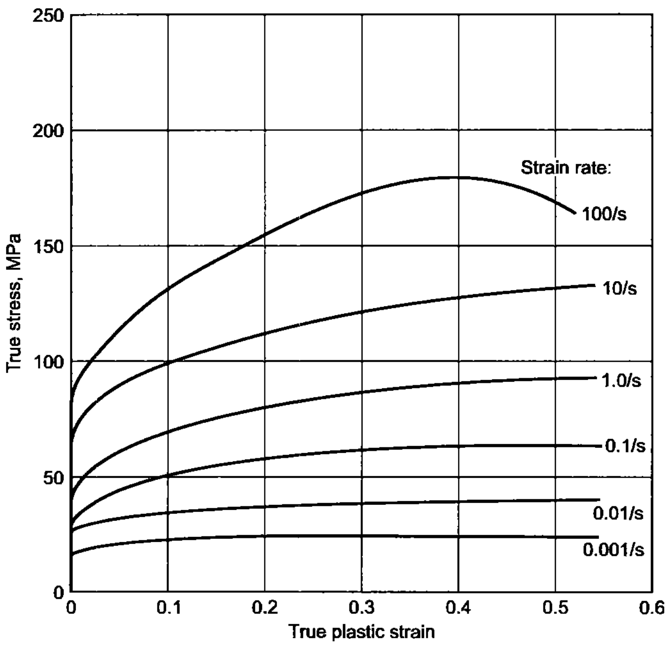
Source: E. Nechtelberger, H. Puhr, J.B. von Nesselrode, and A. Nakayasu, Paper presented at the 49th International Foundry Congress, International Committee of Foundry Technical Associations, Chicago, 1982. As published in D.M. Stefanescu, Compacted Graphite Irons, *Properties and Selection: Irons, Steels, and High-Performance Alloys,* Vol 1, *ASM Handbook,* ASM International, 1990, p 57



CI.073 Alpha (α) iron alloy forging, true compressive stress-strain curves

Tested at 500 °C (932 °F) at strain rates indicated. Specimens were forged at 900 °C (1652 °F) and annealed at 750 °C (1382 °F) for 2 h. Alpha iron has a body-centered-cubic crystal structure. Composition: Fe-0.007C-0.03Mn-0.005S-0.003P

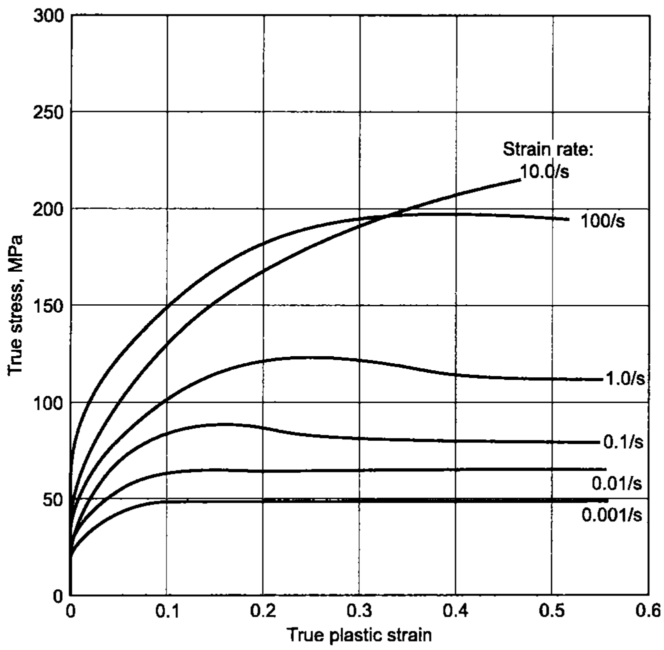
Source: G.S. Avadhani, Indian Institute of Science, Bangalore, India. As published in *Hot Working Guide,* Y.V.R.K. Prasad and S. Sasidhara, Ed., ASM International, 1997, p 263



CI.074 Alpha (α) iron alloy forging, true compressive stress-strain curves

Tested at 800 °C (1472 °F) at strain rates indicated. Specimens were forged at 900 °C (1652 °F) and annealed at 750 °C (1382 °F) for 2 h. Alpha iron has a body-centered-cubic crystal structure. Composition: Fe-0.007C-0.03Mn-0.005S-0.003P

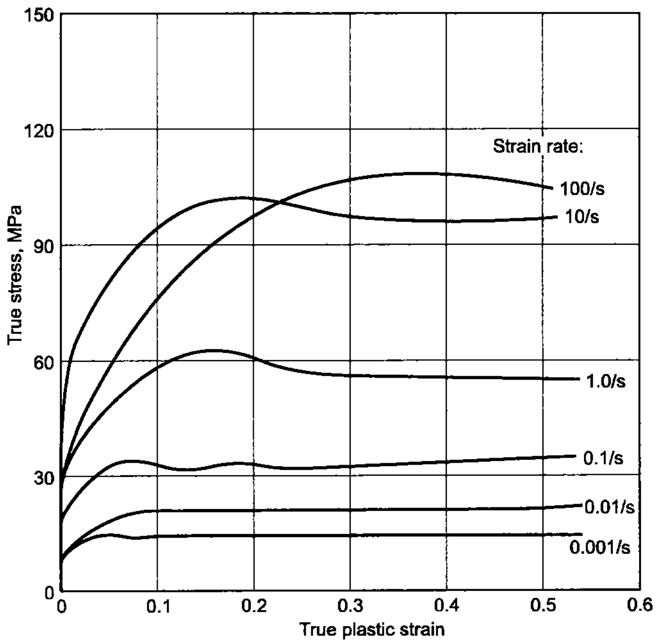
Source: G.S. Avadhani, Indian Institute of Science, Bangalore, India. As published in *Hot Working Guide,* Y.V.R.K. Prasad and S. Sasidhara, Ed., ASM International, 1997, p 263



CI.075 Gamma (γ) iron alloy forging, true compressive stress-strain curves

Tested at 950 °C (1742 °F) at strain rates indicated. Specimens were forged at 900 °C (1652 °F) and annealed at 750 °C (1382 °F) for 2 h. Above 910 °C (1670 °F) pure iron has a face-centered-cubic crystal structure and is called gamma iron. Composition: Fe-0.007C-0.03Mn-0.005S-0.003P

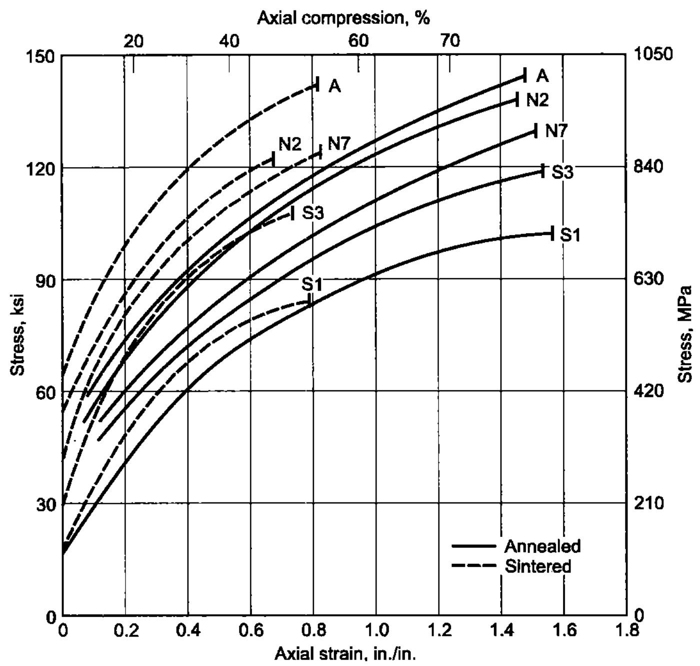
Source: G.S. Avadhani, Indian Institute of Science, Bangalore, India. As published in *Hot Working Guide,* Y.V.R.K. Prasad and S. Sasidhara, Ed., ASM International, 1997, p 267



CI.076 Gamma (γ) iron alloy forging, true compressive stress-strain curves

Tested at 1150 °C (2102 °F) at strain rates indicated. Specimens were forged at 900 °C (1652 °F) and annealed at 750 °C (1382 °F) for 2 h. Above 910 °C (1670 °F) pure iron has a face-centered-cubic crystal structure and is called gamma8 iron. Composition: Fe-0.007C-0.03Mn-0.005S-0.003P

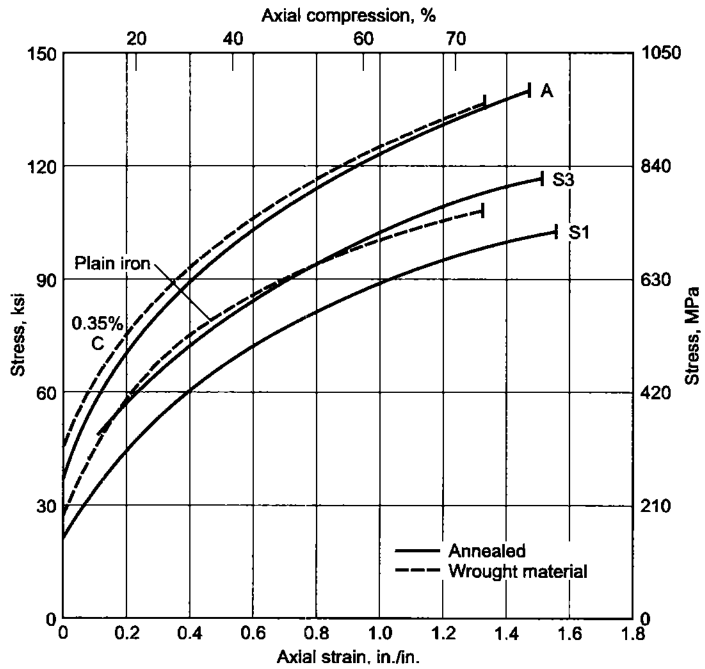
Source: G.S. Avadhani, Indian Institute of Science, Bangalore, India. As published in *Hot Working Guide,* Y.V.R.K. Prasad and S. Sasidhara, Ed., ASM International, 1997, p 267



CI.077 Steel preform powder metal forged cylinder, compressive stress-strain curves

Test direction: longitudinal. Five steel powder compositions used: A, Fe-0.27C-2.0Ni-0.5Mo; N2, Fe-0.17C-2.7Ni-0.8Cr; N7, Fe-0.24C-0.6Ni-0.5Cr-0.2Mo; S1, Fe-0.01C; S3, Fe-0.33C. Preforms compacted to 785 MPa (114 ksi), sintered at 1199 °C (2190 °F), 30 min, and spheroidized (heating three times above and below eutectoid point). The sintered and annealed preforms are compared.

Source: *Source Book on Cold Forming,* American Society for Metals, 1975, p 208

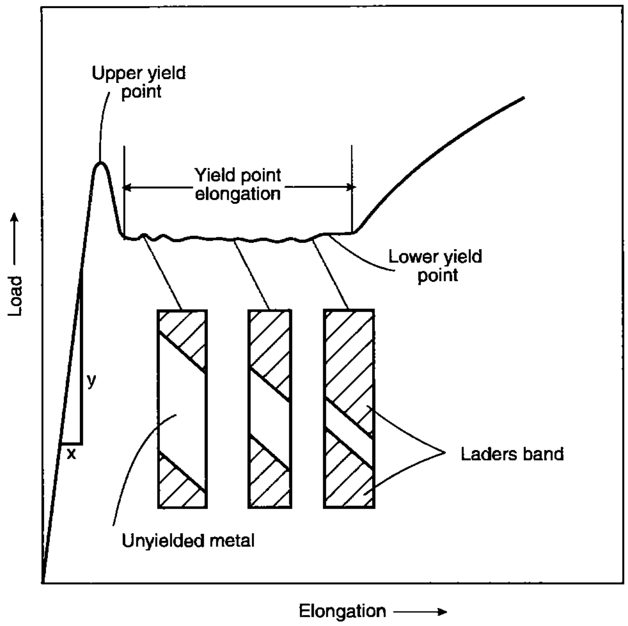


CI.078 Steel preform annealed powder metal, comparison of compressive stress-strain curves

Test direction: longitudinal. Three annealed powders (A, S1, and S3) are compared to wrought 0.35% C steel and plain iron. Compositions: A, Fe-0.27C-2.0Ni-0.5Mo; S1, Fe-0.01C; S3, Fe-0.33C

Source: *Source Book on Cold Forming,* American Society for Metals, 1975, p 208

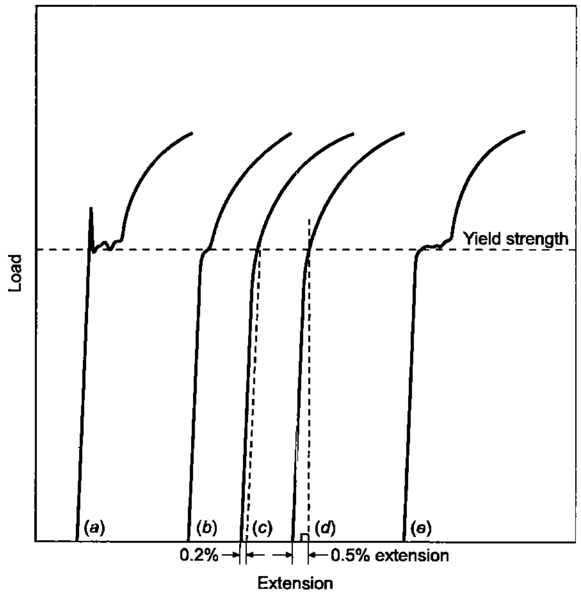
Carbon Steel (CS)



CS.001 Annealed low-carbon steel, load-elongation curve showing Lüders bands

Typical yield point behavior of low-carbon steel. The slope of the initial linear portion of the stress-strain curve ($E = y/x$) is the modulus of elasticity. Many metals, particularly annealed low-carbon steel, show a localized, heterogeneous type of transition from elastic to plastic deformation that produces a yield point rather than a curve with a gradual transition from elastic to plastic behavior. The load increases steadily with elastic strain, then drops suddenly. After the upper yield point, several discrete bands of deformed metal, called Lüders bands, appear at stress concentrations, usually at about 45° to the tensile axis. Load fluctuates about some approximately constant value, and then rises with further strain.

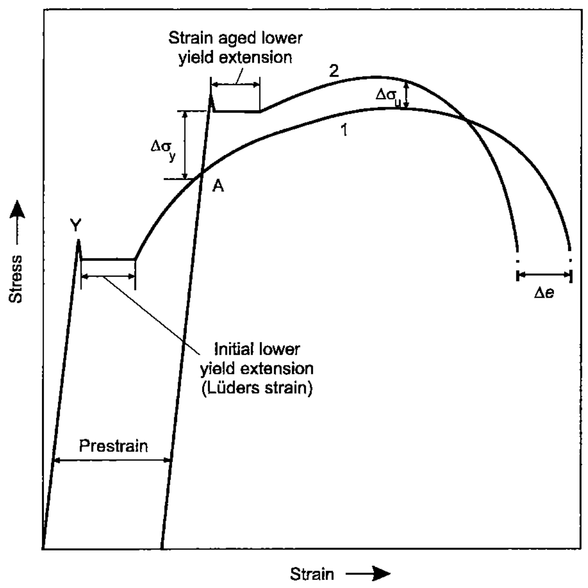
Source: G.E. Dieter, Mechanical Behavior under Tensile and Compressive Loads, *Mechanical Testing and Evaluation*, Vol 8, *ASM Handbook*, ASM International, 2000, p 100



CS.002 Carbon steel, various alloys, load-extension curves showing yield strength

Load-extension curves for steel sheet having the same yield strength (YS) but different characteristic behavior. (a) Annealed dead soft rimmed or aluminum-killed steel. The YS is the average stress measured during yield point elongation. (b) Lightly temper rolled rimmed steel. The stress at the jog in the curve is reported as the YS. (c) and (d) Temper rolled low-carbon steel. May be rimmed, aluminum-killed, or interstitial-free steel with no detectable yield point. The YS is calculated from the load at 0.2% offset (c) or from the load at 0.5% extension (d). (e) Rimmed steel with a yield point elongation due to aging at room temperature for several months. The YS is the average stress measured during yield point elongation.

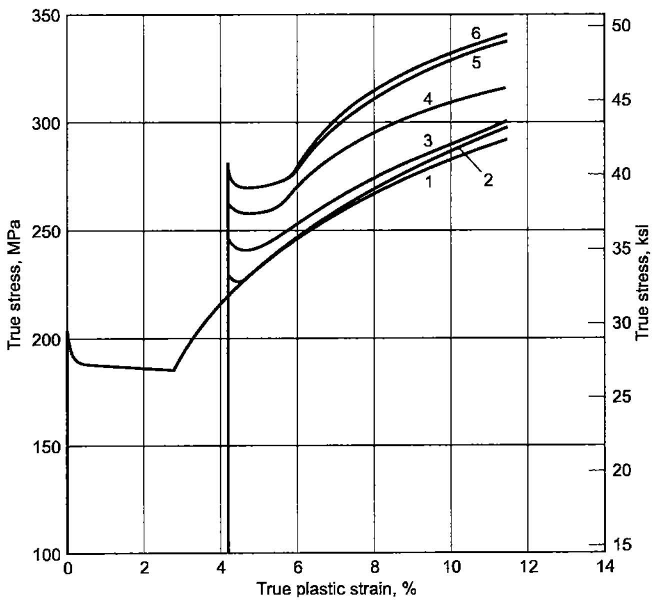
Source: W.G. Granzow, Sheet Formability of Steels, *Properties and Selection: Irons, Steels, and High-Performance Alloys*, Vol 1, *ASM Handbook*, ASM International, 1990, p 574



CS.003 Annealed and normalized low-carbon steel, stress-strain curves showing effects of aging

Y is upper yield point, A is point of initial prestrain. Curve 1: specimen is unloaded and immediately restrained. Curve 2: specimen unloaded, aged, and restrained. $\Delta\sigma_y$ is the change in yield stress due to aging. $\Delta\sigma_u$ is the change in ultimate strength due to aging. Δe is the change in elongation. Similar aging effects can be achieved with various combinations of time and temperature.

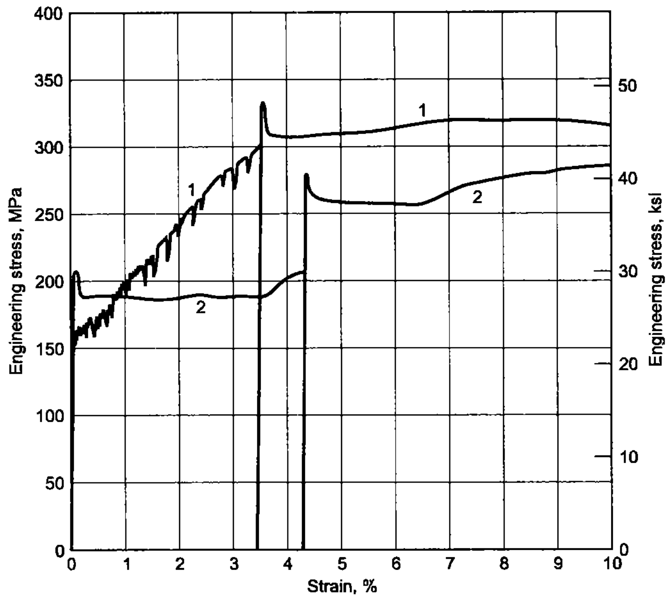
Source: W.T. Lankford, Jr. et al., *The Making, Shaping, and Treating of Steel*, USS, 10th ed., 1985, p 1286



CS.004 Rimmed carbon (0.03% C) steel, true stress-true plastic strain curves

Effect of aging at 60 °C (140 °F): curve 1, no aging; curve 2, 15 min; curve 3, 30 min; curve 4, 4 h; curve 5, 500 h; 6, 126 h

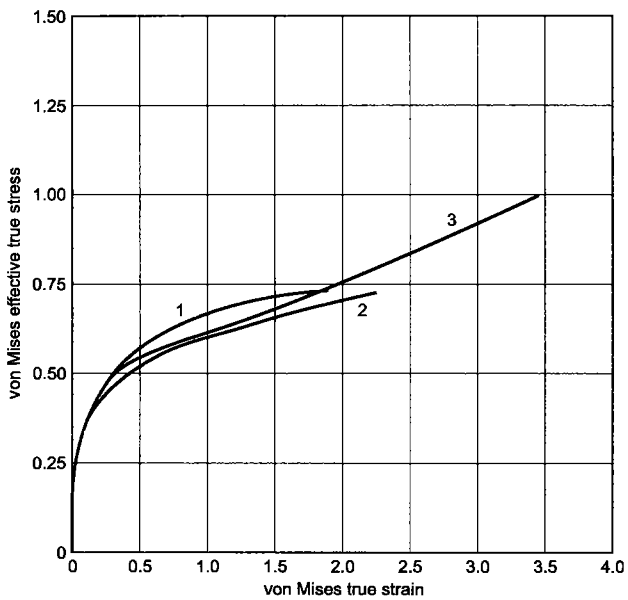
Source: W.T. Lankford, Jr. et al., *The Making, Shaping, and Treating of Steel*, USS, 10th ed., 1985, p 1286



CS.005 Rimmed low-carbon (0.03% C) steel, engineering stress-strain curves

Curve 1: Dynamic strain aging, also called blue brittleness. Straining at 200 °C (390 °F) yields serrated stress-strain curve and is more effective than straining at room temperature. Curve 1 was unloaded and restrained at 25 °C (77 °F). Curve 2 was strained at 25 °C (77 °F) and unloaded, aged for 2 h at 200 °C (390 °F), and restrained at 25 °C (77 °F).

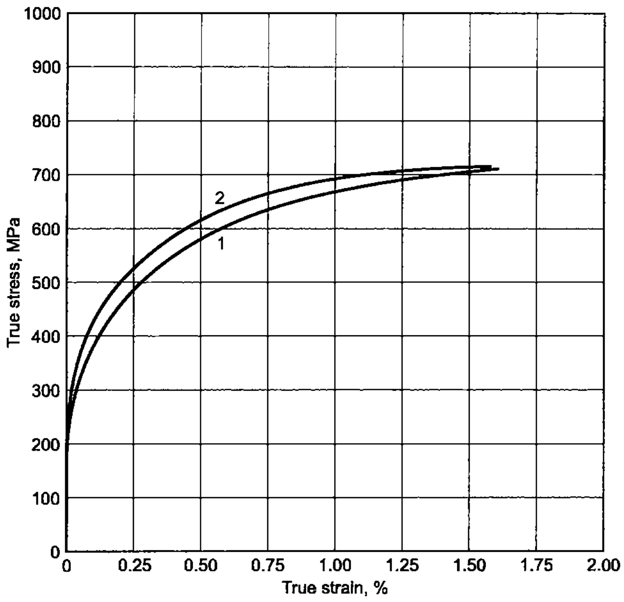
Source: W.T. Lankford, Jr. et al., *The Making, Shaping, and Treating of Steel,* USS, 10th ed., 1985, p 1286



CS.006 1007 and 1008 carbon steel, von Mises effective true stress-von Mises true strain curves

Curve 1: 1008 alloy deformed by plane-strain compression; data source, Ford. Curve 2: 1007 alloy deformed by torsion; data source, G. Sevillano. Curve 3: 1007 alloy deformed by wire drawing plus torsion; data source, G. Sevillano. UNS G10080

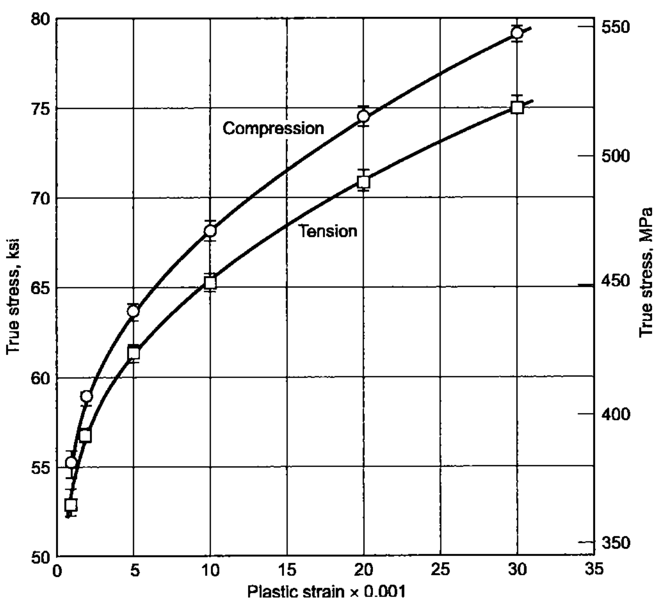
Source: G. Krauss, Ed., *Deformation, Processing, and Structure,* papers presented at the ASM Materials Science Seminar, 23 Oct 1982 (St. Louis, MO), American Society for Metals, 1984, p 9



CS.007 1008 carbon steel, true stress-true strain curves

Comparison of stress-strain curves. Curve 1: monotonic plane-strain compression. Curve 2: rolling prestrain followed by plane-strain compression. Stress states are very similar, and yet the rolling-plus-plane-strain compression curve is different. This difference can be explained on the basis of redundant work; the curvature of the rolls causes some redundant shearing (not contributing to thickness reduction) and extra hardening. UNS G10080

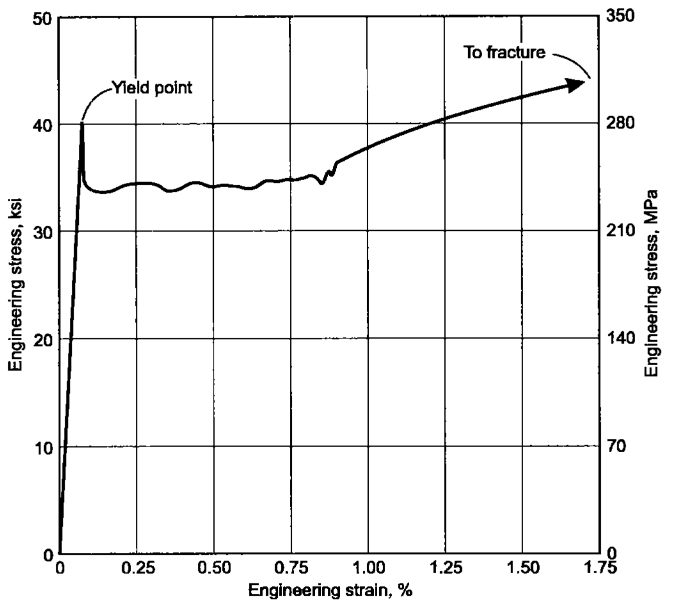
Source: G. Krauss, Ed., *Deformation, Processing, and Structure,* papers presented at the ASM Materials Science Seminar, 23 Oct 1982 (St. Louis, MO), American Society for Metals, 1984, p 10



CS.008 1015 carbon steel, tensile and compressive true stress-plastic strain curves

Niobium-stabilized (+0.02Nb), air cooled from 1200 °C. Widmanstätten ferrite-pearlite. Composition: Fe-0.17C-0.96Mn-0.014P-0.026S-0.040Si-0.044Ni-0.028Cr-0.008Mo-0.006Al-0.025Cu-0.020Nb. UNS G10150

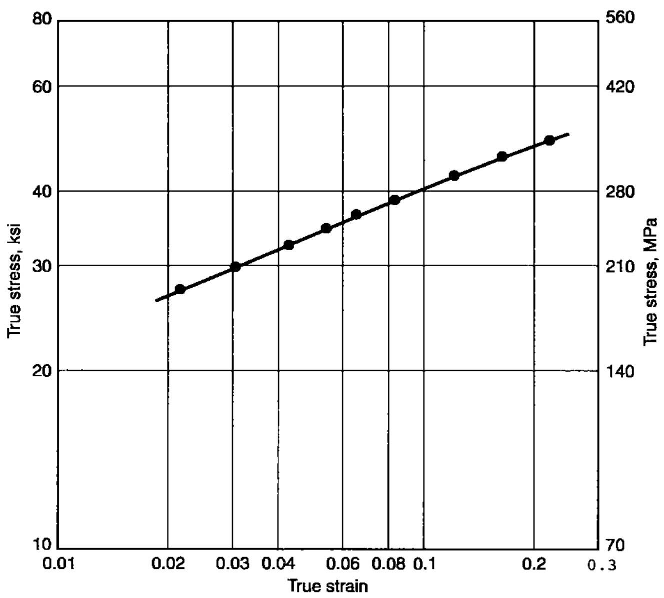
Source: G.C. Rauch and W.C. Leslie, The Extent and Nature of the Strength-Differential Effect in Steels, *Metall. Trans.*, Vol 3, Feb 1972, p 378



CS.009 Annealed low-carbon (0.18% C) steel, engineering stress-strain curve

Curve shows a well-defined yield point. For such cases the 0.2% offset yield strength is not used to define yielding.

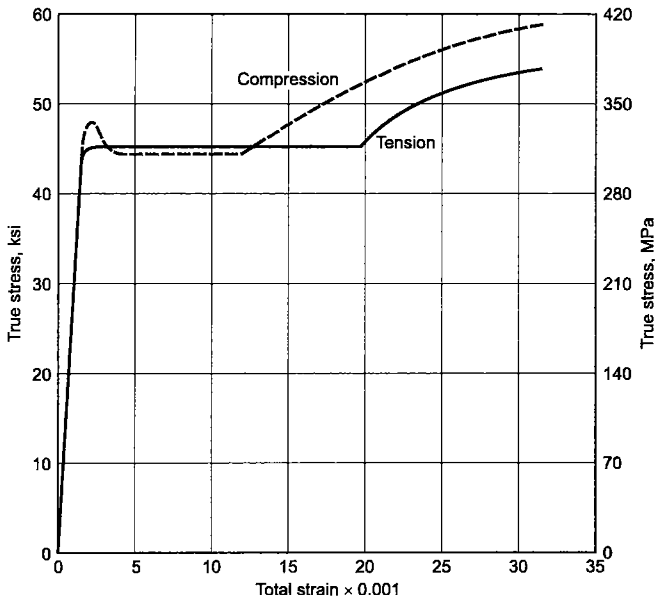
Source: C.R. Brooks, *Heat Treatment, Structure, and Properties of Nonferrous Alloys,* American Society for Metals, 1982, p 4



CS.010 Fully aluminum-killed deep-drawing carbon steel 20-gage sheet, logarithmic true stress-strain curve

Test direction: longitudinal. This figure was a typical result from a series of reproducibility tests conducted on 50 adjacent specimens. Linearity is very good. $n = 0.250$, $k = 71.67$.

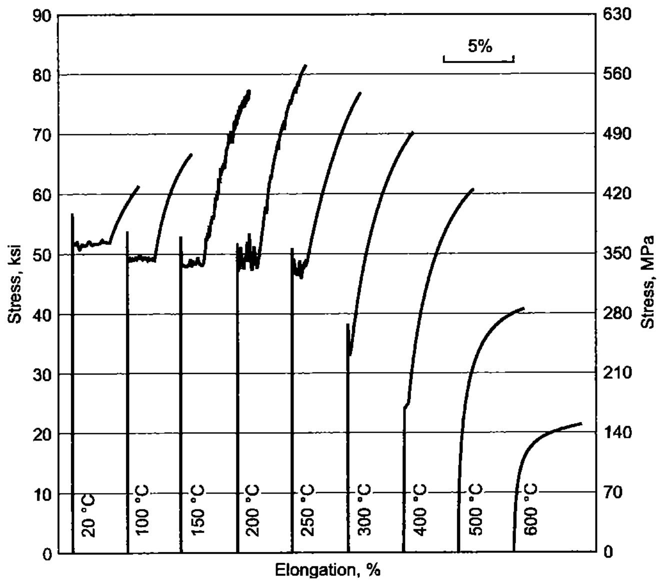
Source: *Source Book on Forming of Steel Sheet,* American Society for Metals, 1975, p 217



CS.011 1015 carbon steel, tensile and compressive true stress-total strain curves. UNS G10150

Samples equiaxed ferrite-pearlite

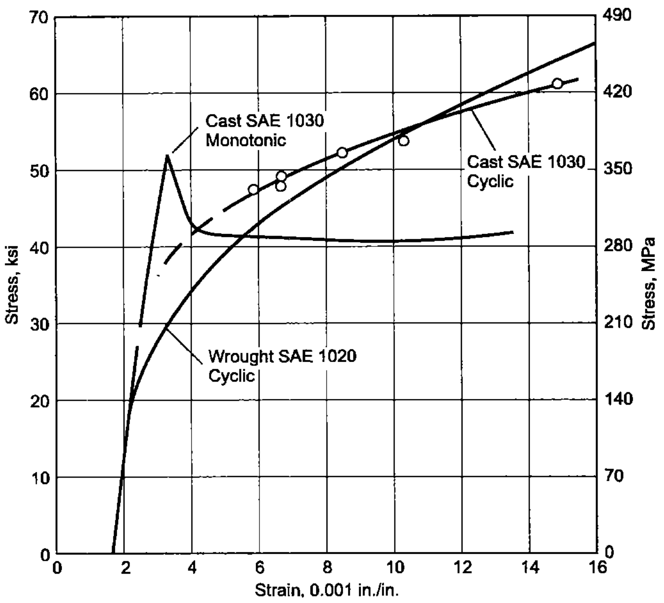
Source: *Metall. Trans.*, Vol 3, 1972, p 379



CS.012 1020 carbon steel, tensile stress-elongation curves at room and elevated temperatures

Strain rate = 0.000175/s. Composition: Fe-0.20C. UNS G10200

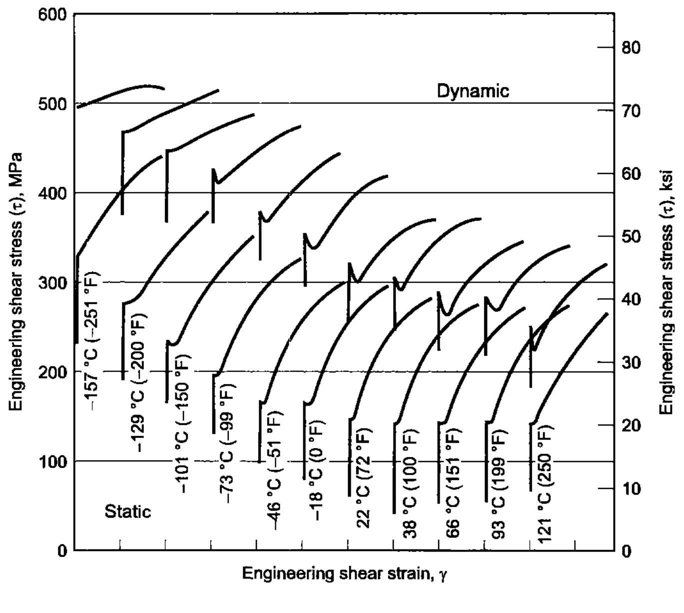
Source: W.C. Leslie, *The Physical Metallurgy of Metals*, McGraw-Hill and Hemisphere Publishing, 1981, p 92



CS.013 1020 wrought and 1030 normalized-and-tempered cast carbon steel, monotonic and cyclic stress strain curves

The cyclic stress-strain characteristics show a reduction of the strain-hardening exponent of the normalized-and-tempered cast carbon steel (SAE 1030) from $n = 0.3$ in monotonic tension to $n' = 0.13$ under cyclic-strain-controlled tests. UNS G10200

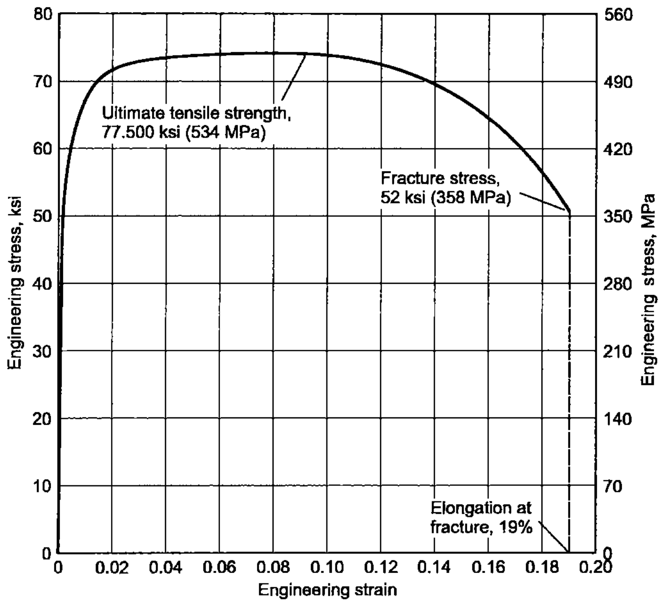
Source: P.F. Wieser, Ed., *Steel Castings Handbook,* 5th ed., Steel Founders' Society of America, 1980, p 14-15



CS.014 Hot-rolled 1020 carbon steel, static and dynamic engineering shear stress-strain curves

Static and dynamic shear stress-shear strain curves for hot rolled 1020 steel. To obtain the shear strain in the specimen, the elastic rotation of the bar between the two differential transformers is subtracted from the total rotation. This elastic rotation is measured by cementing the loading bars together without a specimen and loading them quasi-statically. Typical test results obtained at a variety of temperatures using the Kolsky bar to test 1020 steel at a quasi-static strain rate of 5×10^{-4}/s and dynamic strain rate of 10^3/s are given..

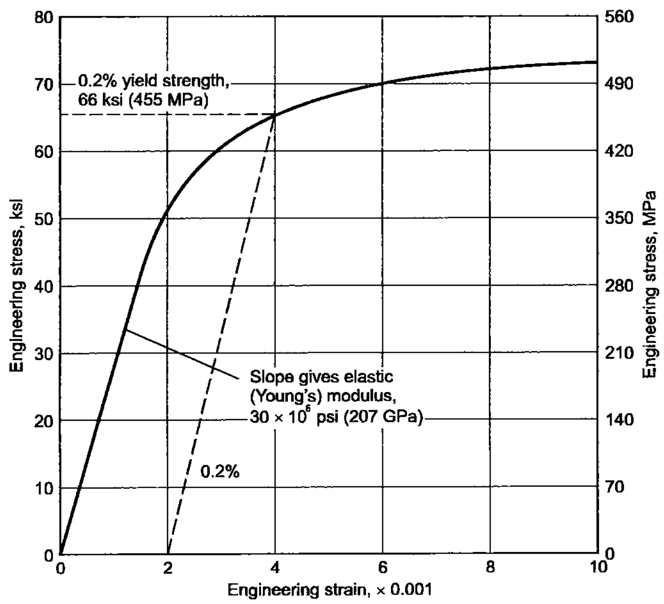
Source: A. Gilat, Torsional Kolsky Bar Testing, *Mechanical Testing and Evaluation,* Vol 8, *ASM Handbook,* ASM International, 2000, p 513



CS.015 Cold-worked carbon (0.2% C) steel, engineering stress-strain curve (full range)

Definition of mechanical property terms

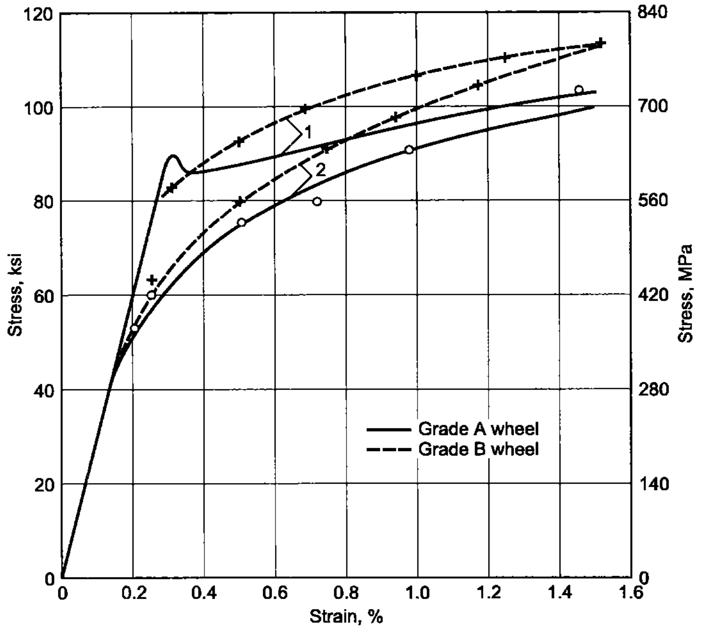
Source: C.R. Brooks, *Heat Treatment, Structure, and Properties of Nonferrous Alloys,* American Society for Metals, 1982, p 2



CS.016 Cold-worked carbon (0.2% C) steel, engineering stress-strain curve (expanded range)

Definition of mechanical property terms

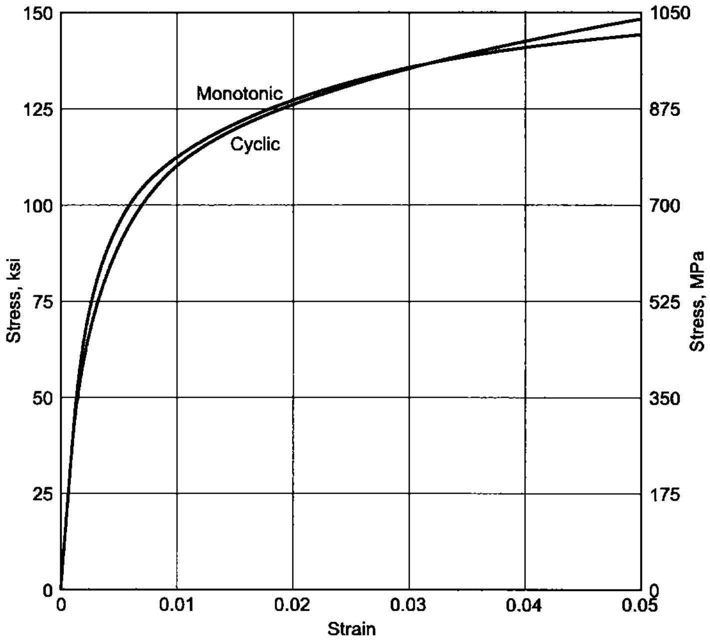
Source: C.R. Brooks, *Heat Treatment, Structure, and Properties of Nonferrous Alloys,* American Society for Metals, 1982, p 2



CS.017 AAR grade A and B high-carbon steel casting wheels, stress-strain curves

Constant-amplitude strain-controlled test (open circles, grade A; "plus" symbols, grade B). Curve 1, monotonic tension test; curve 2, incremental step test. AAR, Association of American Railroads. Compositions: grade A, Fe-0.52C-0.78Mn-0.014S-0.009P-0.26Si; grade B, Fe-0.65C-0.83Mn-0.038S-0.015P-0.21Si

Source: D.H. Stone and Y.J. Park, Cyclic Plasticity of Class A and B Heat-Treated Wheel Steels. As published in "The General Problem of Rolling Contact," AMD-Vol 40, ASME, 1980

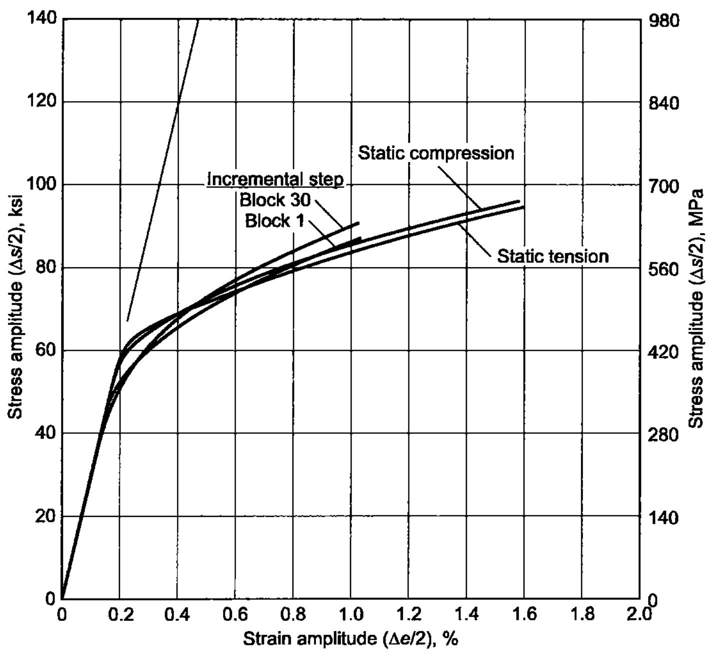


CS.018 AAR grade C high-carbon steel casting wheels, stress-strain curves

Monotonic and cyclic loading curves. AAR, Association of American Railroads. Composition: Fe-0.68C-0.83Mn-0.038S-0.015P-0.33Si

Source: Courtesy of the Transportation Technology Center, Inc. subsidiary of Association of American Railroads

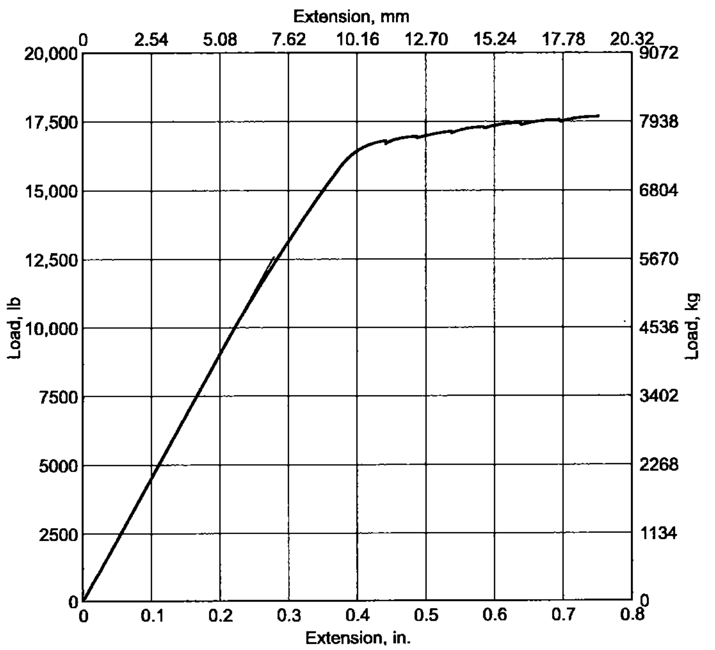
CS.019 Standard grade nonresulfurized carbon steel rails, stress amplitude-strain amplitude curves



Test direction: longitudinal. Static and incremental step loading. Modulus of elasticity = 199 GPa (28.85 × 10^6 psi). Composition: Fe-0.82C-0.87Mn-0.032S-0.035P-0.21Si

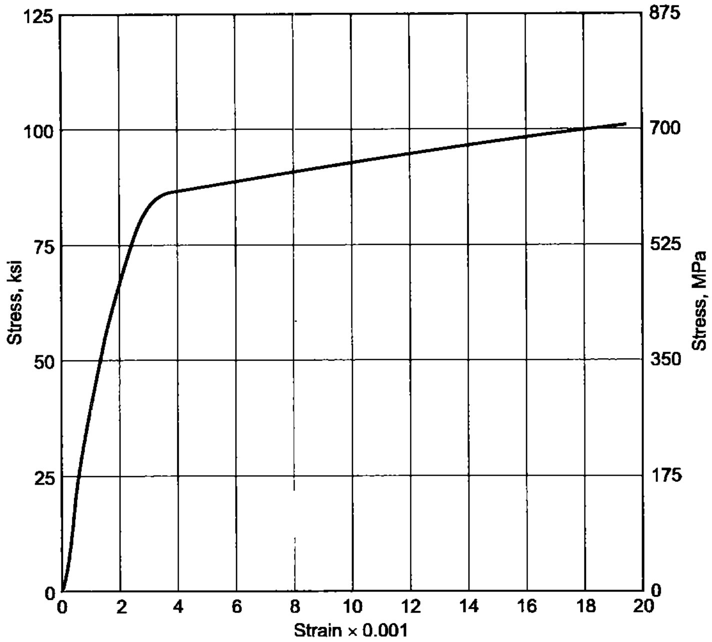
Source: B.N. Leis, Cyclic Deformation and Fatigue Resistance Characteristics of a Rail Steel, *Rail Steels*, STP No. 644, ASTM, Nov 1977

CS.020 High-strength nonresulfurized carbon steel rails, load-extension diagram



Test curve for one specimen 12.751 mm diam × 50.8 mm gage length (0.502 in. diam × 2 in. gage length). Ultimate tensile strength = 1106 MPa (160.5 ksi); 0.2% yield strength = 644 MPa (93.4 ksi). Typical composition for high-strength rail: Fe-0.74C-0.99Mn-0.005S(max)-0.015P-0.17Si

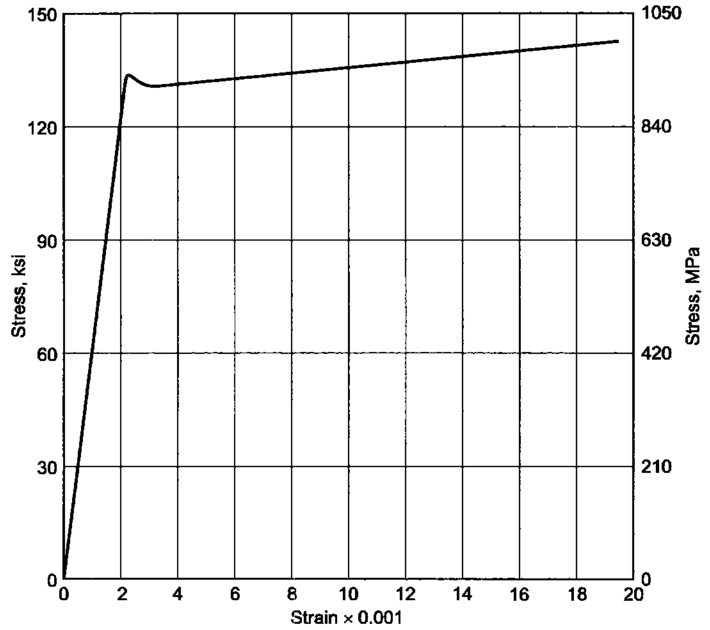
Source: Courtesy of the Transportation Technology Center, Inc. subsidiary of Association of American Railroads



CS.021 AAR specification M101 grade C austenitic manganese steel casting, monotonic tensile stress-strain curve

Normalized and tempered. Strain rate = 0.0002/s. Ultimate strength = 696 MPa (101 ksi); 0.2% yield strength = 605 MPa (87.8 ksi); elongation = 33%; elastic modulus = 204 GPa (29.575 × 10^6 psi); strain-hardening exponent = 0.097475; strength coefficient = 1059 MPa (153.674 ksi). AAR, Association of American Railroads. Composition: Fe-0.31C-1.50Mn-0.027S-0.007P-0.49Si-0.14Ni-0.20Cr-0.17Mo

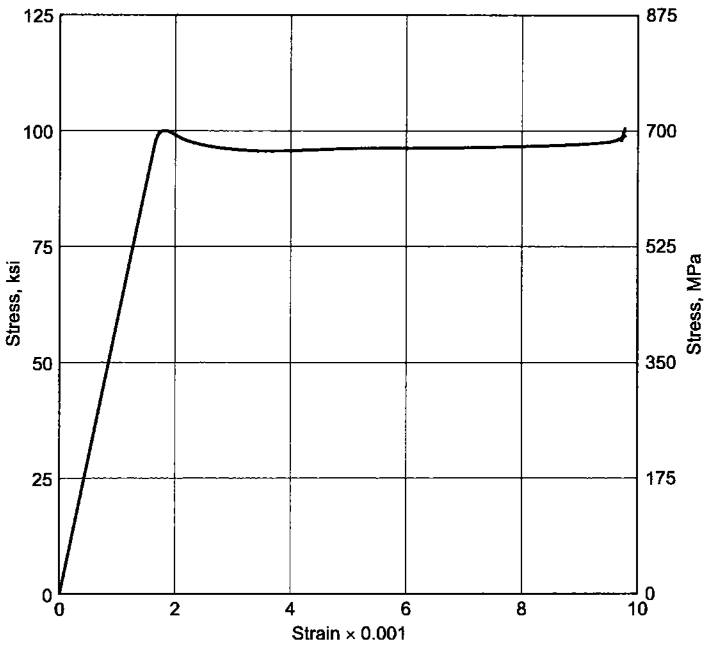
Source: Courtesy of the Transportation Technology Center, Inc. subsidiary of Association of American Railroads



CS.022 AAR specification M101 grade C austenitic manganese steel casting, monotonic tensile stress-strain curve

Quenched and tempered. Strain rate = 0.0002/s. Ultimate strength = 986 MPa (143 ksi); 0.2% yield strength = 909 MPa (132 ksi); elongation = 19.6%; elastic modulus = 217 GPa (31.474 × 10^6 psi). AAR, Association of American Railroads. Composition: Fe-0.28C-1.35Mn-0.025S-0.012P-0.44Si-0.17Ni-0.25Cr-0.17Mo

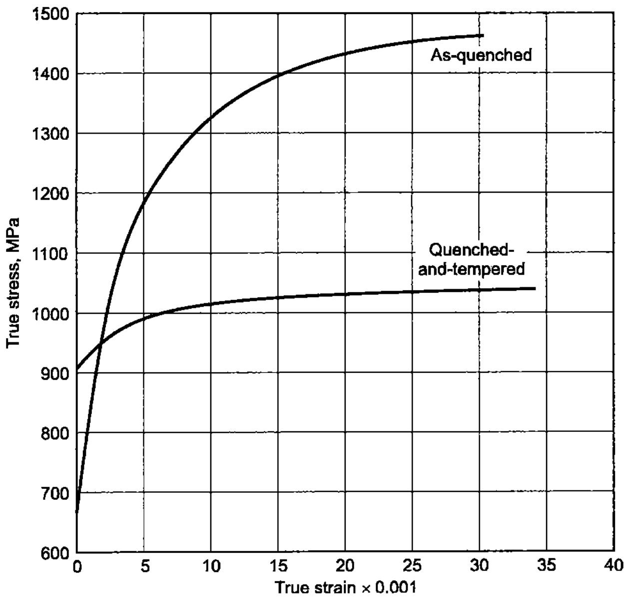
Source: Courtesy of the Transportation Technology Center, Inc. subsidiary of Association of American Railroads



CS.023 AAR specification M101 grade E austenitic manganese steel casting, monotonic tensile stress-strain curve

Quenched and tempered. Strain rate = 0.0002/s. Ultimate strength = 730 MPa (106 ksi); 0.2% yield strength = 655 MPa (95 ksi); elongation = 27.8%; elastic modulus = 210 GPa (30.43 × 10^6 psi); strain-hardening exponent = 0.93697; strength coefficient = 1086 MPa (157.661 ksi). AAR, Association of American Railroads. Composition: Fe-0.29C-1.03Mn-0.026S-0.014P-0.49Si-0.60Ni-0.47Cr-0.15Mo

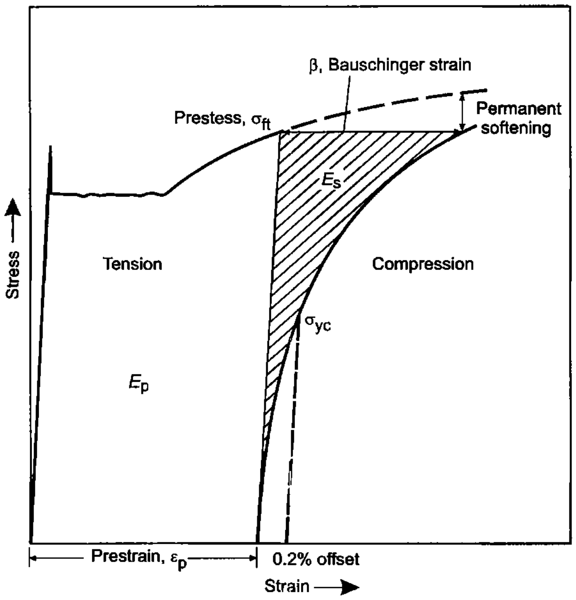
Source: Courtesy of the Transportation Technology Center, Inc. subsidiary of Association of American Railroads



CS.024 As-quenched and quenched-and-tempered carbon (0.2% C) steel, true stress-strain curves

As-quenched martensite quenched in NaOH-NaCl solution and quenched-and-tempered lath martensite with packet size of 8.2 μm was tempered in lead at 400 °C (750 °F) for 1 min. Work-hardening rate for as-quenched is quite high compared to tempered sample. Composition: Fe-0.2C

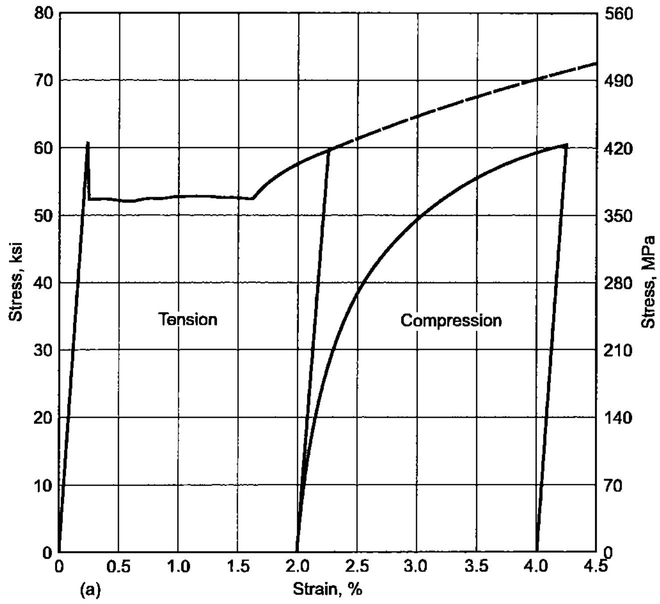
Source: T. Swarr and G. Krauss, The Effect of Structure on the Deformation of As-Quenched and Tempered Martensite in an Fe-0.2% C Alloy, *Metall. Trans. A*, Vol 7A, 1976, p 41–48

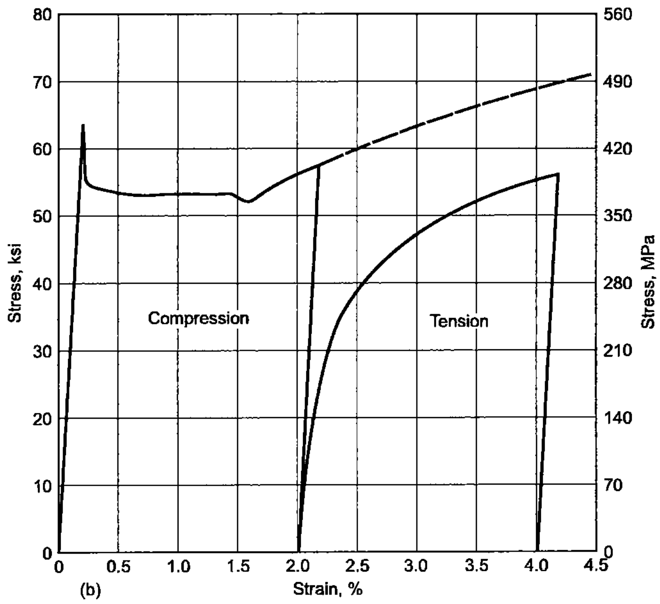


CS.025 Carbon steel, Bauschinger effect on stress-strain curves

The elastic limit of a metal is lowered after reverse loading. The area E_p is the energy expended in prestrain, and E_s is the energy saved in reverse loading.

Source: C.-C. Li, J.D. Flasck, J.A. Yaker, and W.C. Leslie, On Minimizing the Bauschinger Effect in Steels by Dynamic Strain Aging, *Metall. Trans. A,* Jan 1978, p 86

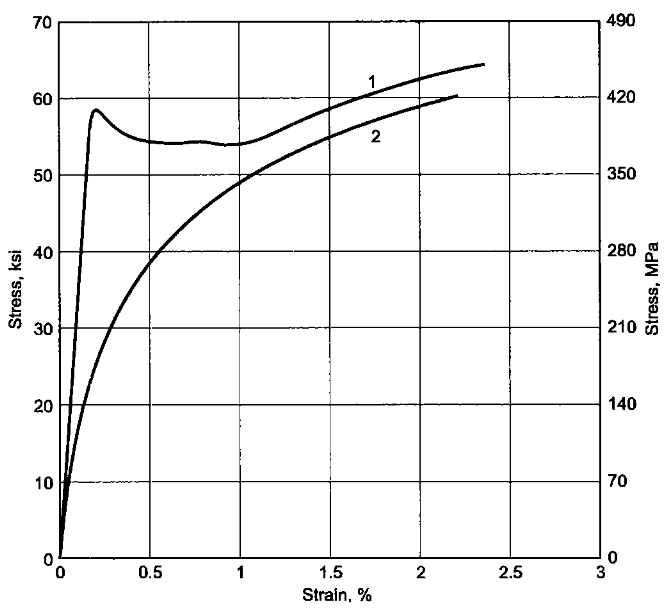




CS.026 1020 carbon steel, true stress-strain curves

(a) Bauschinger effect shown for test sequence of tension to 2% strain followed by compression of another 2%.
(b) The sequence is compression-tension. Tested at 25 °C. Composition: Fe-0.21C-0.64Mn-0.030S-0.018P-0.23Si-0.007N. UNS G10200

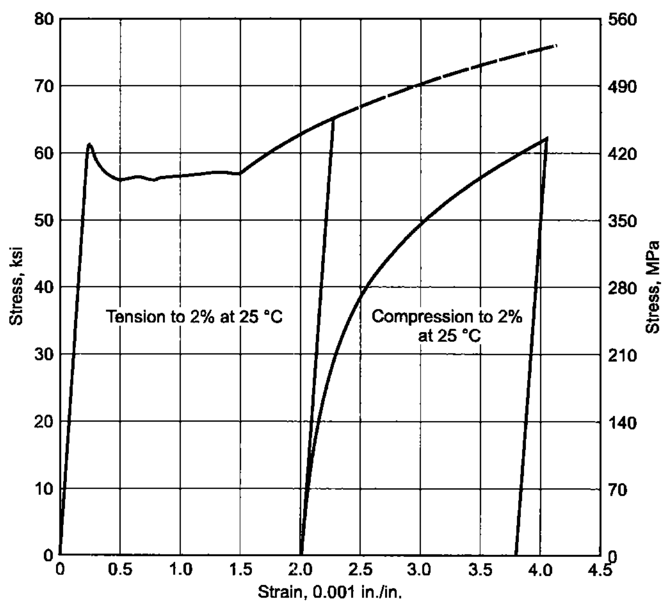
Source: C.-C. Li, J.D. Flasck, J.A. Yaker, and W.C. Leslie, On Minimizing the Bauschinger Effect in Steels by Dynamic Strain Aging, *Metall. Trans. A,* Jan 1978, p 86



CS.027 1020 carbon steel, true stress-strain curves

Curve 1: specimen is prestrained in tension at 250 °C to 2% strain and tested in compression at room temperature. Curve 2: the specimen is prestrained in tension at room temperature to 2% strain and tested in compression at room temperature. The Bauschinger effect is reduced. Composition: Fe-0.21C-0.64Mn-0.030S-0.018P-0.23Si-0.007N. UNS G10200

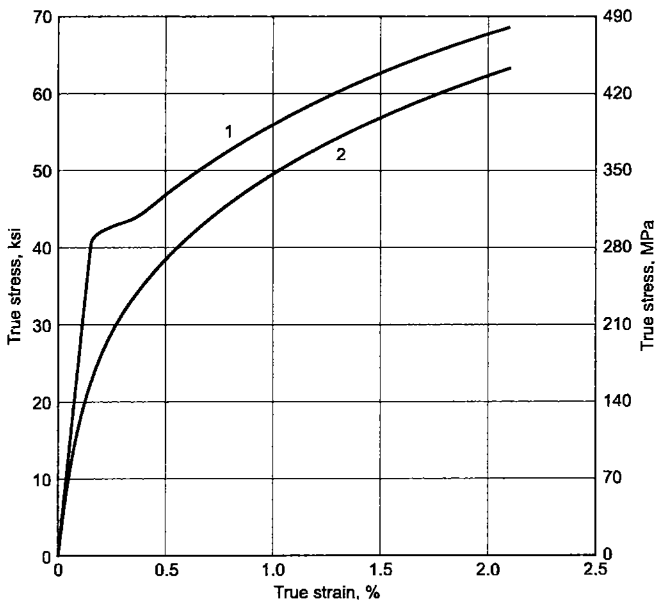
Source: C.-C. Li, J.D. Flasck, J.A. Yaker, and W.C. Leslie, On Minimizing the Bauschinger Effect in Steels by Dynamic Strain Aging, *Metall. Trans. A*, Jan 1978, p 88



CS.028 1035 carbon steel, true stress-strain curves

Bauschinger effect shown with test sequence of tension to 2% strain followed by compression of another 2%. Tested at 25 °C. Composition: Fe-0.34C-0.65Mn-0.007S-0.003P-0.17Si-0.021Al-0.006N. UNS G10350

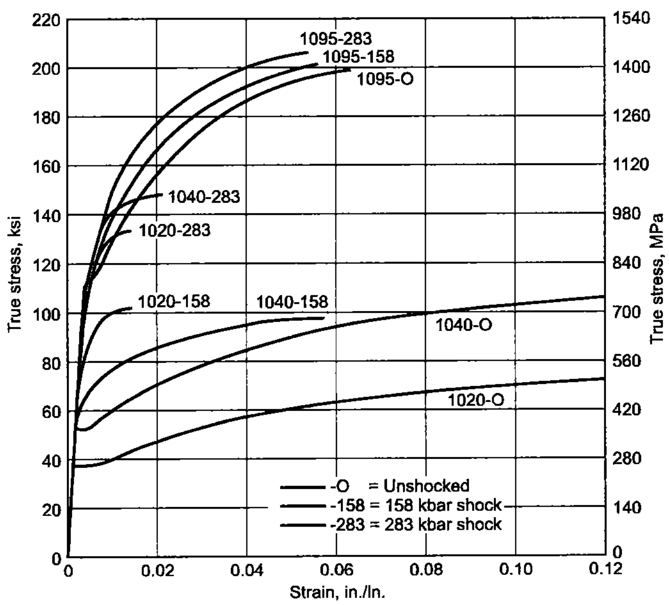
Source: C.-C. Li, J.D. Flasck, J.A. Yaker and W.C. Leslie, On Minimizing the Bauschinger Effect in Steels by Dynamic Strain Aging, *Metall. Trans. A*, Jan 1978, p 86



CS.029 1035 carbon steel, true stress-strain curves

Curve 1: specimen is prestrained in tension at 250 °C to 2% strain and tested in compression at 25 °C. Curve 2: the specimen is prestrained in tension at 25 °C to 2% strain and tested in compression at 25 °C. Composition: Fe-0.34C-0.65Mn-0.007S-0.003P-0.17Si-0.021Al-0.006N. UNS G10350

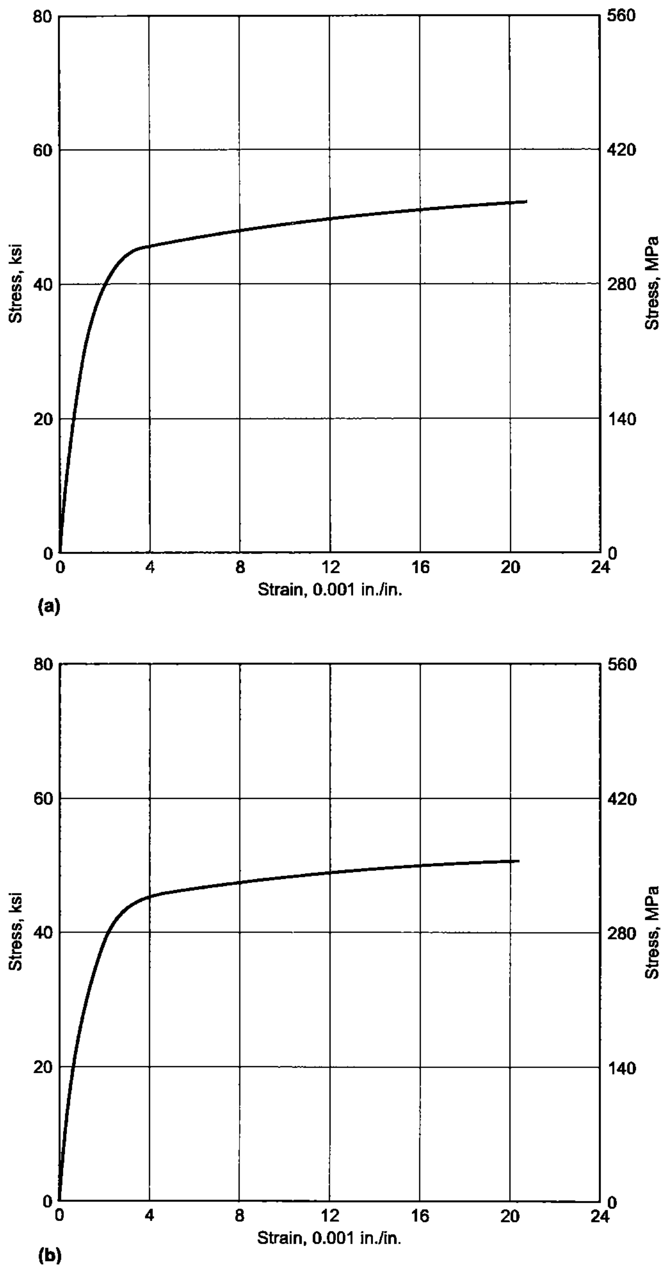
Source: C.-C. Li, J.D. Flasck, J.A. Yaker and W.C. Leslie, On Minimizing the Bauschinger Effect in Steels by Dynamic Strain Aging, *Metall. Trans. A*, Jan 1978, p 88



CS.030 1020, 1040, and 1095 carbon steel plate, true stress-strain curves showing effects of shock loading

Preshock normalizing: 1020, 927 °C (1700 °F), 45 min; 1040, 899 °C (1650 °F), 45 min; 1095, 899 °C (1650 °F), 45 min, austenitizing 802 °C (1475 °F), 45 min, oil quenched, tempered 204 °C (400 °F), 1 h. Shocked at 158 and 283 kbar (peak).. UNS G10200, G10400, G10950

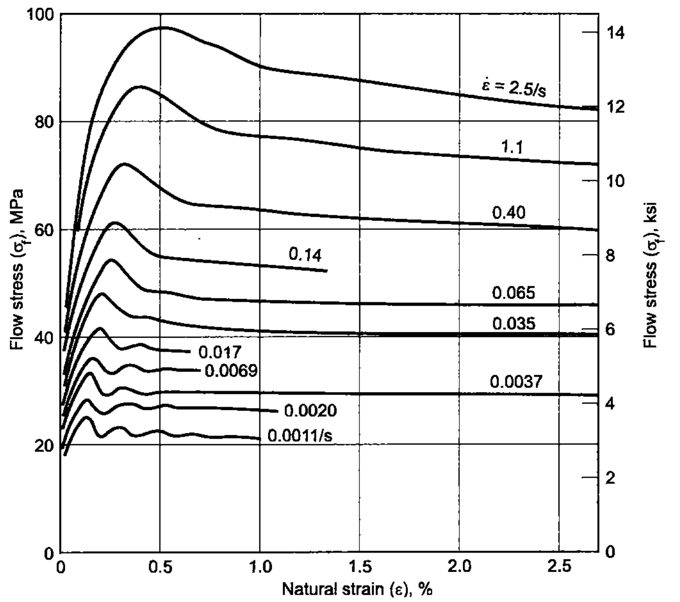
Source: B.G. Koepke, R.P. Jewett, W.T. Chandler, and T.E. Scott, Effects of Initial Microstructure and Shock Method on the Shock Induced Transformation Strengthening of Carbon Steels, *Metall. Trans.*, Vol 2, ASM, 1971, p 2045



CS.031 1023 carbon steel sheet, tensile stress-strain curves

(a) Longitudinal. (b) Transverse. Composition: 0.23C-0.39Mn-0.009P-0.024S-0.03Si-0.02Cr-0.01Ni-0.01Mo. UNS G10230

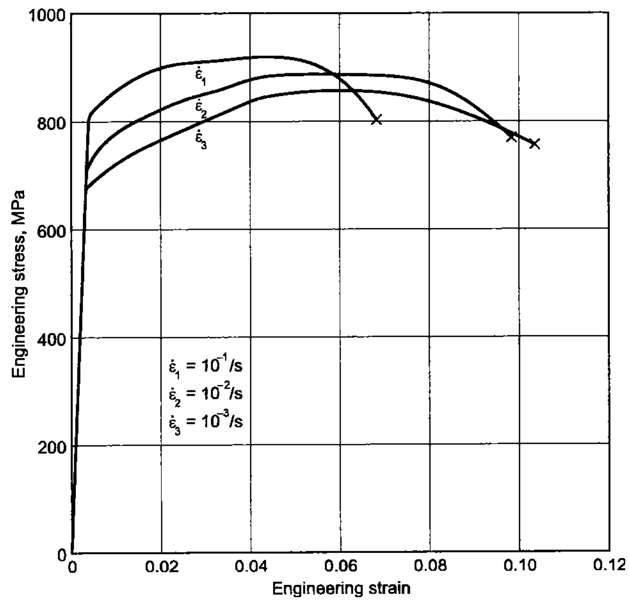
Source: *Structural Alloys Handbook*, Vol 1, Battelle Columbus Laboratories, Columbus, OH, 1980, p 28



CS.032 1025 carbon (0.25% C) steel, flow stress-strain curves at various strain rates

Temperature (T) = 1100 °C (2012 °F). Stress-strain curves show that at higher strains the flow stress is approximately constant. This is increasingly true at smaller strain rates ($\dot{\varepsilon}$). Curves were obtained in hot torsion experiments. UNS G10250

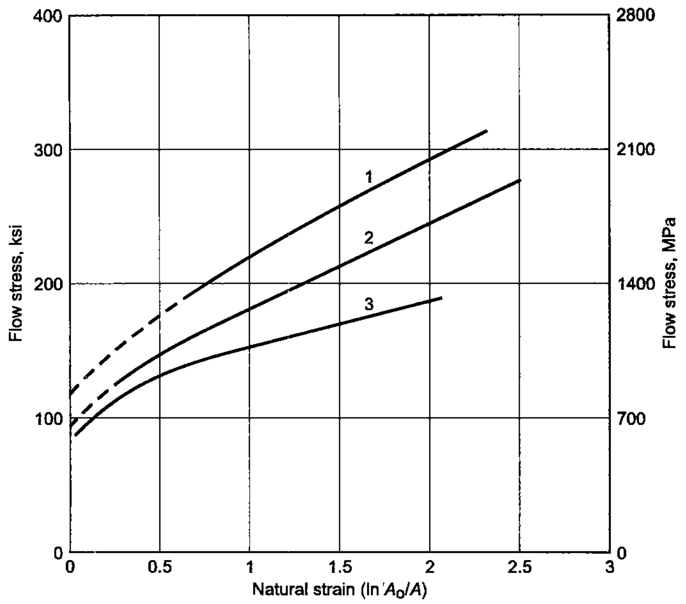
Source: K. Lange, Ed., *Handbook of Metal Forming*, McGraw-Hill, 1985, p 16.11



CS.033 1040 carbon steel, engineering stress-strain curves with effect of strain rate

Effect of different strain rates on the tensile response. The yield stress and flow stresses at different values of strain increase with strain rate. The work-hardening rate (m), on the other hand, is not as sensitive to strain rate. This illustrates the importance of correctly specifying the strain rate when giving the yield stress of a metal. Not all metals exhibit a high strain-rate sensitivity. Aluminum and some of its alloys have either 0 or $-m$. In general, m varies between 0.02 and 0.2 for homologous temperatures between 0 and 0.9 (90% of melting point in K). Therefore, one would have, at the most, an increase of 15% in the yield stress by doubling the strain rate. UNS G10400

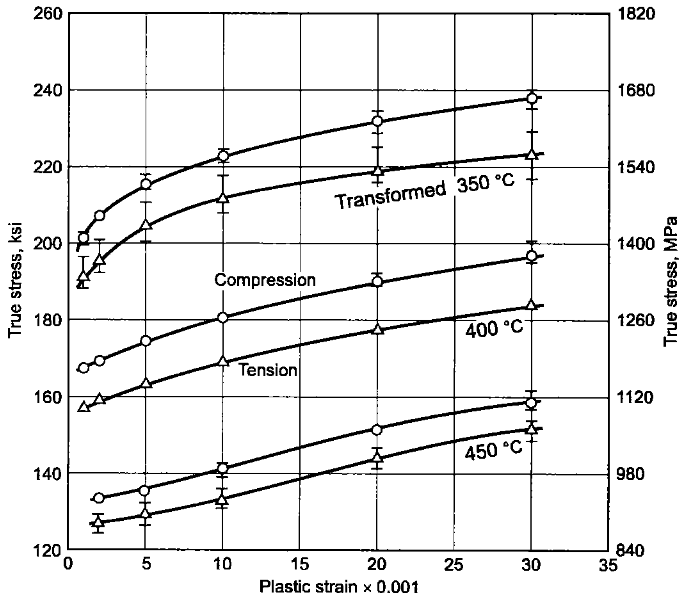
Source: M.A. Meyers and K.K. Chawla, *Mechanical Metallurgy: Principles and Applications*, Prentice-Hall, 1984, p 572



CS.034 1045 carbon steel, flow stress-natural strain curves

Strain-rate hardening for 1045 steels with different treatments. Curve 1: quenched and spheroidized. Curve 2: as rolled. Curve 3: quenched and tempered. For most of the curve the relationship is linear. The greater the initial hardness, the greater the rate of strain hardening throughout the range of possible deformation. UNS G10450

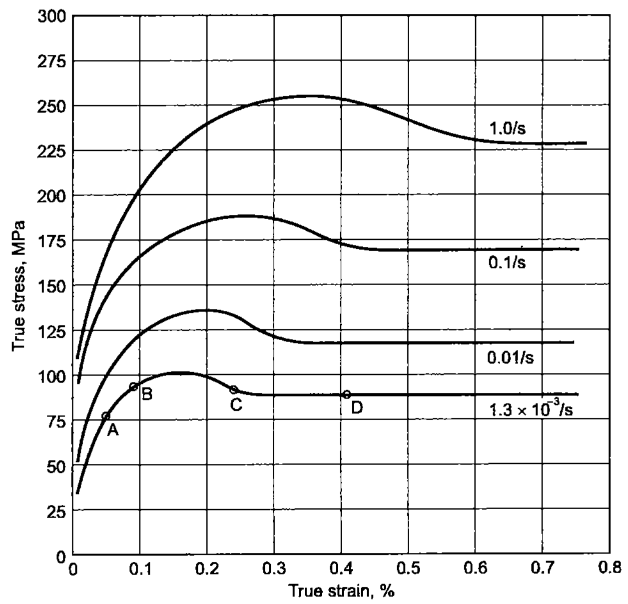
Source: J.V. Russell, Steels for Cold Forming, *Sourcebook on Cold Forming,* American Society of Metals, 1975, p 106



CS.035 10B46 carbon steel, true stress-plastic strain curves in tension and compression

Curves for lower, intermediate, and upper bainite in AISI 10B46 steel. Composition: Fe-0.44C-1.00Mn-0.025P-0.026S-0.27Si-0.05Ni-0.08Cr-0.01Mo-0.01Cu-0.0013B

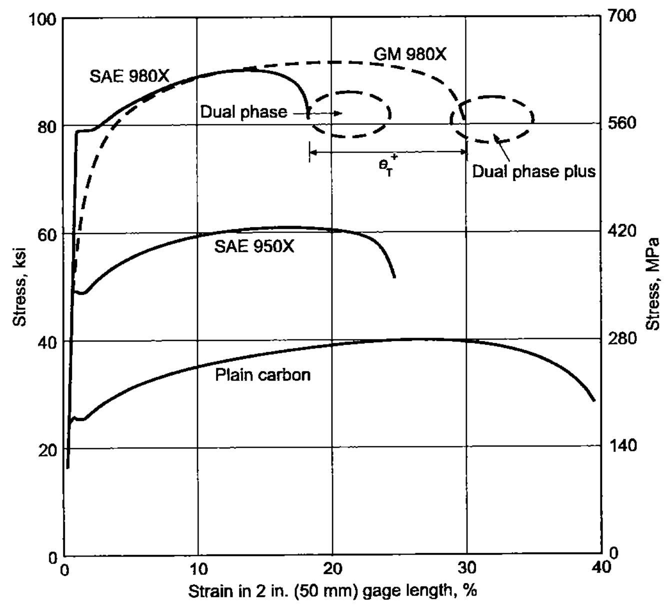
Source: G.C. Rauch and W.C. Leslie, The Extent and Nature of the Strength-Differential Effect in Steels, *Metall. Trans. A,* Feb 1972, p 377



CS.036 1060 carbon steel rod, true stress-strain curves

Rod diameter = 5.6 mm (0.22 in.). Flow curves for steel compressed at 780 °C at various strain rates. Letters A, B, C, and D represent the interruption strains used in the experiments. Composition: 0.68% C. UNS G10600

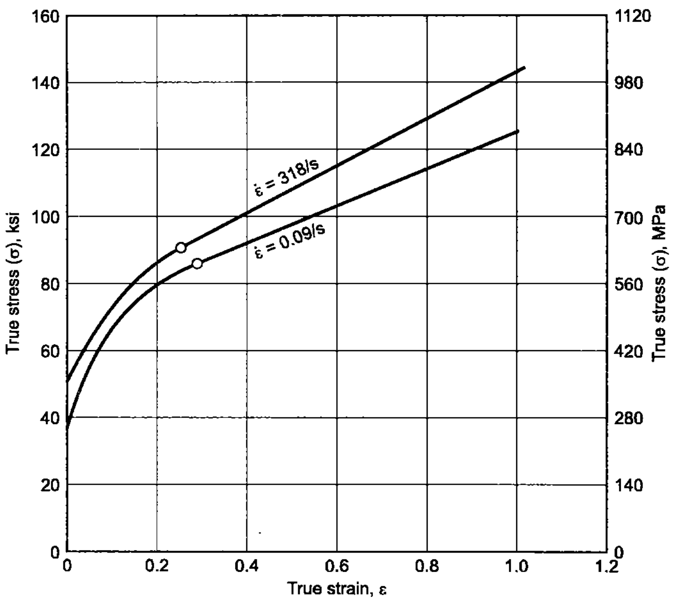
Source: R.A.P. Djaic and J.J. Jonas, Recrystallization of High Carbon Steel between Intervals of High Temperature Deformation, *Metall. Trans. A*, Feb 1973, p 622



CS.037 Carbon and high-strength low-alloy (HSLA) steels (SAE 950X, SAE 980X, and GM 980X), stress-strain curves

The GM 980X has been intercritically annealed and dual-phase microstructures produced. The two dashed ellipses indicate reported ranges of elongation for dual-phase steels. The basis for three stages in the development of ferritic low-carbon steels is shown. The lower stress-strain curve represents the deformation behavior of mild steel with ferrite-pearlite microstructures. The yielding is discontinuous and yield strengths are typically 30 ksi (207 MPa). SAE 950X and SAE 980X are HSLA steels with yield strengths of 50 ksi (345 MPa) and 80 ksi (562 MPa), respectively. The microstructures still consist of ferrite and pearlite, but the ferrite grain size is highly refined because of controlled rolling and microalloying with vanadium. GM 980X is similar to SAE 980X, but has been intercritically annealed to convert the pearlite to martensite. The resulting microstructure is termed "dual phase" to distinguish the ferrite-martensite microstructure from the ferrite-pearlite microstructure of conventionally treated mild steels of HSLA steels.

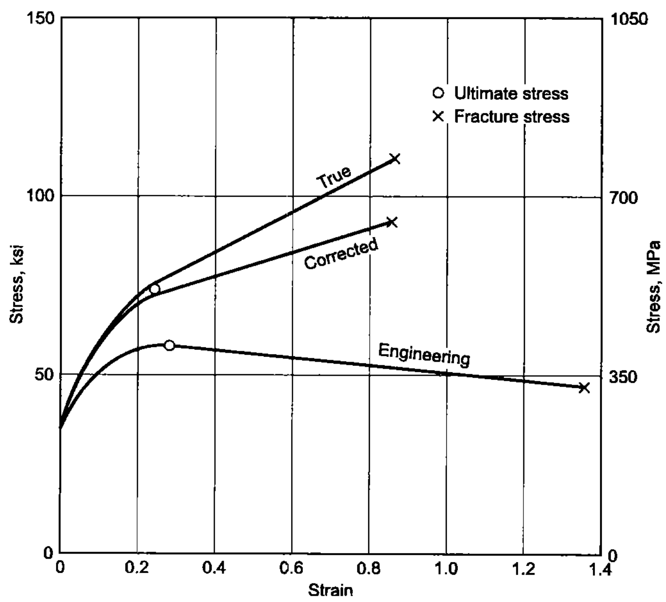
Source: G. Krauss, *Principles of Heat Treatment of Steel,* American Society for Metals, 1980, p 242



CS.038 1112 carbon steel, true stress-strain curves with effect of strain rate

True stress-strain curves for 1112 steel at different strain rates at 21 °C (70 °F). When metals are tested in tension at different strain rates, the flow stress corresponding to a given strain is found to increase with strain rate. The following equation is frequently used to relate flow stress and strain rate at a given strain and temperature: $\sigma = \sigma_1 \dot{\varepsilon}^m$, where $\dot{\varepsilon} = d\varepsilon/dt$ and σ_1 and m are material constants. The exponent m (strain-rate sensitivity) is found to increase with temperature, especially above the strain recrystallization temperature. In the hot-working region, metals tend to approach the behavior of a Newtonian liquid for which $m = 1$.

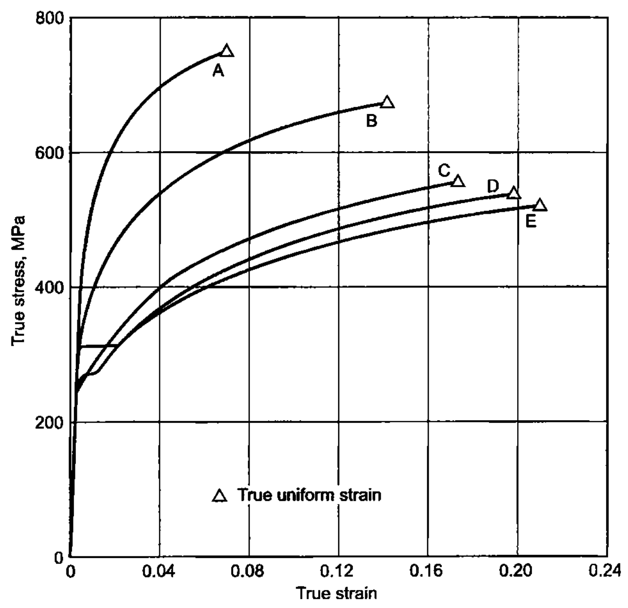
Source: M.C. Shaw, *Metal Cutting Principles,* Clarendon Press, Oxford, 1984, p 69



CS.039 1112 carbon steel, relationship of engineering, true, and corrected stress-strain curves

Relationship between engineering, true, and corrected tensile stress-strain curves for AISI 1112 steel. The figure above shows the relationship between the so-called engineering stress-strain curve based on the original area, the true stress-strain curve, and the corrected true stress-strain curve where the stress plotted (σ_c) is the uniaxial tensile stress in the absence of the hydrostatic component introduced by curvature of the neck. It is evident that interpretation of tensile test results is really quite involved despite the apparent simplicity of the test.

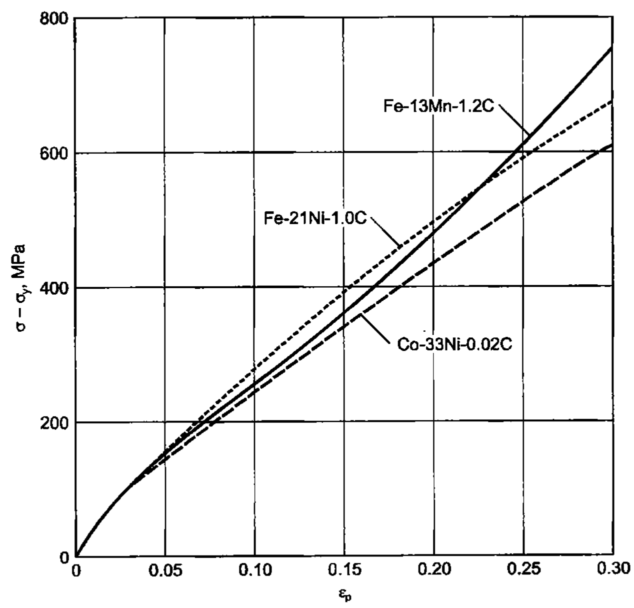
Source: M.C. Shaw, *Metal Cutting Principles,* Clarendon Press, Oxford, 1984, p 67



CS.040 Carbon steel, true stress-strain curves showing effect of different cooling rates

Specimens annealed at 810 °C, 10 min. Cooling rate: curve A, 1000 °C/s; curve B, 300 °C/s; curve C, 60 °C/s; curve D, 32 °C/s; curve E, 5 °C/s. Composition: Fe-0.063C-1.29Mn-0.24Si

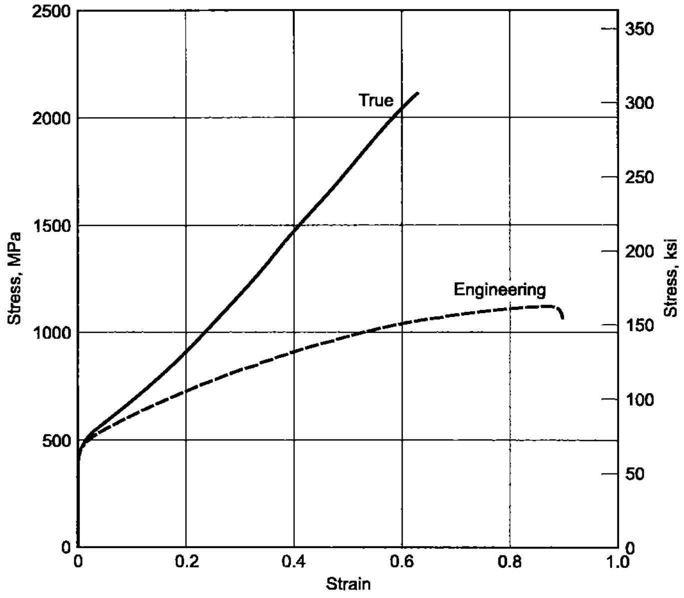
Source: G. Krauss, Ed., *Deformation, Processing, and Structure,* papers presented at the ASM Materials Science Seminar, 23 Oct 1982 (St. Louis, MO); American Society for Metals, 1984, p 70



CS.041 Carbon steel plate, true tensile stress (σ) minus yield stress (σ_y) versus true plastic strain (ε) curves at room temperature

Tested at room temperature. Plate thickness = 6.35 mm (0.25 in.). Comparison of work-hardening curve of Hadfield steel (Fe-13Mn-1.2C) with that of austenites deformed by slip (Fe-21Ni-1.0C) or twinning (Co-33Ni-0.02C). The three have the same yield strength and similar deformation below strain of 0.05.

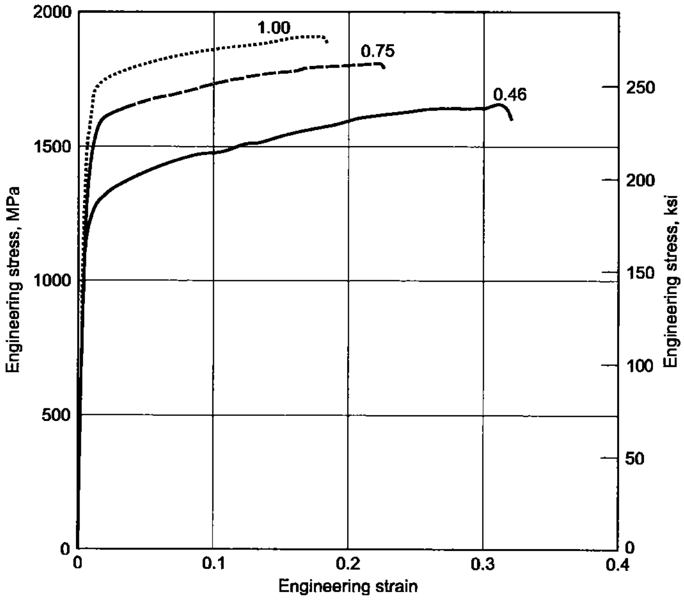
Source: F. Maratray, *High Carbon Manganese Austenitic Steels,* International Manganese Institute, Paris, 1995, p 28



CS.042 A128-E2 carbon steel bar, true and engineering tensile stress-strain curves

Molybdenum-modified Hadfield steel heat treated 1030–1040 °C, for 1 h. Engineering curve is drawn to fracture. True curve drawn to uniform strain at maximum load. Composition: Fe-12.5Mn-2.01Mo-1.15C-0.73Si-0.33Cr

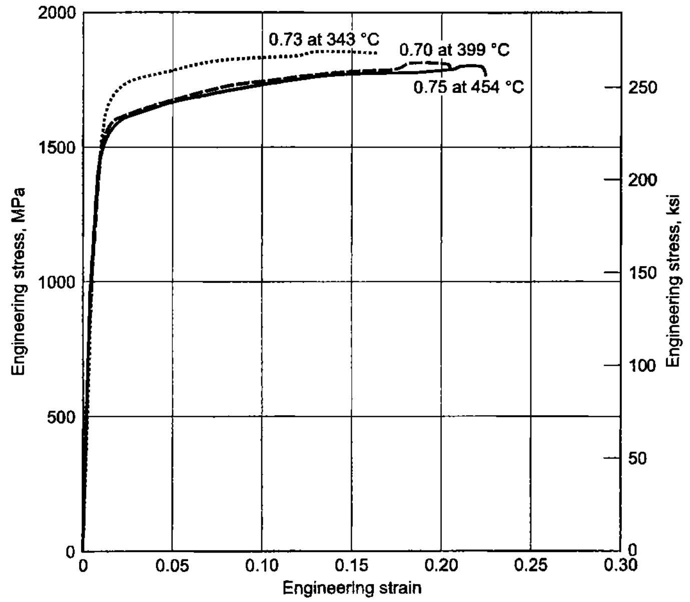
Source: J.F. Chinella, Mechanical Properties and Microstructure of Thermomechanically Processed, High Manganese Steel, *High Manganese High Nitrogen Austenitic Steels,* Conf. Proc., ASM International, 1992, p 145



CS.043 A128-E2 carbon steel bar, engineering tensile stress-strain curves showing effect of thermomechanical treatment

Molybdenum-modified Hadfield steel heat treated 1030–1040 °C, for 1 h. Thermomechanical treatment (TMT) at 454 °C. 1.00, 0.75, 0.46 are the effective strains, corresponding to 61, 50, and 35% thickness reduction. Strength increased with increased effective strain, but uniform strain in tension decreased. Composition: Fe-12.5Mn-2.01Mo-1.15C-0.73Si-0.33Cr

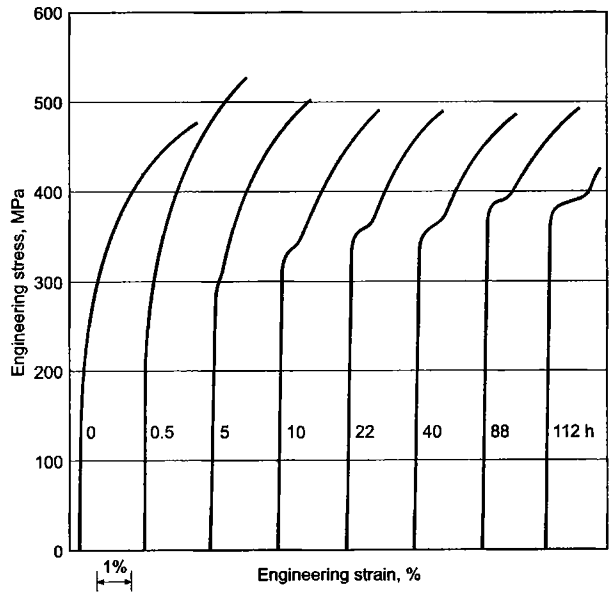
Source: J.F. Chinella, Mechanical Properties and Microstructure of Thermomechanically Processed, High Manganese Steel, *High Manganese High Nitrogen Austenitic Steels,* Conf. Proc., ASM International, 1992, p 148



CS.044 A128-E2 carbon steel bar, engineering tensile stress-strain curves showing effect of thermomechanical treatment

Molybdenum-modified Hadfield steel heat treated 1030–1040 °C, for 1 h. Thermomechanical treatment (TMT) at similar effective strains at the temperatures noted. Thickness reduction at 343 °C, 49%; at 399 °C, 48%, at 454 °C, 50%. Temperature had little effect on strength, but uniform strain increased with temperature. Composition: Fe-12.5Mn-2.01Mo-1.15C-0.73Si-0.33Cr

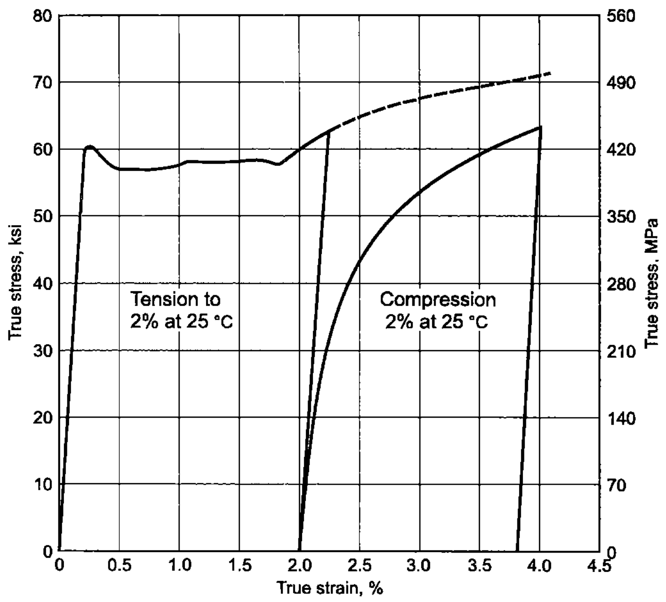
Source: J.F. Chinella, Mechanical Properties and Microstructure of Thermomechanically Processed, High Manganese Steel, *High Manganese High Nitrogen Austenitic Steels,* Conf. Proc., ASM International, 1992, p 148



CS.045 Fe-0.08C-1.45Mn-0.21Si carbon steel, engineering stress-strain curves showing effect of aging

Cold-rolled 50% and intercritically annealed 760 °C, 2 min, water quenched, aged at 120 °C (248 °F) for the times given. Yield strength and discontinuous yielding increase with aging time.

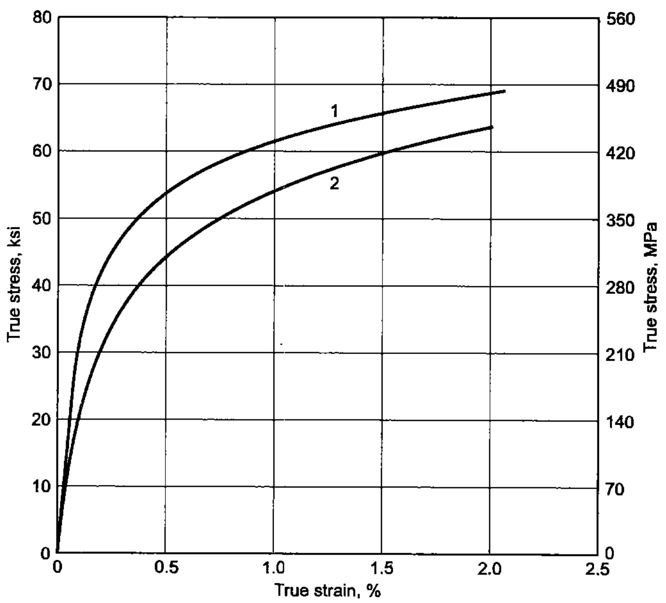
Source: G. Krauss, *Steels: Heat Treatment and Processing Principles,* ASM International, 1990, p 130



CS.046 1522 carbon steel, true stress-strain curves

Bauschinger effect shown with test sequence of tension to 2% strain followed by compression of another 2%. Tested at 25 °C. Composition: Fe-0.21C-1.10Mn-0.016S-0.011P-0.05Si-0.007Al-0.004N. UNS G15220

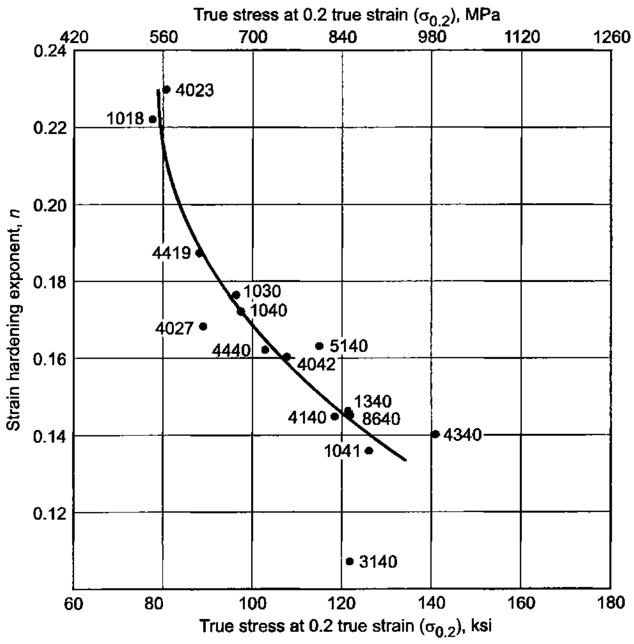
Source: C.-C. Li, J.D. Flasck, J.A. Yaker, and W.C. Leslie, On Minimizing the Bauschinger Effect in Steels by Dynamic Strain Aging, *Metall. Trans. A,* Jan 1978, p 87



CS.047 1522 carbon steel, true stress-strain curves

Curve 1: specimen is prestrained in tension at 250 °C to 2% strain and tested in compression at room temperature. Curve 2: the specimen is prestrained in tension at 25 °C to 2% strain and tested in compression at room temperature. The Bauschinger effect is reduced. Composition: Fe-0.21C-1.10Mn-0.016S-0.011P-0.05Si-0.007Al-0.004N. UNS G15220

Source: C.-C. Li, J.D. Flasck, J.A. Yaker, and W.C. Leslie, On Minimizing the Bauschinger Effect in Steels by Dynamic Strain Aging, *Metall. Trans. A,* Jan 1978, p 88

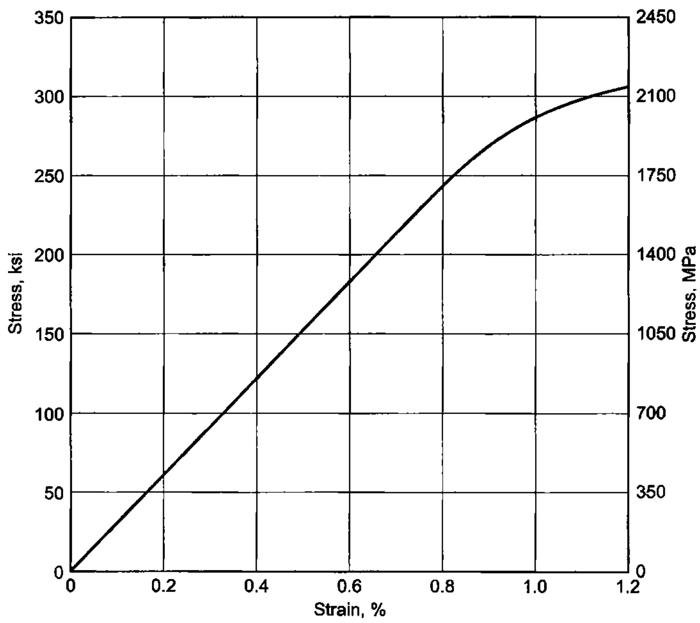


CS.048 Various carbon steels, strain-hardening exponent versus true stress curve at 0.2 true strain

Variations in strain-hardening exponents (n) for various plain carbon (10*xx*) and molybdenum alloy (4*xxx*) cold-forming steels. 5140 is a chromium alloy and 8640 is a Ni-Cr-Mo alloy steel.

Source: R.R. Crawford, R.G. Dunn, J.H. Humphrey, Influence of Alloying Elements on the Cold Deformation of Steel, *Sourcebook on Cold Forming*, American Society of Metals, 1975, p 142

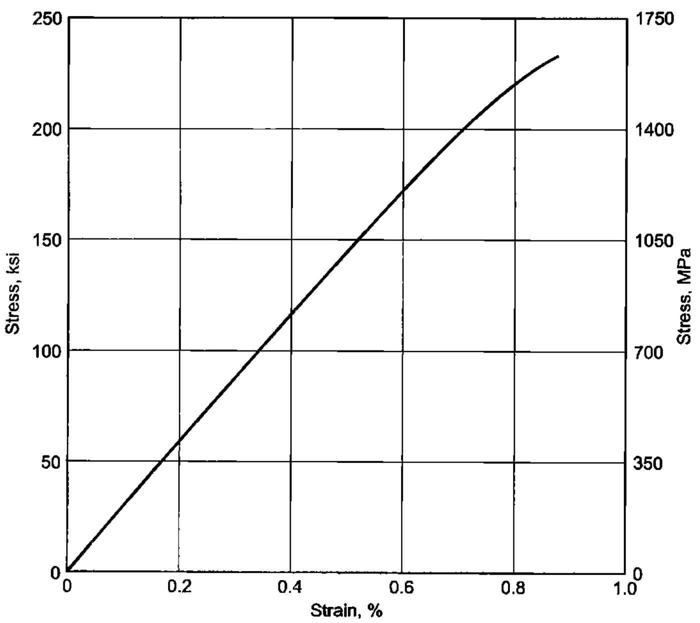
Alloy Steel (AS)



AS.001 52100 chromium alloy steel rod, tensile stress-strain curve

Heat treatment: 835 °C (1535 °F), oil quenched and tempered 160 °C (320 °F), 20 min. Hardness = 65 HRC. Composition: Fe-1C-1.45Cr. UNS G52986

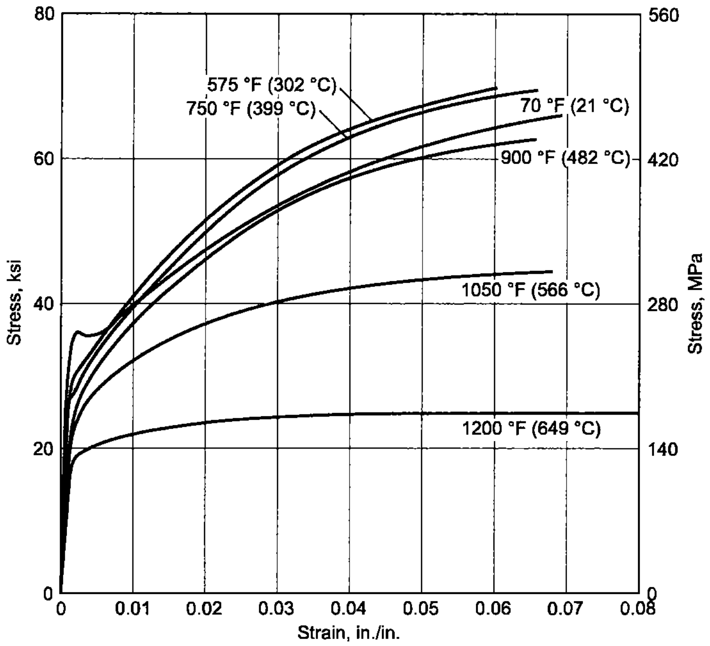
Source: G. Sachs, R. Sell, and W.F. Brown, Jr., Tension, Compression and Fatigue Properties of Several Steels for Aircraft Bearing Applications, *Proc. ASTM*, Vol 59, 1959. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1207, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 5



AS.002 52100 chromium alloy steel rod, compressive stress-strain curve

Heat treatment: 835 °C (1535 °F), oil quenched and tempered 160 °C (320 °F), 0.5 h, 274 °C (525 °F), 1 h. Hardness = 58 HRC. Composition: Fe-1C-1.45Cr. UNS G52986

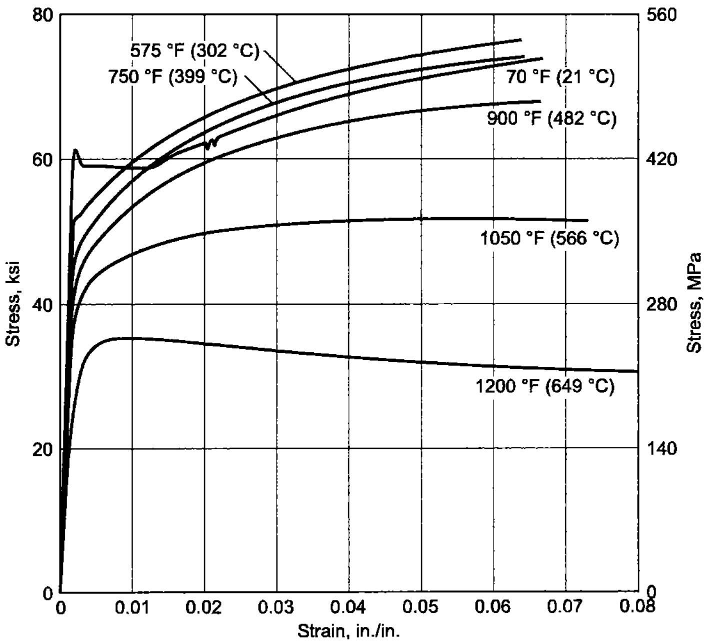
Source: G. Sachs, R. Sell, and W.F. Brown, Jr., Tension, Compression and Fatigue Properties of Several Steels for Aircraft Bearing Applications, *Proc. ASTM*, Vol 59, 1959. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1207, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 6



AS.003 2.25Cr-1Mo annealed chromium-molybdenum alloy steel plate, tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal. ASME SA-387 grade D plate. Test specimens machined from 25.4 mm (1 in.) thick plate. Specimens 6.40 mm diam × 50.8 mm gage length (0.252 in. diam × 2 in. gage length). Nominal strain rate = 0.01/min. Mill composition: Fe-0.12C-2.19Cr-0.93Mo-0.46Mn-0.24Si-0.014P-0.014S

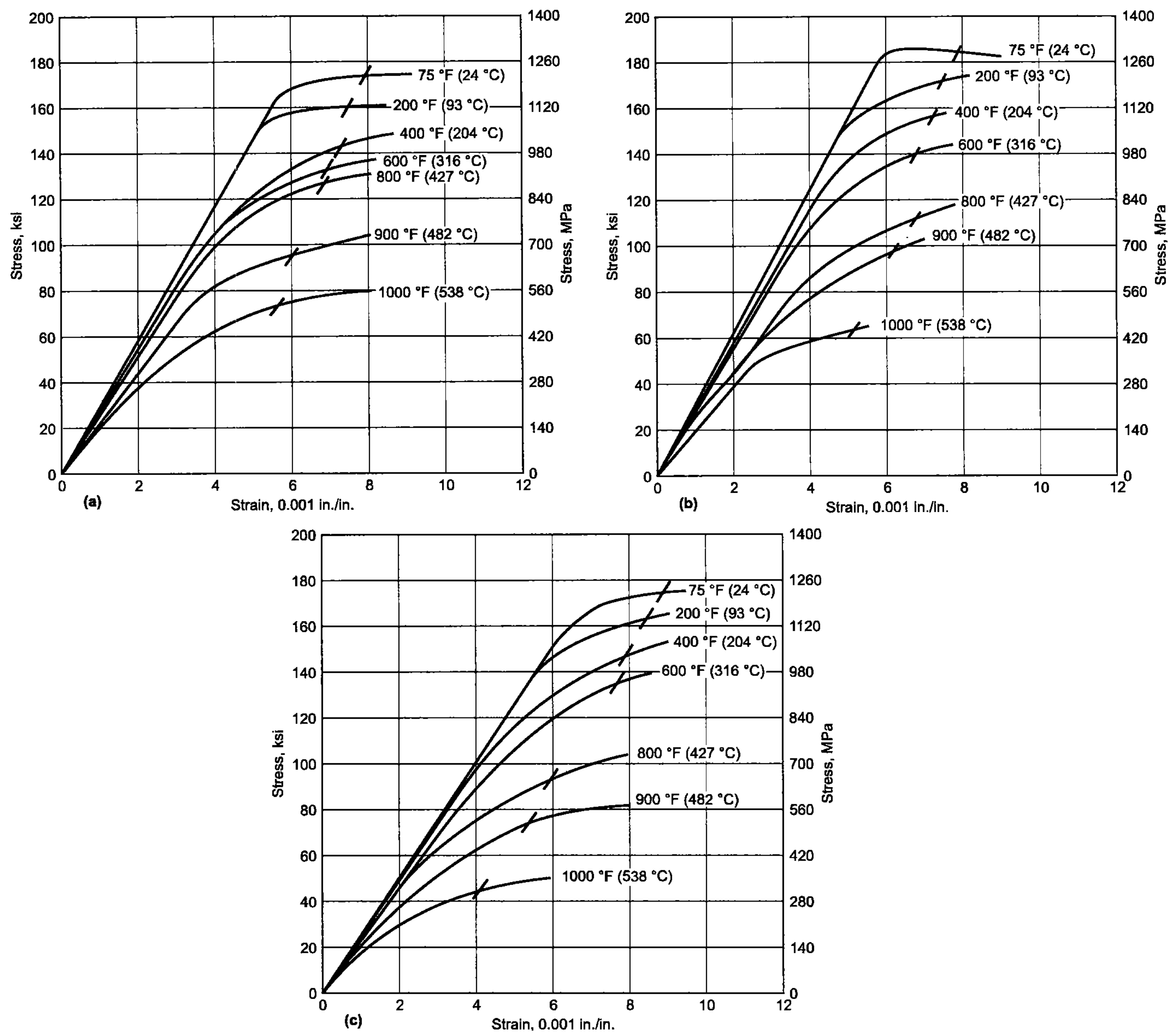
Source: J.E. Bynum, F.V. Ellis, and B.W. Roberts, Tensile and Creep Properties for an Annealed Versus Normalized and Tempered 2¼-1Mo Steel Plate, *Chrome Moly Steel in 1976,* The American Society of Mechanical Engineers, 1976, p 5



AS.004 2.25Cr-1Mo normalized-and-tempered chromium-molybdenum alloy steel plate, tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal. ASME SA-387 grade D plate. Test specimens machined from 25.4 mm (1 in.) thick plate. Specimens 6.40 mm diam × 50.8 mm gage length (0.252 in. diam × 2 in. gage length). Nominal strain rate = 0.01/min. Mill composition: Fe-0.12C-2.19Cr-0.93Mo-0.46Mn-0.24Si-0.014P-0.014S

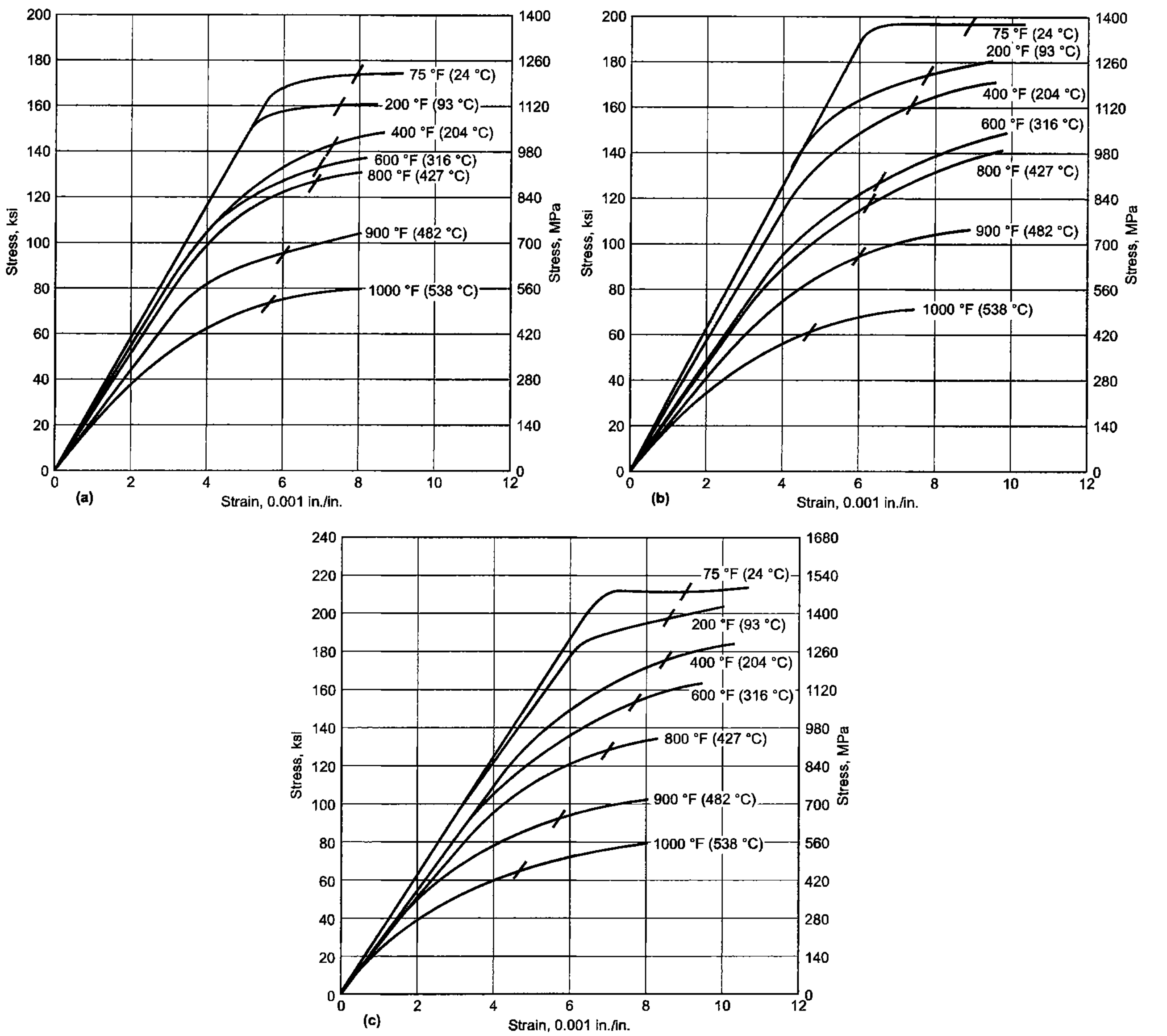
Source: J.E. Bynum, F.V. Ellis, and B.W. Roberts, Tensile and Creep Properties for an Annealed Versus Normalized and Tempered 2¼-1Mo Steel Plate, *Chrome Moly Steel in 1976,* The American Society of Mechanical Engineers, 1976, p 5



AS.005 4130 chromium-molybdenum alloy steel sheet, tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Sheet thickness = 1.626 mm (0.064 in.). Families of curves for different heat treatments. Left, 857 °C (1575 °F), oil quenched and tempered 538 °C (1000 °F); nominal strength = 1034 MPa (150 ksi). Center, 857 °C (1575 °F), oil quenched and tempered 443 °C (830 °F); nominal strength = 1241 MPa (180 ksi). Right, 857 °C (1575 °F), oil quenched and tempered 399 °C (750 °F); nominal strength = 1379 MPa (200 ksi). Specimens were held at temperature for 0.5–100 h. Composition: Fe-0.3C-0.95Cr-0.2Mo. UNS G41300

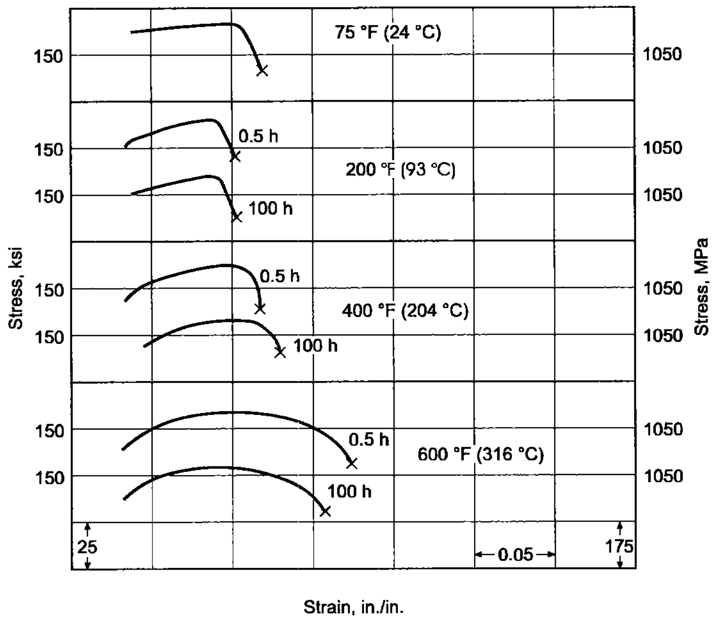
Source: J.V. Melonas and J.R. Kattus, "Determination of Tensile, Compressive, Bearing, and Shear Properties of Ferrous and Non-Ferrous Structural Sheet Metals at Elevated Temperatures," WADC TR56-340, ASTIA Document No. AD 131 069, Southern Research Institute, Sept 1957. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1201, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 29



AS.006 4130 chromium-molybdenum alloy steel sheet, compressive stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Sheet thickness = 1.626 mm (0.064 in.). Families of curves for different heat treatments. Left, 857 °C (1575 °F), oil quenched and tempered 538 °C (1000 °F); nominal strength = 1034 MPa (150 ksi). Center, 857 °C (1575 °F), oil quenched and tempered 443 °C (830 °F); nominal strength = 1241 MPa (180 ksi). Right, 857 °C (1575 °F), oil quenched and tempered 399 °C (750 °F); nominal strength = 1379 MPa (200 ksi). Specimens were held at temperature for 0.5–100 h. Composition: Fe-0.3C-0.95Cr-0.2Mo. UNS G41300

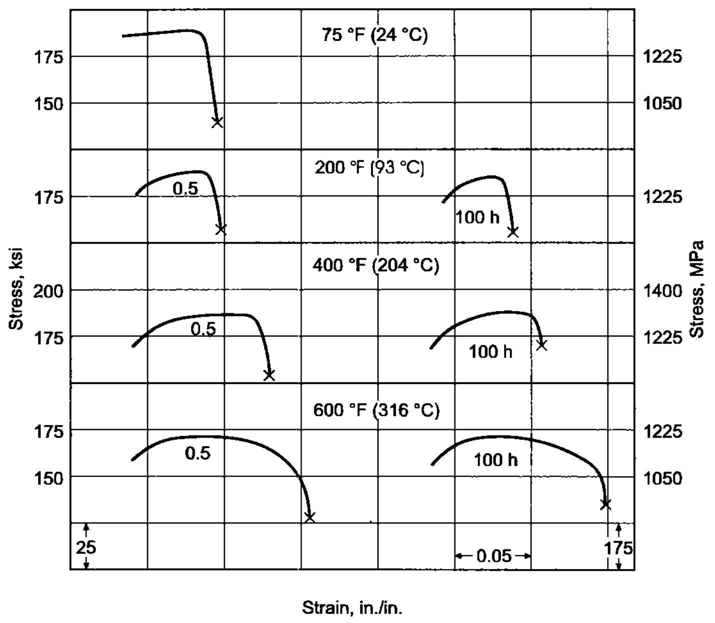
Source: J.V. Melonas and J.R. Kattus, "Determination of Tensile, Compressive, Bearing, and Shear Properties of Ferrous and Non-Ferrous Structural Sheet Metals at Elevated Temperatures," WADC TR56-340, ASTIA Document No. AD 131 069, Southern Research Institute, Sept 1957. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1201, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 33



AS.007 4130 chromium-molybdenum alloy steel sheet, stress-strain curves (full range) at various exposure times to elevated temperatures

Hot rolled and normalized, austenitized 857 °C (1575 °F), oil quenched, tempered at 538 °C (1000 °F) for 1034 MPa (150 ksi) ultimate tensile strength. Composition of heat: Fe-0.31C-0.50Mn-0.014P-0.015S-0.92Cr-0.19Mo. UNS G41300

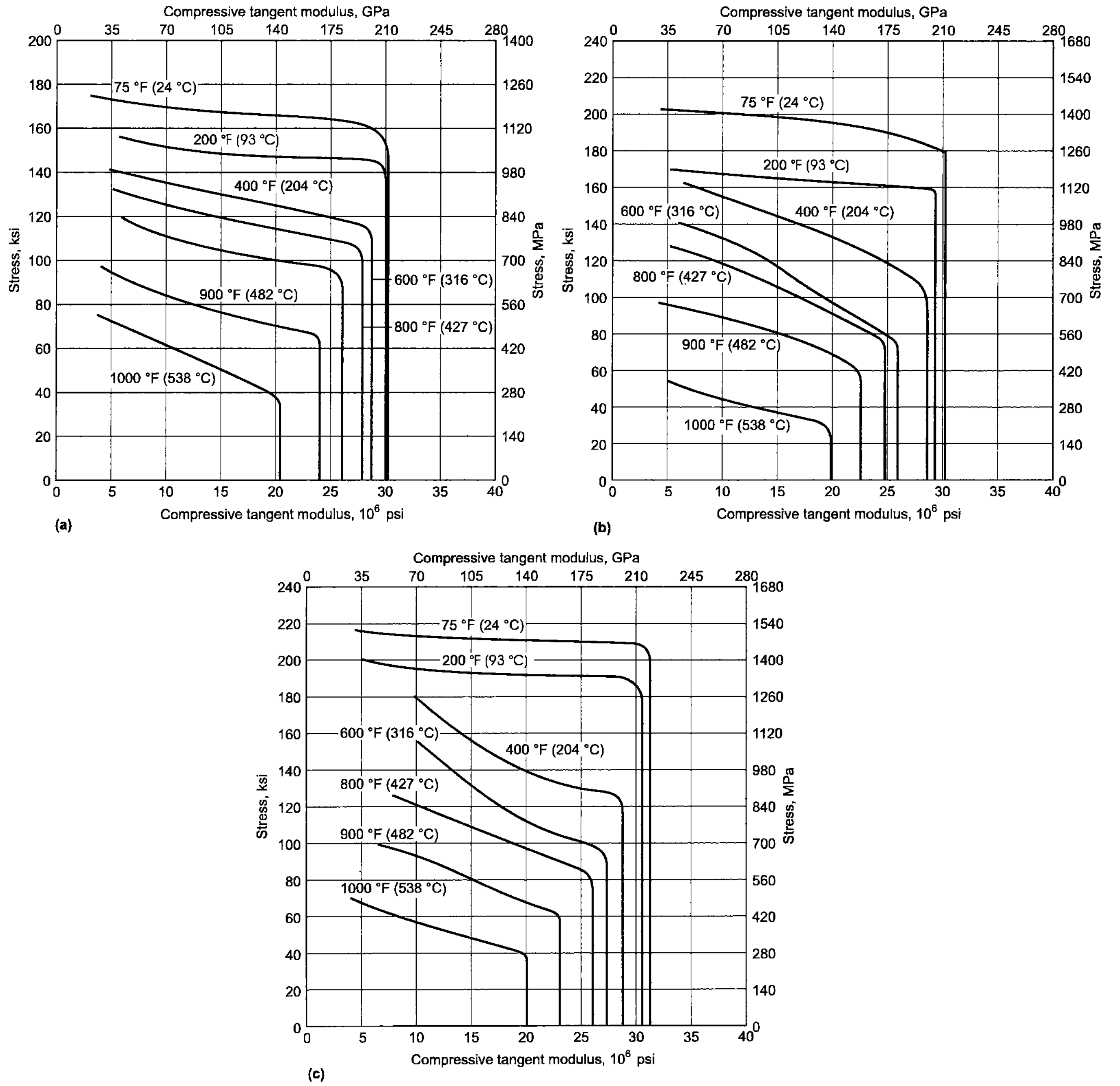
Source: J.V. Melonas and J.R. Kattus, "Determination of Tensile, Compressive, Bearing, and Shear Properties of Ferrous and Non-Ferrous Structural Sheet Metals at Elevated Temperatures," WADC TR56-340, ASTIA Document No. AD 131 069, Southern Research Institute, Sept 1957. As published in *Structural Alloys Handbook,* Vol 1, CINDAS/Purdue University, 1994, p 22



AS.008 4130 chromium-molybdenum alloy steel sheet, stress-strain curves (full range) at various exposure times to elevated temperatures

Hot rolled and normalized, austenitized 857 °C (1575 °F), oil quenched, tempered at 443 °C (830 °F) for 1241 MPa (180 ksi) ultimate tensile strength. Composition of heat: Fe-0.31C-0.50Mn-0.014P-0.015S-0.92Cr-0.19Mo. UNS G41300

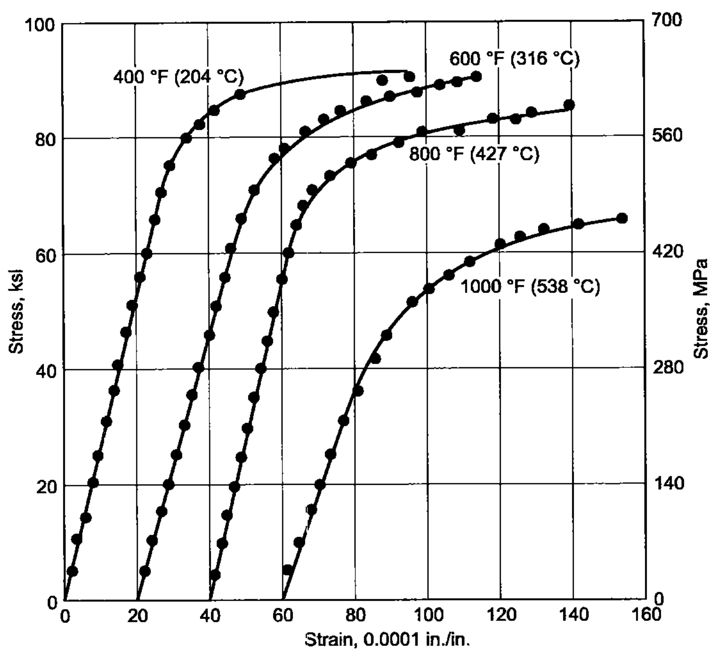
Source: J.V. Melonas and J.R. Kattus, "Determination of Tensile, Compressive, Bearing, and Shear Properties of Ferrous and Non-Ferrous Structural Sheet Metals at Elevated Temperatures," WADC TR56-340, ASTIA Document No. AD 131 069, Southern Research Institute, Sept 1957. As published in *Structural Alloys Handbook,* Vol 1, CINDAS/Purdue University, 1994, p 24



AS.009 4130 chromium-molybdenum alloy steel sheet, compressive tangent modulus curves at room and elevated temperatures

Test direction: longitudinal. Sheet thickness = 1.626 mm (0.064 in.). Families of curves for different heat treatments. (a) 857 °C (1575 °F), oil quenched and tempered 538 °C (1000 °F); nominal strength = 1034 MPa (150 ksi). (b) 857 °C (1575 °F), oil quenched and tempered 443 °C (830 °F); nominal strength = 1241 MPa (180 ksi). (c) 857 °C (1575 °F), oil quenched and tempered 399 °C (750 °F); nominal strength = 1379 MPa (200 ksi). Specimens were held at temperature for 0.5–100 h. Composition: Fe-0.3C-0.95Cr-0.2Mo. UNS G41300

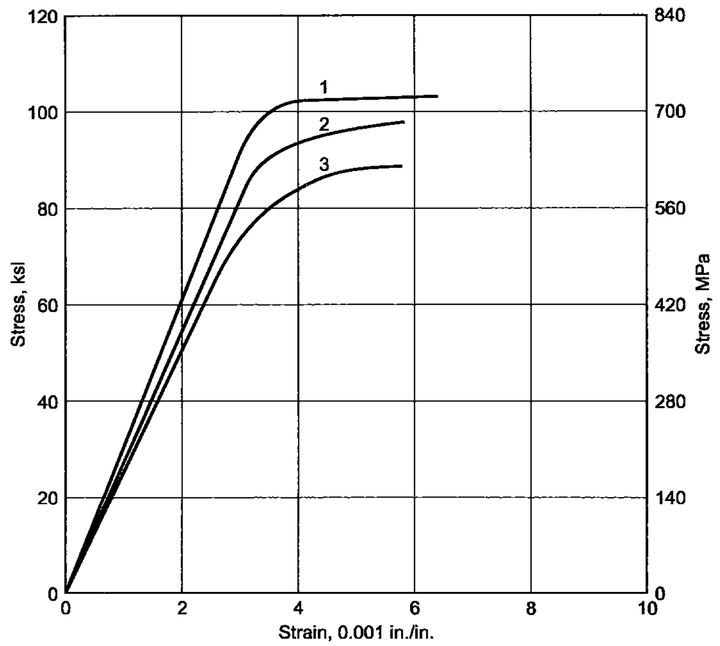
Source: J.V. Melonas and J.R. Kattus, "Determination of Tensile, Compressive, Bearing, and Shear Properties of Ferrous and Non-Ferrous Structural Sheet Metals at Elevated Temperatures," WADC TR56-340, ASTIA Document No. AD 131 069, Southern Research Institute, Sept 1957. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1201, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 44



AS.010 4130 chromium-molybdenum alloy steel sheet, compressive stress-strain curves at various elevated temperatures

Sheet thickness = 1.575 mm (0.062 in.). Heat treated for 862 MPa (125 ksi) nominal tensile strength. Strain rate = 0.01/min. Composition of heat: Fe-0.30C-0.60Mn-0.019P-0.034S-1.05Cr-0.20Mo. UNS G41300

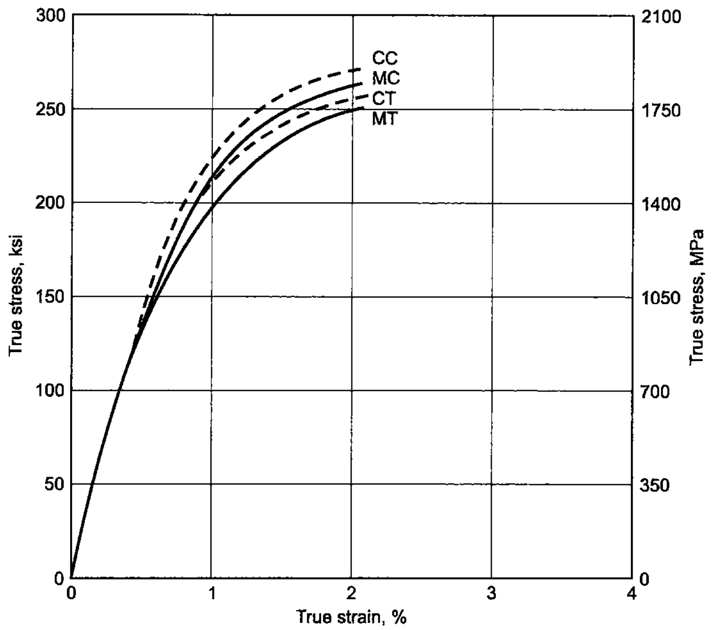
Source: D.E. Miller, "Determination of Tensile, Compressive, and Bearing Properties of Ferrous and Non-Ferrous Structural Sheet Materials at Elevated Temperatures," WADC AFTR 6517, Part V, AD 142218, Armour Research Foundation, Dec 1957. As published in *Structural Alloys Handbook,* Vol 1, CINDAS/Purdue University, 1994, p 34



AS.011 4130 chromium-molybdenum alloy steel sheet, compressive stress-strain curves at room and elevated temperatures

Test direction: transverse. Sheet thickness = 1.626 mm (0.064 in.). Heat treated to 862 MPa (125 ksi) nominal tensile strength. Strain rate = 0.01/min. Curve 1: Room temperature, modulus of elasticity = 205 GPa (29.8 × 10^6 psi). Curve 2: 204 °C (400 °F), modulus of elasticity = 189 GPa (27.4 × 10^6 psi). Curve 3: 316 °C (600 °F), modulus of elasticity = 178 GPa (25.8 × 10^6 psi). Composition: Fe-0.30C-0.60Mn-0.019P-0.034S-1.05Cr-0.20Mo. UNS G41300

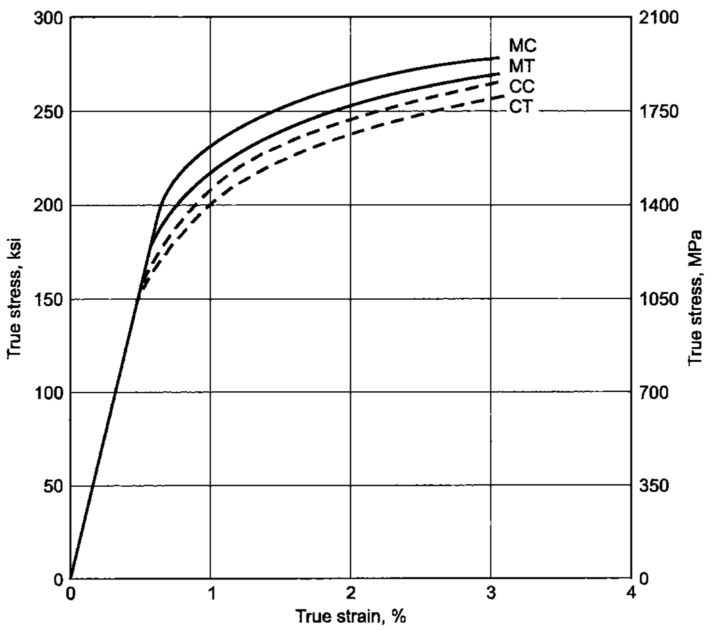
Source: R.J. Favor, W.P. Archbach, and W.S. Hyler, "Material-Property-Design Criteria for Metals, Part 7, The Conventional Short-Time Elevated Temperature Properties of Selected Low-and-Medium-Alloy Steels," WADC TR 55-150, Part 7, AD 142064, Oct 1957. As published in *Structural Alloys Handbook,* Vol 1, CINDAS/Purdue University, 1994, p 34



AS.012 4140 chromium-molybdenum alloy steel bar, monotonic and cyclic true stress-strain curves

Heat treatment: austenitized 999 °C (1830 °F), 1 h, oil quenched. Gage section size = 5.08 mm diam × 7.62 mm long (0.2 in. diam × 0.3 in. long). Strain rate = 0.5/min. Test condition: MT, monotonic tension; MC, monotonic compression; CT, cyclic tension; CC, cyclic compression. Composition: Fe-0.4C-1Cr-0.2Mo. UNS G41400

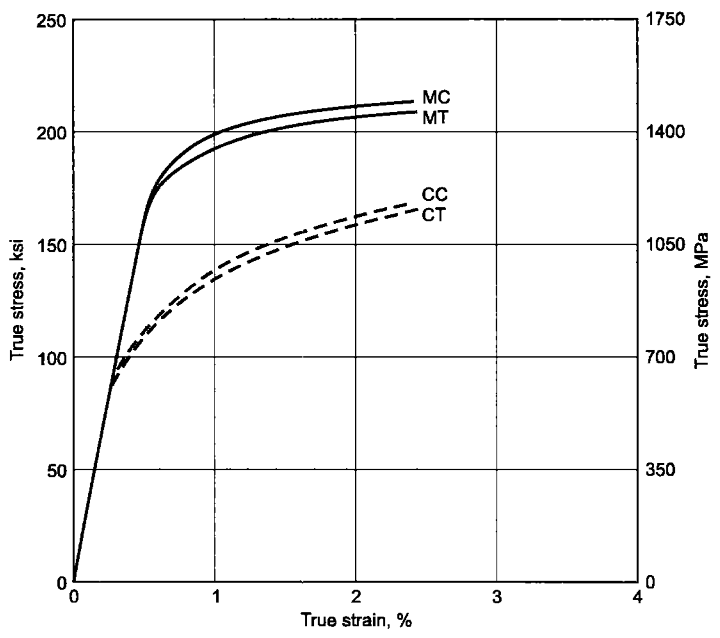
Source: P.N. Thielen, M.F. Fine, and R.A. Fournelle, Cyclic Stress Strain Relations and Strain-Controlled Fatigue of 4140 Steel, *Acta Metall.*, Vol 24 (No. 1), Jan 1976, p 1–10. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1203, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 18



AS.013 4140 chromium-molybdenum alloy steel bar, monotonic and cyclic true stress-strain curves

Heat treatment: austenitized 999 °C (1830 °F), 1 h, oil quenched, tempered 199 °C (390 °F), 1 h, water quenched. Gage section size = 5.08 mm diam × 7.62 mm long (0.2 in. diam × 0.3 in. long). Strain rate = 0.5/min. Test condition: MT, monotonic tension; MC, monotonic compression; CT, cyclic tension; CC, cyclic compression. Composition: Fe-0.4C-1Cr-0.2Mo. UNS G41400

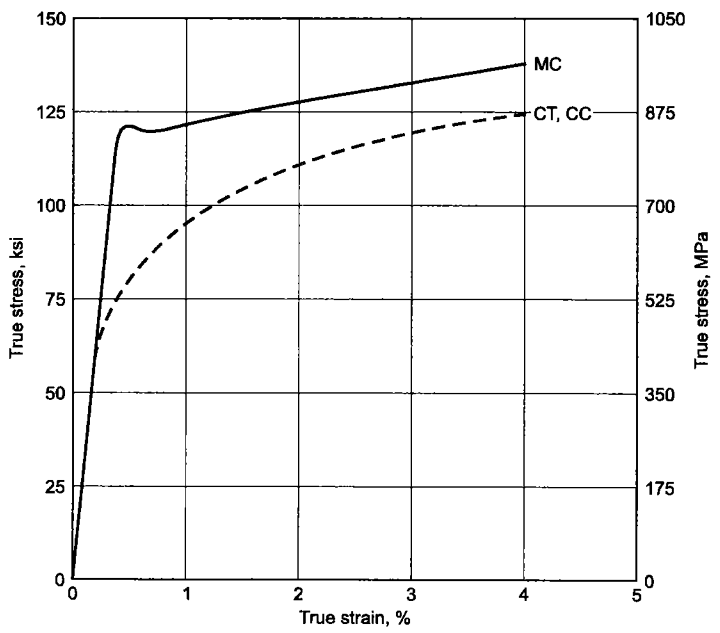
Source: P.N. Thielen, M.F. Fine, and R.A. Fournelle, Cyclic Stress Strain Relations and Strain-Controlled Fatigue of 4140 Steel, *Acta Metall.*, Vol 24 (No. 1), Jan 1976, p 1–10. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1203, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 18



AS.014 4140 chromium-molybdenum alloy steel bar, monotonic and cyclic true stress-strain curves

Heat treatment: austenitized 999 °C (1830 °F), 1 h, oil quenched, tempered 399 °C (750 °F), 1 h, water quenched. Gage section size = 5.08 mm diam × 7.62 mm long (0.2 in. diam × 0.3 in. long). Strain rate = 0.5/min. Test condition: MT, monotonic tension; MC, monotonic compression; CT, cyclic tension; CC, cyclic compression. Composition: Fe-0.4C-1Cr-0.2Mo. UNS G41400

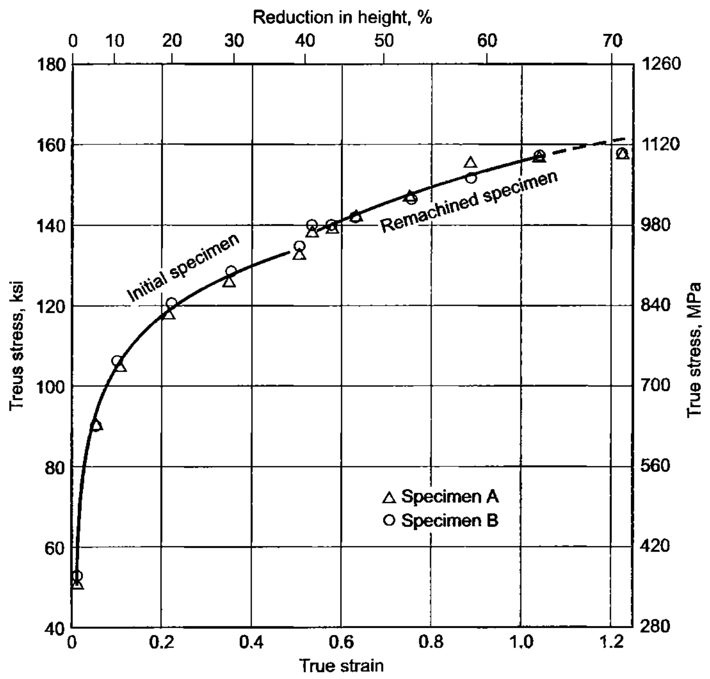
Source: P.N. Thielen, M.F. Fine, and R.A. Fournelle, Cyclic Stress Strain Relations and Strain-Controlled Fatigue of 4140 Steel, *Acta Metall.*, Vol 24 (No. 1), Jan 1976, p 1–10. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1203, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 18



AS.015 4140 chromium-molybdenum alloy steel bar, monotonic and cyclic true stress-strain curves

Heat treatment: austenitized 999 °C (1830 °F), 1 h, oil quenched, tempered 649 °C (1200 °F), 1 h, water quenched. Gage section size = 5.08 mm diam × 7.62 mm long (0.2 in. diam × 0.3 in. long). Strain rate = 0.5/min. Test condition: MC, monotonic compression; CT, cyclic tension; CC, cyclic compression. Composition: Fe-0.4C-1Cr-0.2Mo. UNS G41400

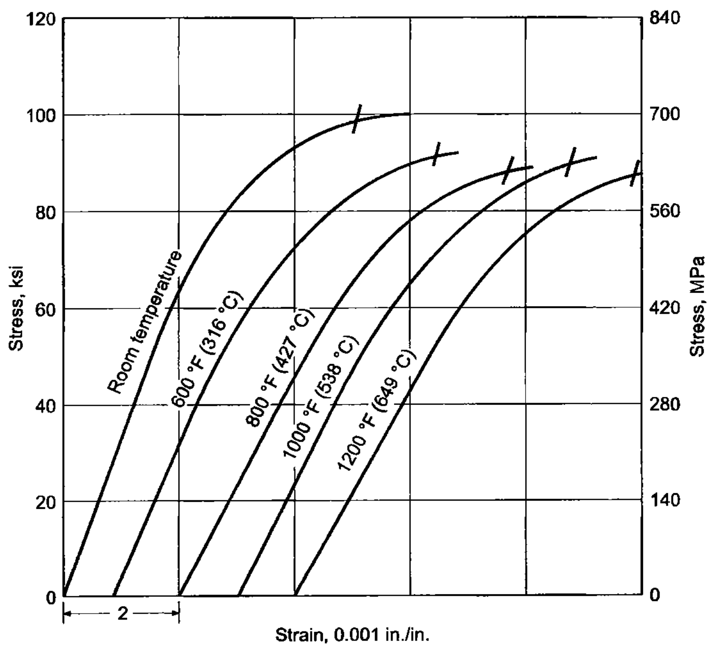
Source: P.N. Thielen, M.F. Fine, and R.A. Fournelle, Cyclic Stress Strain Relations and Strain-Controlled Fatigue of 4140 Steel, *Acta Metall.*, Vol 24 (No. 1), Jan 1976, p 1–10. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1203, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 18



AS.016 4140 chromium-molybdenum alloy steel bar, true compressive stress-strain curve

Specimens taken from hot-worked 57.15 mm (2.25 in.) diam bar, test specimen 20 mm diam × 40 mm long, normalized and annealed. After compression of about 40%, specimens remachined to 14 mm diam × 21 mm long. The discontinuity of results was typical. True yield stress at 0.2% offset = 813 MPa (118 ksi); strain-hardening exponent n = 0.145. Composition: Fe-0.39C-1.00Cr-0.82Mn-0.26Si-0.21Mo-0.025S-0.012P. UNS G41400

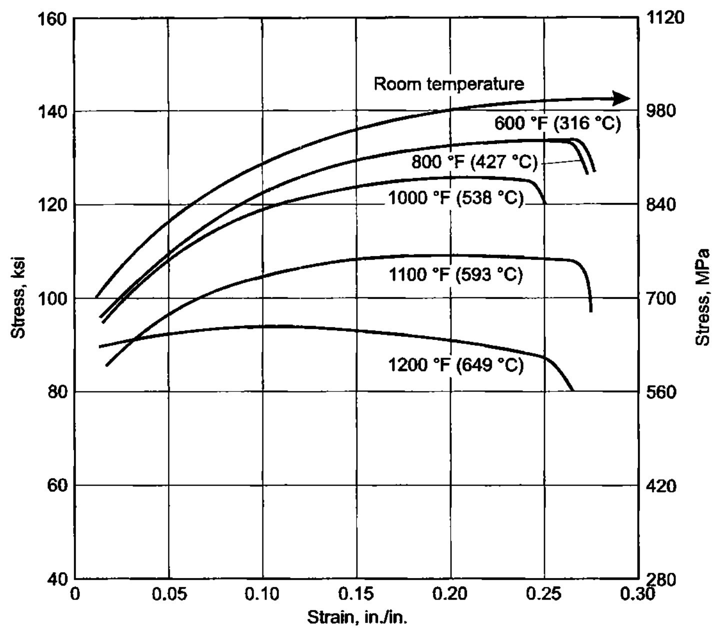
Source: J.D. Crawford, R.G. Dunn, and J.H. Humphrey, The Influence of Alloying Elements on the Cold Deformation of Steel, *Source Book on Cold Forming*, American Society for Metals, 1975, p 142



AS.017 A286 nickel-chromium-molybdenum alloy steel sheet, tensile stress-strain curves (expanded range) at room and elevated temperatures

Sheet thickness = 1.575 mm (0.062 in.). 0.5–1000 h exposure. Heat treated: 982 °C (1800 °F), 1 h, argon, oil quenched, 718 °C (1325 °F), 16 h, air cool. Composition: Fe-25Ni-15Cr-2Ti-1.5Mn-1.3Mo-0.3V. UNS S66286

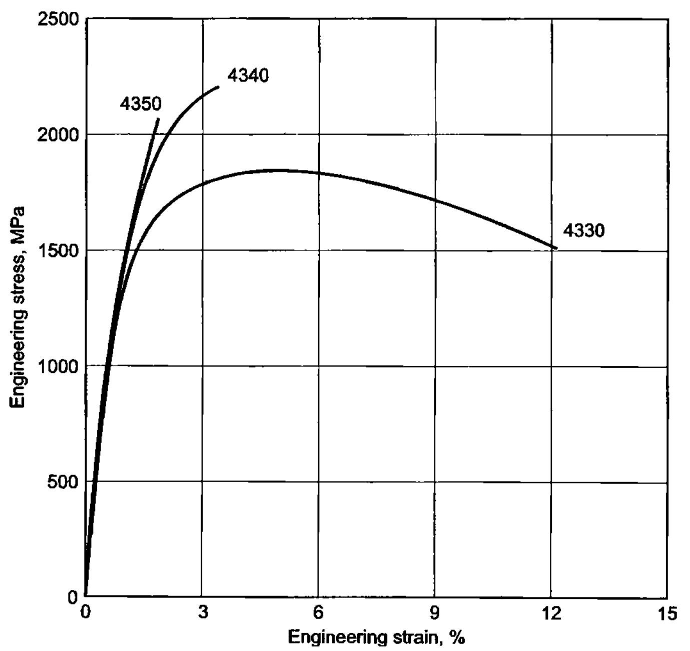
Source: J.R. Kattus, J.B. Preston, and H.L. Lessle, "Determination of Tensile, Compressive, Bearing, and Shear Properties at Elevated Temperatures," WADC TR 58-365, Nov 1958. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1601, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 19



AS.018 A286 nickel-chromium-molybdenum alloy steel sheet, tensile stress-strain curves (full range) at room and elevated temperatures

Sheet thickness = 1.575 mm (0.062 in.). Heat treated: 982 °C (1800 °F), 1 h, argon, oil quenched, 718 °C (1325 °F), 16 h, air cool. Composition: Fe-25Ni-15Cr-2Ti-1.5Mn-1.3Mo-0.3V. UNS S66286

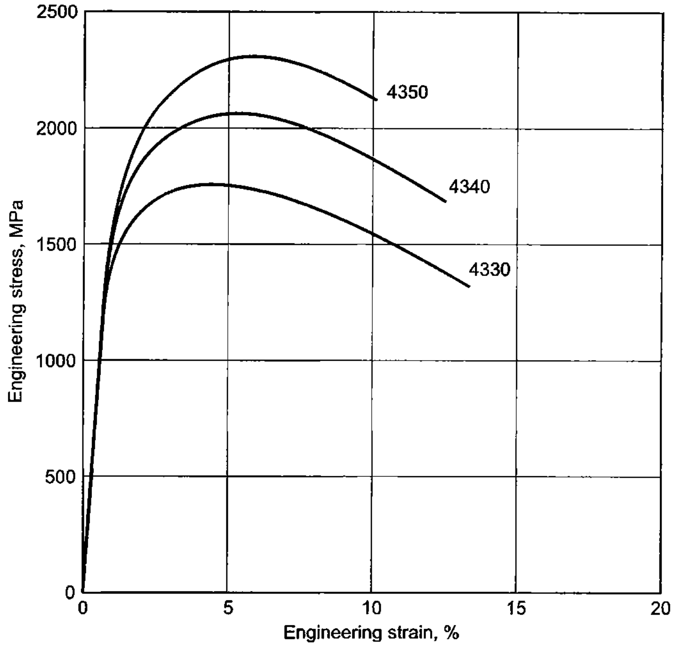
Source: J.R. Kattus, J.B. Preston, and H.L. Lessle, "Determination of Tensile, Compressive, Bearing, and Shear Properties at Elevated Temperatures," WADC TR 58-365, Nov 1958. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1601, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 19



AS.019 4330, 4340, 4350 nickel-chromium-molybdenum alloy steel hot-rolled plate, tensile engineering stress-strain curves

Test direction: long transverse. Specimen size = 6.25 mm diam × 38 mm long, austenitized in salt bath at 936 °C, 20 min, oil quenched. Tested as-quenched with Instron machine with crosshead velocity of 8.5 mm/s, which corresponds to strain rate of 0.0033/s

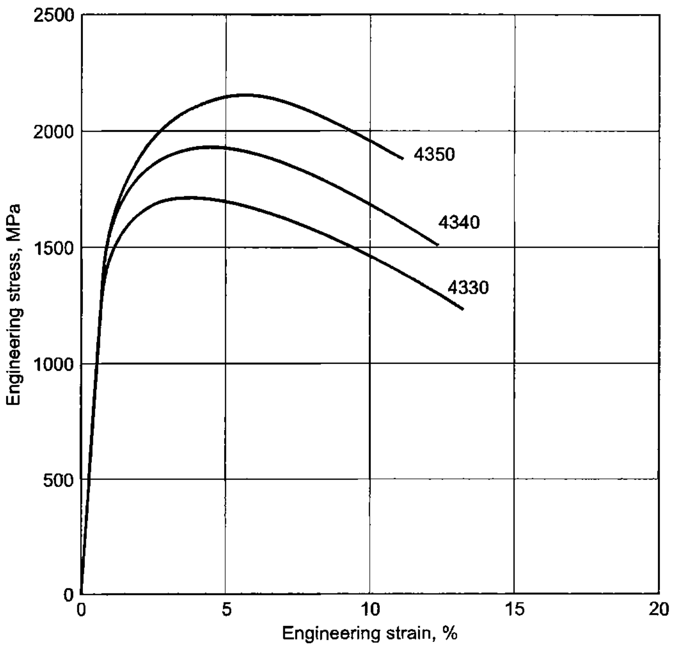
Source: M. Saeglitz and G. Krauss, Deformation, Fracture, and Mechanical Properties of Low-Temperature-Tempered Martensite in SAE 43xx Steels, *Metall. Mater. Trans.,* Vol 28A (No. 2), Feb 1997, p 382



AS.020 4330, 4340, 4350 nickel-chromium-molybdenum alloy steel hot-rolled plate, tensile engineering stress-strain curves

Test direction: long transverse. Specimen size = 6.25 mm diam × 38 mm long, austenitized in salt bath at 936 °C, 20 min, oil quenched, tempered 10 h in 150 °C oil bath. Tested with Instron machine with crosshead velocity of 8.5 mm/s, which corresponds to strain rate of 0.0033/s

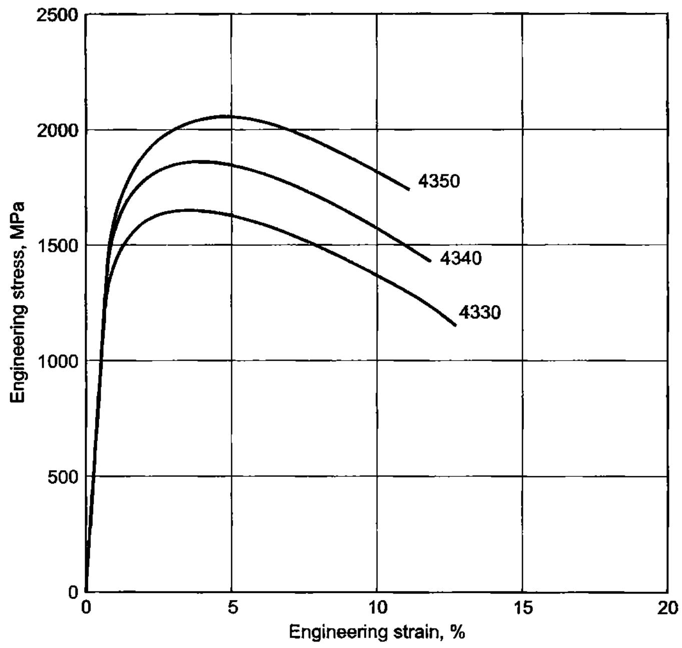
Source: M. Saeglitz and G. Krauss, Deformation, Fracture and Mechanical Properties of Low-Temperature-Tempered Martensite in SAE 43xx Steels, *Metall. Mater. Trans.*, Vol 28A (No. 2), Feb 1997, p 379



AS.021 4330, 4340, 4350 nickel-chromium-molybdenum alloy steel hot-rolled plate, tensile engineering stress-strain curves

Test direction: long transverse. Specimen size = 6.25 mm diam × 38 mm long, austenitized in salt bath at 936 °C, 20 min, oil quenched, tempered 10 h in 175 °C oil bath. Tested with Instron machine with crosshead velocity of 8.5 mm/s, which corresponds to strain rate of 0.0033/s

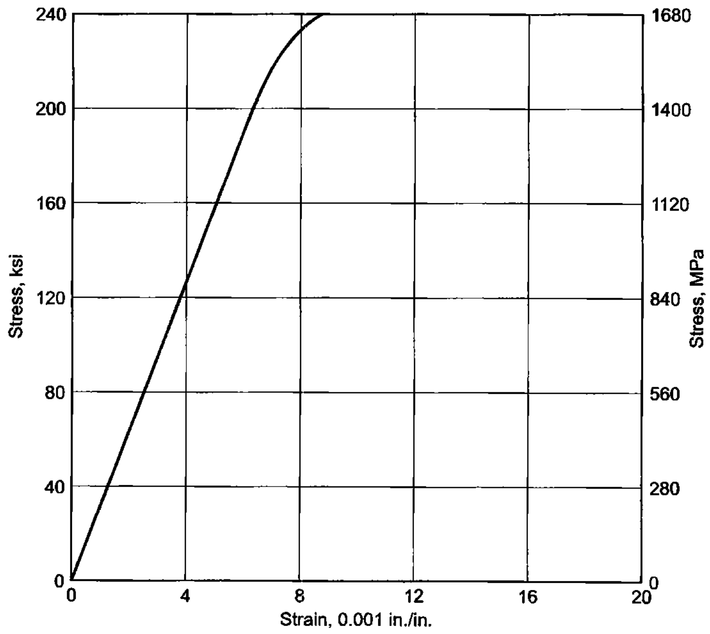
Source: M. Saeglitz and G. Krauss, Deformation, Fracture and Mechanical Properties of Low-Temperature-Tempered Martensite in SAE 43xx Steels, *Metall. Mater. Trans.*, Vol 28A (No. 2), Feb 1997, p 379



AS.022 4330, 4340, 4350 nickel-chromium-molybdenum alloy steel hot-rolled plate, tensile engineering stress-strain curves

Test direction: long transverse. Specimen size = 6.25 mm diam × 38 mm long, austenitized in salt bath at 936 °C, 20 min, oil quenched, tempered 10 h in 200 °C oil bath. Tested with Instron machine with crosshead velocity of 8.5 mm/s, which corresponds to strain rate of 0.0033/s

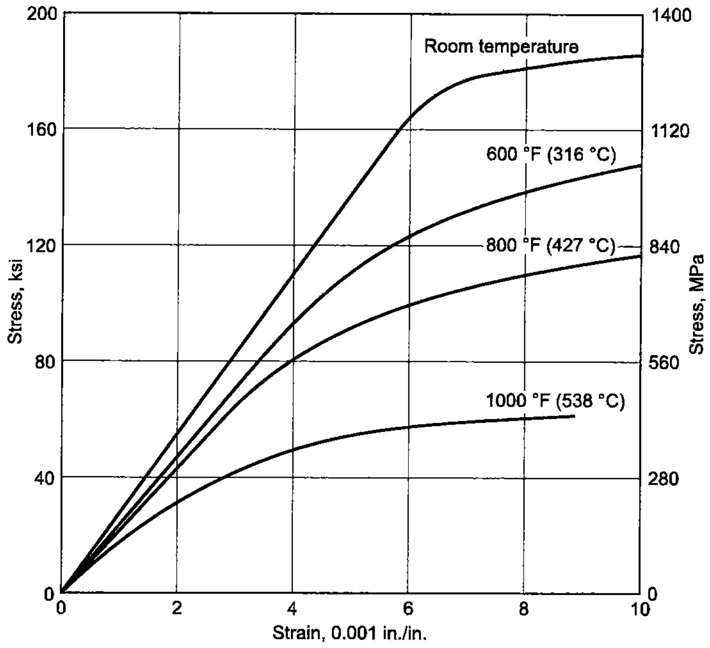
Source: M. Saeglitz and G. Krauss, Deformation, Fracture and Mechanical Properties of Low-Temperature-Tempered Martensite in SAE 43xx Steels, *Metall. Mater. Trans.*, Vol 28A (No. 2), Feb 1997, p 379



AS.023 4335V nickel-chromium-molybdenum alloy steel bar, compressive stress-strain curve

Bar thickness = 31.75 mm (1.25 in.). Vanadium-modified version of the standard 4335 steel. Austenitized 829 °C (1525 °F), 1 h, oil quenched, room temperature, tempered 241 °C (465 °F), 2 h, air cooled. Composition: Fe-0.35C-1.8Ni-0.8Cr-0.35Mo-0.2V. UNS K33517

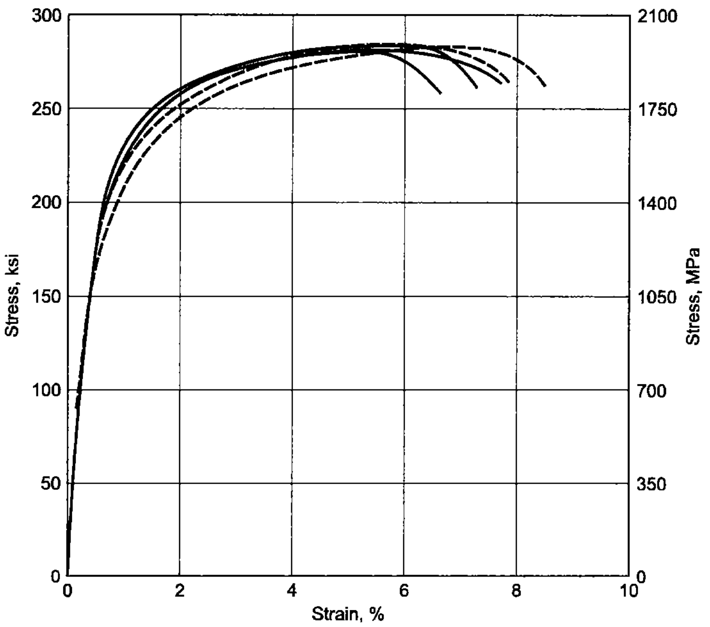
Source: R.C. Jones, "Materials—SAE 4335 (Modified) Steel 260,000 to 280,000 psi Heat Treatment—Development of Process Control and Mechanical Properties for," Convair Division—General Dynamics, 24 Oct 1962. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1205, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 17



AS.024 4340 nickel-chromium-molybdenum alloy steel sheet, tensile stress-strain curves at room and elevated temperatures

Heat treated: 829 °C (1525 °F), 10 min, air cooled, tempered 427 °C (800 °F), 1 h, to ultimate tensile strength = 1379 MPa (200 ksi). Composition: Fe-0.4C-1.8Ni-0.8Cr-0.25Mo. UNS G43400

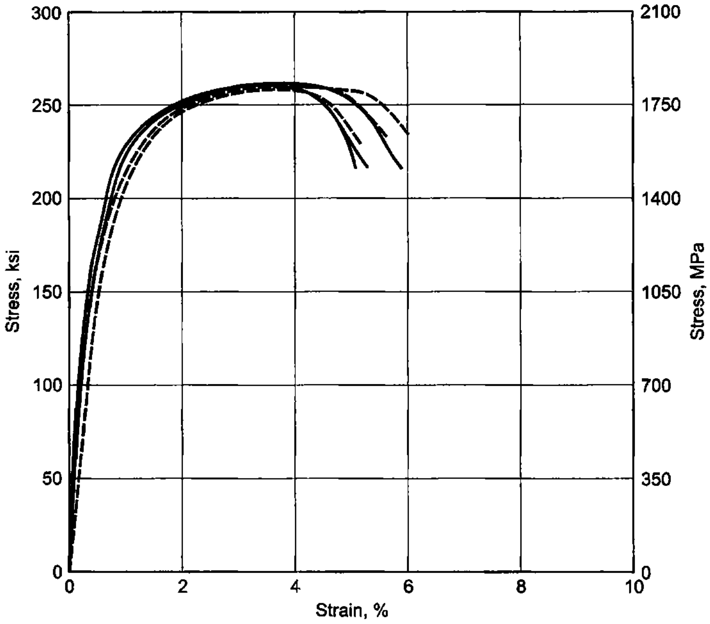
Source: P.J. Hughes, J.E. Inge, and S.B. Prosser, "Tensile and Compressive Stress-Strain Properties of Some High Strength Sheet Alloys at Elevated Temperatures," NACA TN 3315, 1954. As published in *Aerospace Structural Metals Handbook,* Vol 1, Code 1206, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 28



AS.025 4340 nickel-chromium-molybdenum alloy steel sheet, tensile stress-strain curves

Test direction: solid curves, transverse; dashed curves, longitudinal. Specimen size = 2.54 × 25.4 × 101.6 mm (0.1 × 1 × 4 in.) gage tempered at 177 °C (350 °F). Composition: Fe-0.4C-1.8Ni-0.8Cr-0.25Mo. UNS G43400

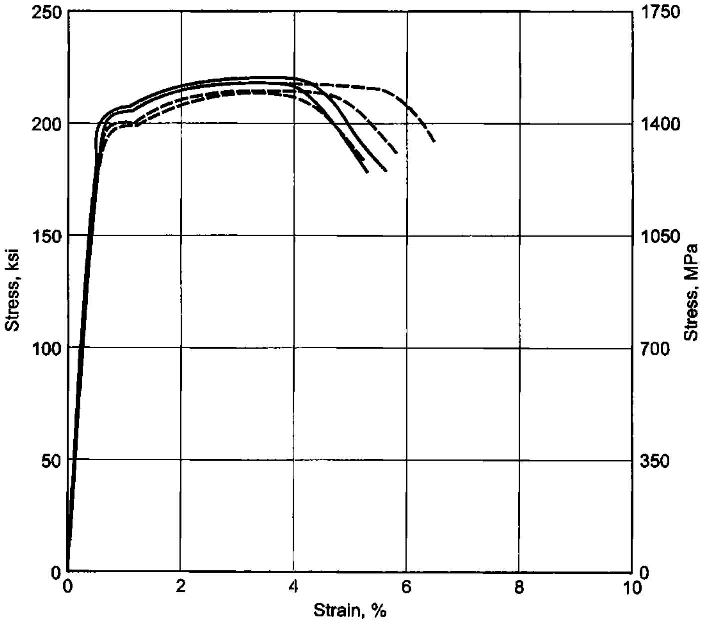
Source: D.P. Fitzgibbon, "Semiannual Report on Pressure Vessel Design Criteria," TR-59-0000-00714, Space Technology Laboratories, Air Force Ballistic Missile Division, June 1959, AD 607630. As published in *Structural Alloys Handbook,* Vol 1, CINDAS/Purdue University, 1994, p 42



AS.026 4340 nickel-chromium-molybdenum alloy steel sheet, tensile stress-strain curves

Test direction: solid curves, transverse; dashed curves, longitudinal. Specimen size = 2.54 × 25.4 × 101.6 mm (0.1 × 1 × 4 in.) gage tempered at 232 °C (450 °F). Composition: Fe-0.4C-1.8Ni-0.8Cr-0.25Mo. UNS G43400

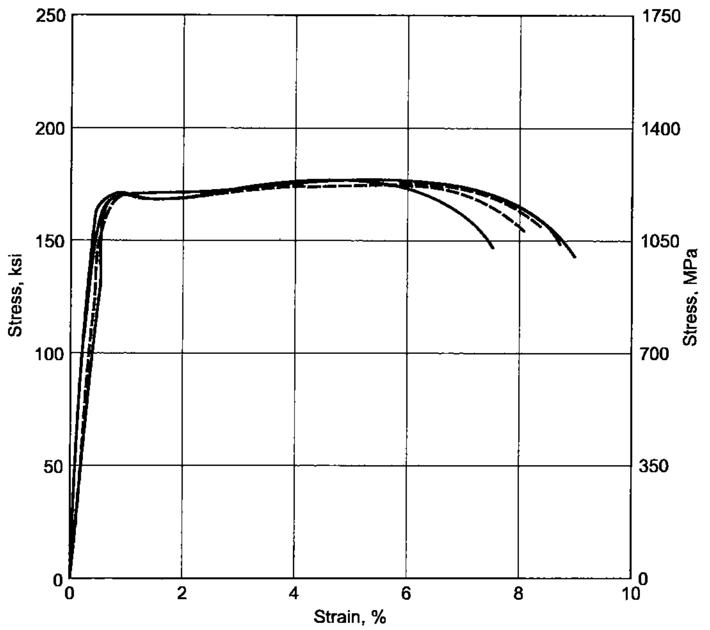
Source: D.P. Fitzgibbon, "Semiannual Report on Pressure Vessel Design Criteria," TR-59-0000-00714, Space Technology Laboratories, Air Force Ballistic Missile Division, June 1959, AD 607630. As published in *Structural Alloys Handbook*, Vol 1, CINDAS/Purdue University, 1994, p 42



AS.027 4340 nickel-chromium-molybdenum alloy steel sheet, tensile stress-strain curves

Test direction: solid curves, transverse; dashed curves, longitudinal. Specimen size = 2.54 × 25.4 × 101.6 mm (0.1 × 1 × 4 in.) gage tempered at 371 °C (700 °F). Composition: Fe-0.4C-1.8Ni-0.8Cr-0.25Mo. UNS G43400

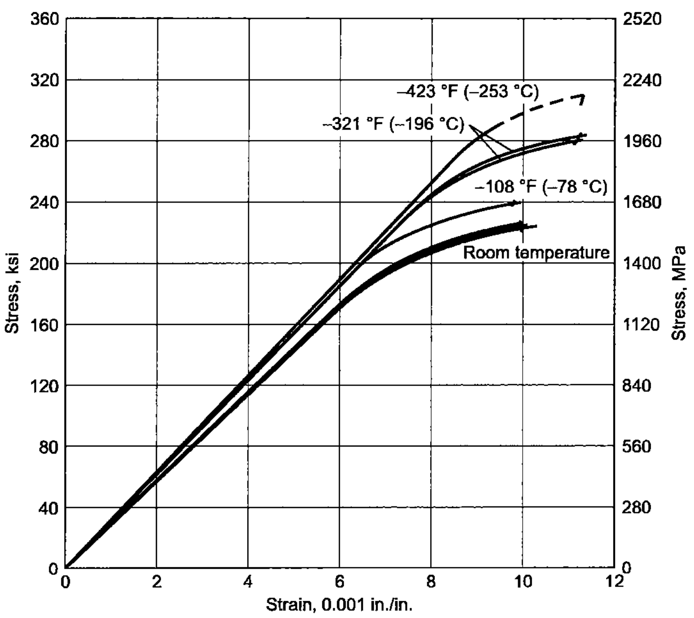
Source: D.P. Fitzgibbon, "Semiannual Report on Pressure Vessel Design Criteria," TR-59-0000-00714, Space Technology Laboratories, Air Force Ballistic Missile Division, June 1959, AD 607630. As published in *Structural Alloys Handbook*, Vol 1, CINDAS/Purdue University, 1994, p 42



AS.028 4340 nickel-chromium-molybdenum alloy steel sheet, tensile stress-strain curves

Test direction: solid curves, transverse; dashed curves, longitudinal. Specimen size = 2.54 × 25.4 × 101.6 mm (0.1 × 1 × 4 in.) gage tempered at 510 °C (950 °F). Composition: Fe-0.4C-1.8Ni-0.8Cr-0.25Mo. UNS G43400

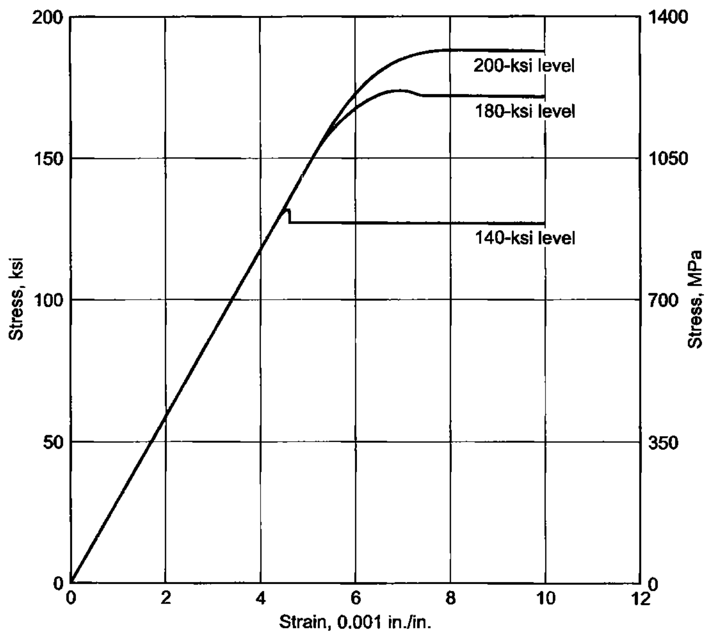
Source: D.P. Fitzgibbon, "Semiannual Report on Pressure Vessel Design Criteria," TR-59-0000-00714, Space Technology Laboratories, Air Force Ballistic Missile Division, June 1959, AD 607630. Adapted from *Structural Alloys Handbook,* Vol 1, CINDAS/Purdue University, 1994, p 42



AS.029 4340 nickel-chromium-molybdenum alloy steel bar, tensile stress-strain curves at room and low temperatures

Bar thickness = 25.4 mm (1 in.). Heat treated to ultimate tensile strength of 1862 MPa (270 ksi). Composition: Fe-0.4C-1.8Ni-0.8Cr-0.25Mo. UNS G43400

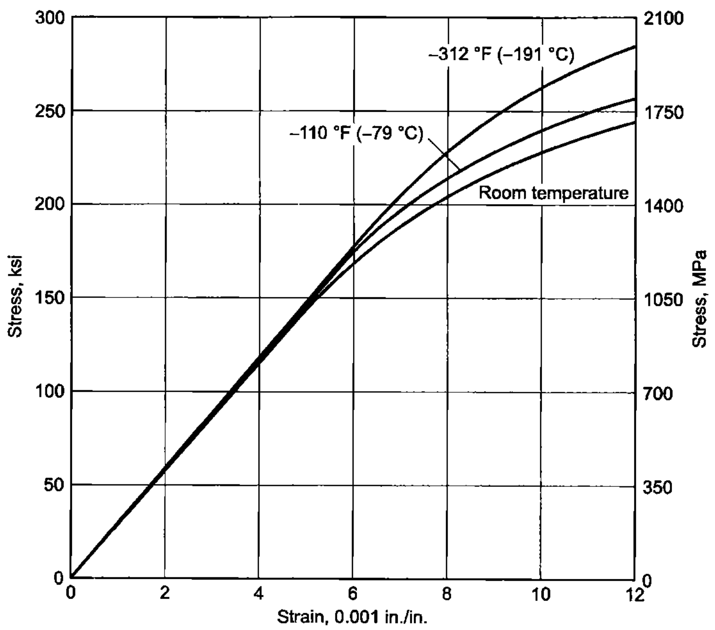
Source: "Design Properties as Affected by Cryogenic Temperatures," Battelle Memorial Institute, DMIC Memorandum 81, Jan 1961. As published in *Structural Alloys Handbook,* Vol 1, CINDAS/Purdue University, 1994, p 41



AS.030 4340 nickel-chromium-molybdenum alloy steel (all products), typical tensile stress-strain curves

Heat treated to the levels indicated. Composition: Fe-0.4C-1.8Ni-0.8Cr-0.25Mo. UNS G43400

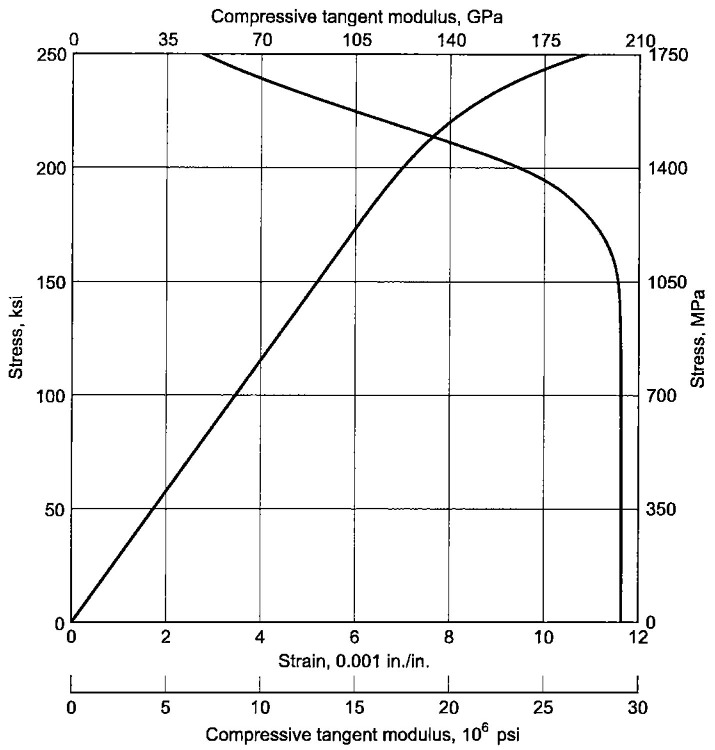
Source: *MIL-HDBK-5H,* Dec 1998, p 2-40



AS.031 4340 nickel-chromium-molybdenum alloy steel bar, tensile stress-strain curves at room and low temperatures

Test direction: longitudinal. 0.5 h exposure. Ramberg-Osgood parameters: n(room temperature) = 7.0, n(−110 °F) = 8.2, n(−312 °F) = 8.9. Composition: Fe-0.4C-1.8Ni-0.8Cr-0.25Mo. UNS G43400

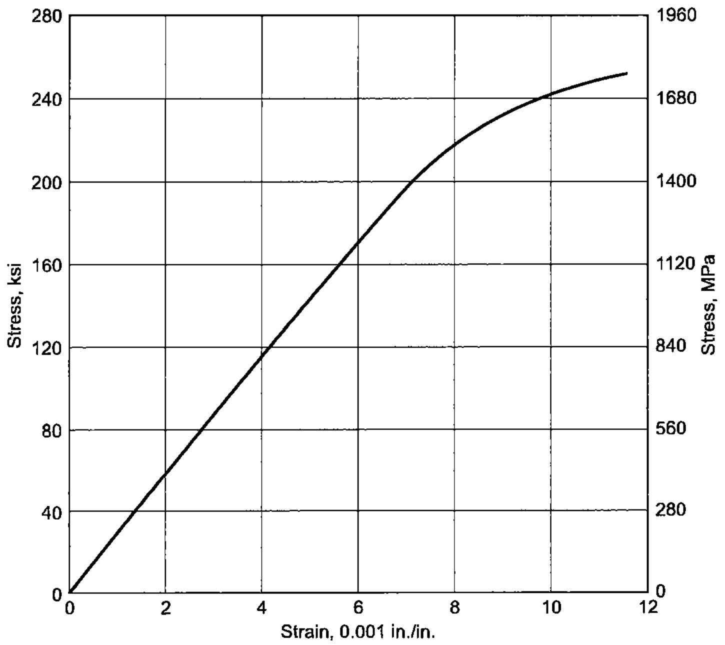
Source: *MIL-HDBK-5H,* Dec 1998, p 2-40



AS.032 4340 nickel-chromium-molybdenum alloy steel bar, compressive stress-strain and compressive tangent modulus curves

Ramberg-Osgood parameters: n(room temperature) = 13. Composition: Fe-0.4C-1.8Ni-0.8Cr-0.25Mo. UNS G43400

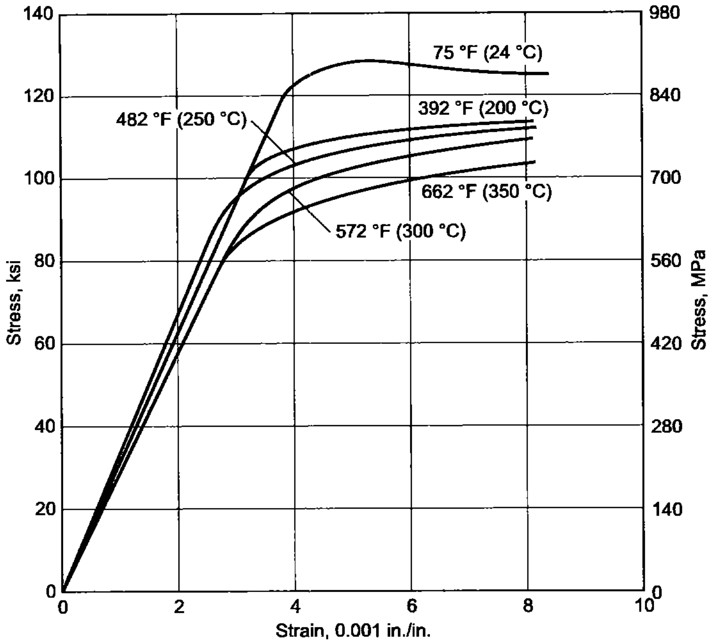
Source: *MIL-HDBK-5H*, Dec 1998, p 2-41



AS.033 4340 nickel-chromium-molybdenum alloy steel bar, compressive stress-strain curve

Austenitized, oil quenched, tempered to ultimate tensile strength of 1793 MPa (260 ksi). Tested at 24 °C (75 °F). Composition: Fe-0.4C-1.8Ni-0.8Cr-0.25Mo. UNS G43400

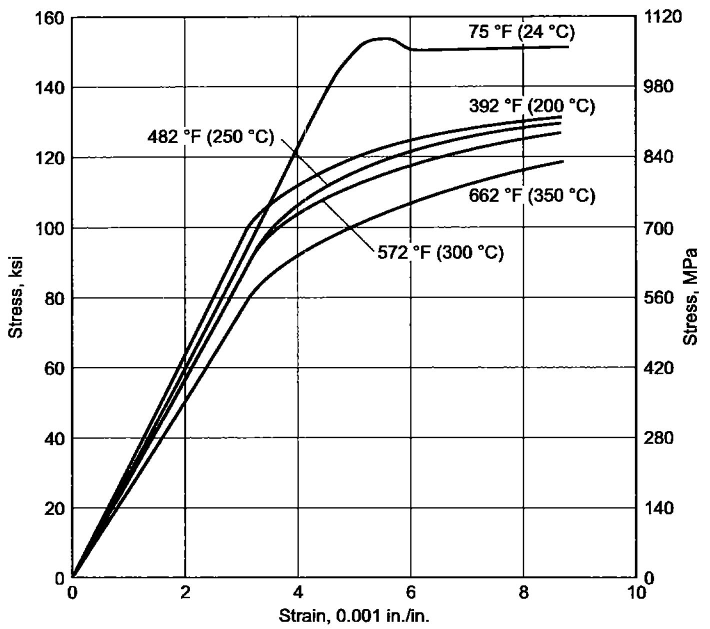
Source: *MIL-HDBK-5C*, Vol 1, 15 Dec 1978. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1206, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 21



AS.034 4340 nickel-chromium-molybdenum alloy steel tube, tensile stress-strain curves at room and elevated temperatures

Tube size = 57.15 mm OD × 22.275 mm ID (2.25 in. OD × 0.875 in. ID). Hot rolled, air cooled, tempered at 538 °C (1000 °F), air cooled. Composition: Fe-0.4C-1.8Ni-0.8Cr-0.25Mo. UNS G43400

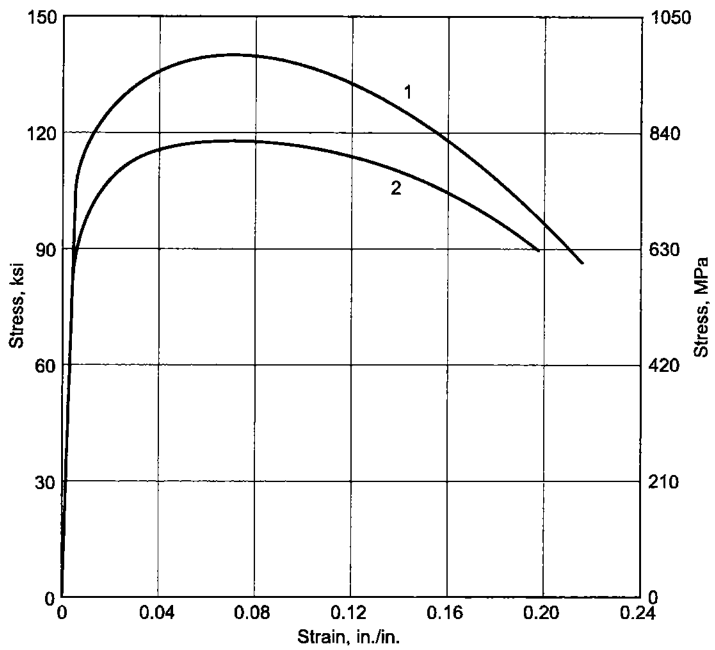
Source: "Properties of High-Strength Low-Alloy Steels at Slightly Elevated Temperatures," Timken Co., Resume of Investigations on Steels for High-Temperature High-Pressure Applications, 1960–1962. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1206, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 29



AS.035 4340 nickel-chromium-molybdenum alloy steel tube, tensile stress-strain curves at room and elevated temperatures

Tube size = 57.15 mm OD × 22.275 mm ID (2.25 in. OD × 0.875 in. ID). Heat treatment 843 °C (1550 °F), oil quenched, tempered at 566 °C (1050 °F), air cooled. Composition: Fe-0.4C-1.8Ni-0.8Cr-0.25Mo. UNS G43400

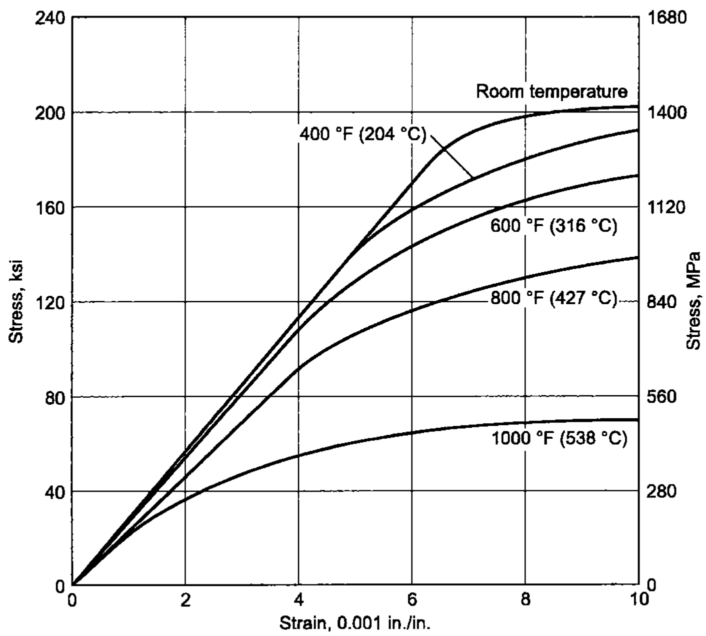
Source: "Properties of High-Strength Low-Alloy Steels at Slightly Elevated Temperatures," Timken Co., Resume of Investigations on Steels for High-Temperature High-Pressure Applications, 1960–1962. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1206, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 29



AS.036 4340 nickel-chromium-molybdenum alloy steel tube, tensile stress-strain curves (full range) at elevated temperature

Tube size = 57.15 mm OD × 22.275 mm ID (2.25 in. OD × 0.875 in. ID). Comparison at 350 °C (662 °F) test temperature. Curve 1: hot rolled, air cooled, tempered 538 °C (1000 °F), air cooled. Curve 2: 843 °C (1550 °F), oil quenched, tempered 566 °C (1050 °F), air cooled. Composition: Fe-0.4C-1.8Ni-0.8Cr-0.25Mo. UNS G43400

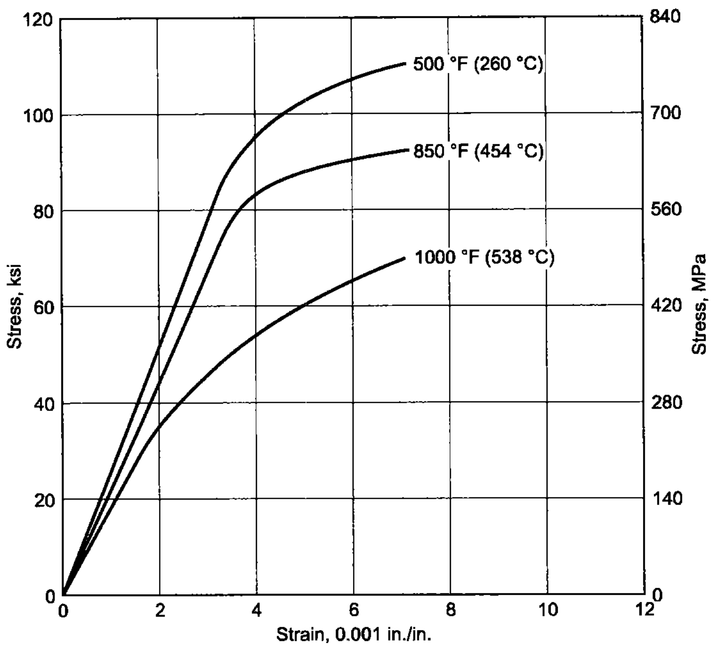
Source: "Properties of High-Strength Low-Alloy Steels at Slightly Elevated Temperatures," Timken Co., Resume of Investigations on Steels for High-Temperature High-Pressure Applications, 1960–1962. As published in *Aerospace Structural Metals Handbook,* Vol 1, Code 1206, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 29



AS.037 4340 nickel-chromium-molybdenum alloy steel sheet, compressive stress-strain curves at room and elevated temperatures

Sheet thickness = 1.626 mm (0.064 in.). Heat treated: 829 °C (1525 °F), 10 min, air cooled, tempered 427 °C (800 °F), 1 h, to ultimate tensile strength of 1379 MPa (200 ksi). Composition: Fe-0.4C-1.8Ni-0.8Cr-0.25Mo. UNS G43400

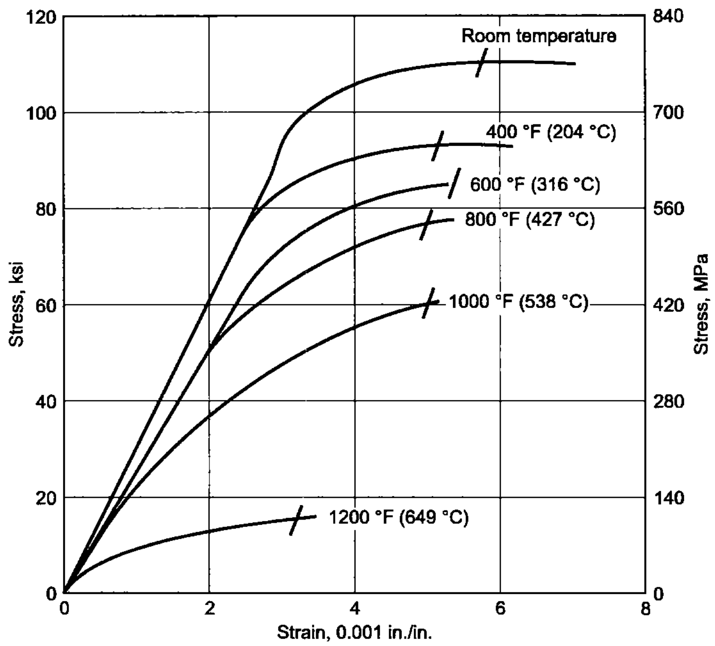
Source: P.J. Hughes, J.E. Inge, and S.B. Prosser, "Tensile and Compressive Stress-Strain Properties of Some High Strength Sheet Alloys at Elevated Temperatures," NACA TN 3315, 1954. As published in *Aerospace Structural Metals Handbook,* Vol 1, Code 1206, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 32



AS.038 8630 nickel-chromium-molybdenum alloy steel (all products), typical tensile stress-strain curves at elevated temperatures

Heat treated to ultimate tensile strength of 862 MPa (125 ksi). 0.5 h exposure. Ramberg-Osgood parameters: n(500 °F) = 9.0, n(850 °F) = 19, n(1000 °F) = 4.4. Composition: Fe-0.3C-0.55Ni-0.5Cr-0.25Mo. UNS G86300

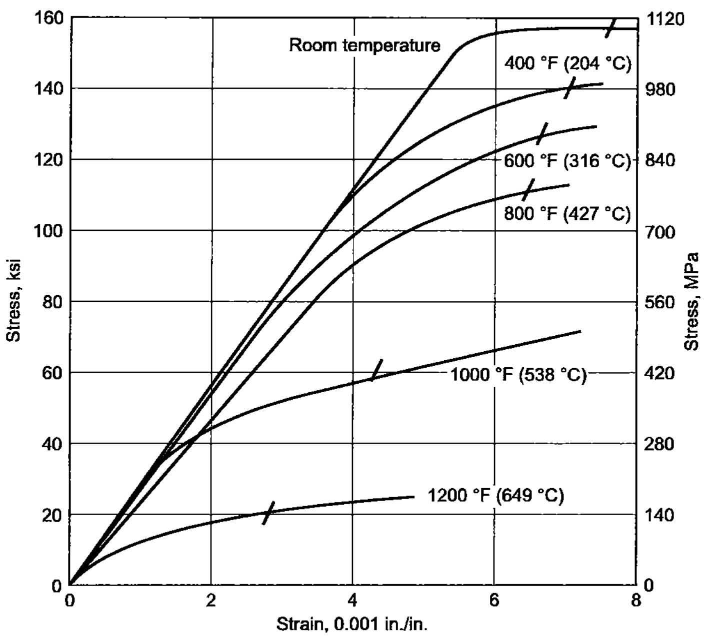
Source: *MIL-HDBK-5H,* Dec 1998, p 2-31



AS.039 8630 nickel-chromium-molybdenum alloy steel sheet, tensile stress-strain curves at room and elevated temperatures

Sheet thickness = 1.626 mm (0.064 in.). Quenched and tempered to ultimate tensile strength of 862 MPa (125 ksi) (at room temperature). Composition: Fe-0.3C-0.55Ni-0.5Cr-0.25Mo. UNS G86300

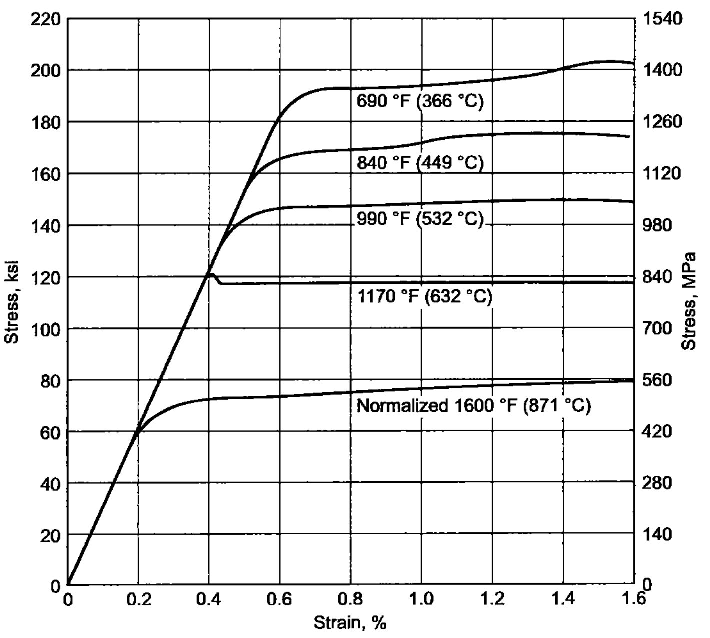
Source: D.D. Doerr, "Determination of Physical Properties of Ferrous and Non-Ferrous Structural Sheet Materials at Elevated Temperatures," WADC AF TR 6517, Pt 2, Armour Research Foundation, April 1954. As published in *Aerospace Structural Metals Handbook,* Vol 1, Code 1208, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 14



AS.040 8630 nickel-chromium-molybdenum alloy steel sheet, tensile stress-strain curves at room and elevated temperatures

Sheet thickness = 1.626 mm (0.064 in.). Quenched and tempered to ultimate tensile strength of 1103 MPa (160 ksi) (at room temperature). Composition: Fe-0.3C-0.55Ni-0.5Cr-0.25Mo. UNS G86300

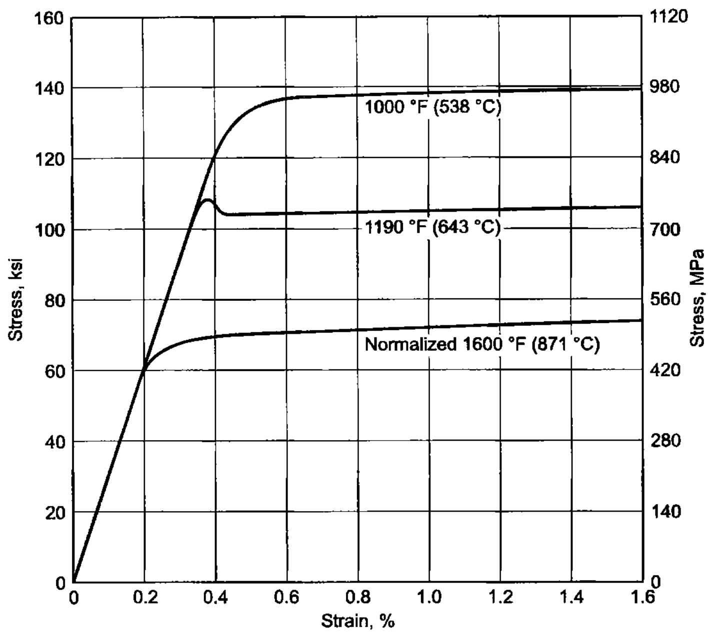
Source: D.D. Doerr, "Determination of Physical Properties of Ferrous and Non-Ferrous Structural Sheet Materials at Elevated Temperatures," WADC AF TR 6517, Pt 2, Armour Research Foundation, April 1954. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1208, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 14



AS.041 8630 nickel-chromium-molybdenum alloy steel sheet, tensile stress-strain curves for various tempering temperatures

Test direction: longitudinal. Sheet thickness = 1.575 mm (0.062 in.). Heat treatment: 857 °C (1575 °F), oil quenched, tempered at indicated temperature, lowest curve normalized as indicated. Composition: Fe-0.3C-0.55Ni-0.5Cr-0.25Mo. UNS G86300

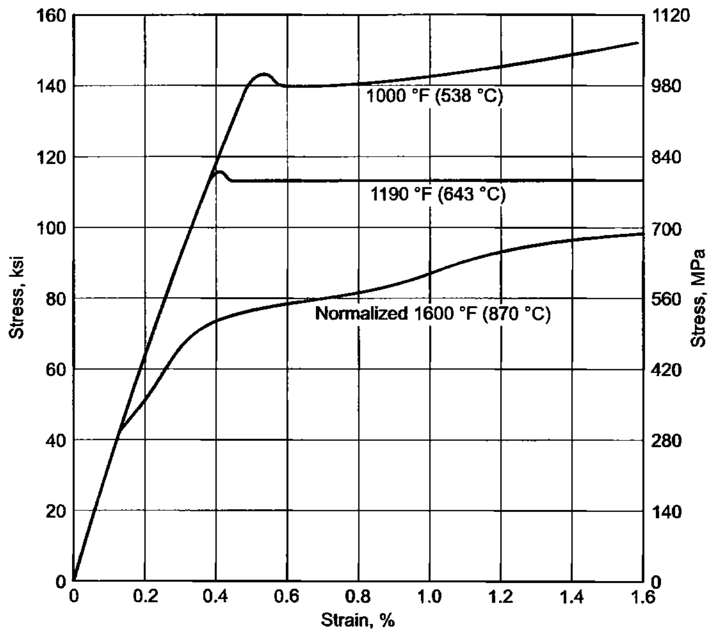
Source: L.R. Jackson and N.A. Crites, "Development of Mechanical Properties Information on Carbon and Alloy Steels at Various Strength Levels," Battelle Memorial Institute Report to AISA, 1 Feb 1951. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1208, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 9



AS.042 8630 nickel-chromium-molybdenum alloy steel bar, tensile stress-strain curves for various tempering temperatures

Bar diameter = 25.4 mm (1 in.). Heat treatment: 857 °C (1575 °F), oil quenched, tempered at indicated temperature, lowest curve normalized as indicated. Composition: Fe-0.3C-0.55Ni-0.5Cr-0.25Mo. UNS G86300

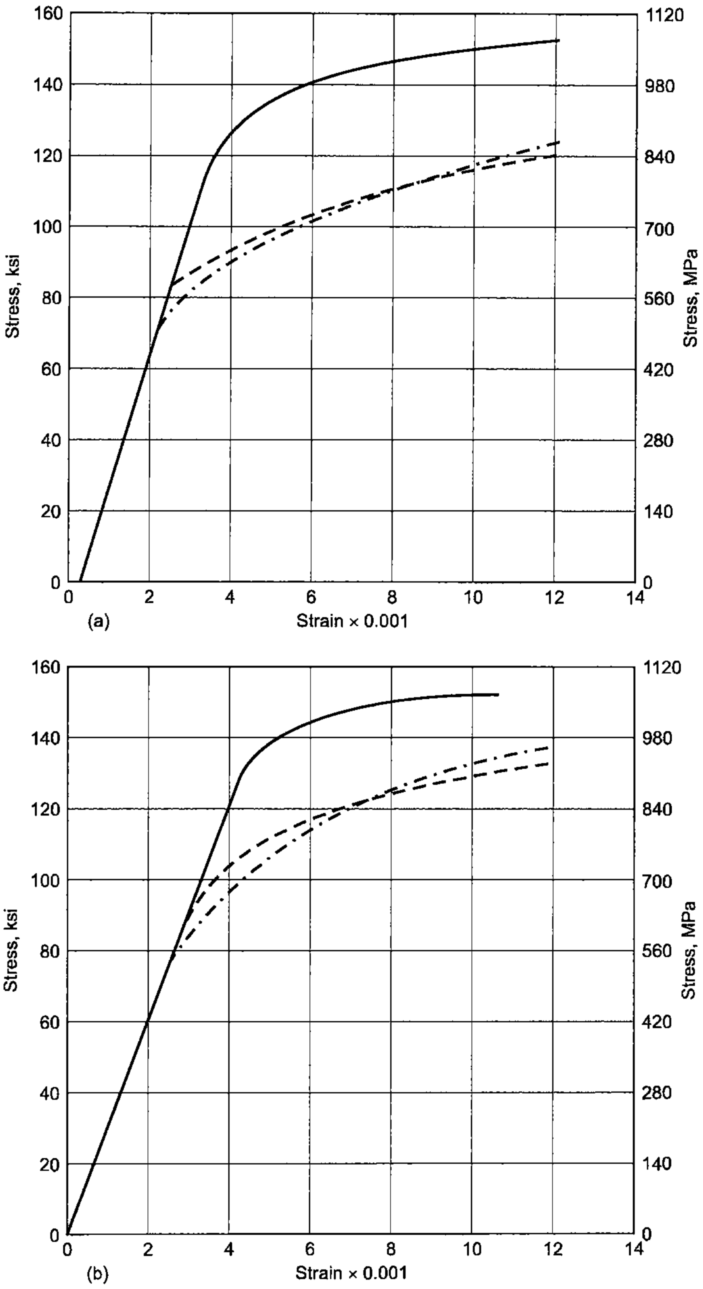
Source: L.R. Jackson and N.A. Crites, "Development of Mechanical Properties Information on Carbon and Alloy Steels at Various Strength Levels," Battelle Memorial Institute Report to AISA, 1 Feb 1951. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1208, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 9



AS.043 8630 nickel-chromium-molybdenum alloy steel bar, compressive stress-strain curves for various tempering temperatures

Bar diameter = 25.4 mm (1 in.). Heat treatment: 857 °C (1575 °F), oil quenched, tempered at indicated temperature, lowest curve normalized as indicated. Composition: Fe-0.3C-0.55Ni-0.5Cr-0.25Mo. UNS G86300

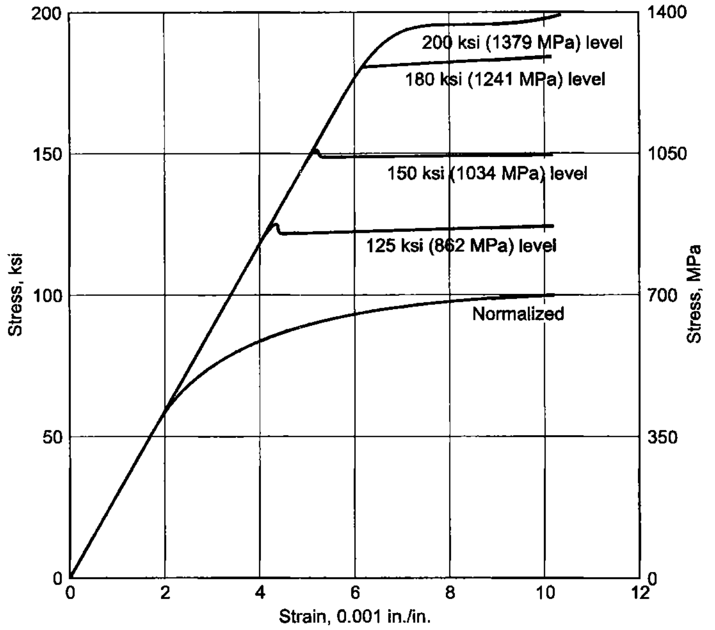
Source: L.R. Jackson and N.A. Crites, "Development of Mechanical Properties Information on Carbon and Alloy Steels at Various Strength Levels," Battelle Memorial Institute Report to AISA, 1 Feb 1951. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1208, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



AS.044 8630 nickel-chromium-molybdenum alloy steel casting, monotonic and cyclic stress-strain curves at room temperature (a) and −46 °C (−50 °F) (b)

Heat treatment: Normalized 900 °C (1652 °F), austenitized 885 °C (1625 °F), water quenched, tempered 510 °C (950 °F), 1.5 h. Solid curve, monotonic loading; dashed curves, cyclic loading. Composition: Fe-0.3C-0.55Ni-0.5Cr-0.25Mo. UNS J13042, UNS J13050

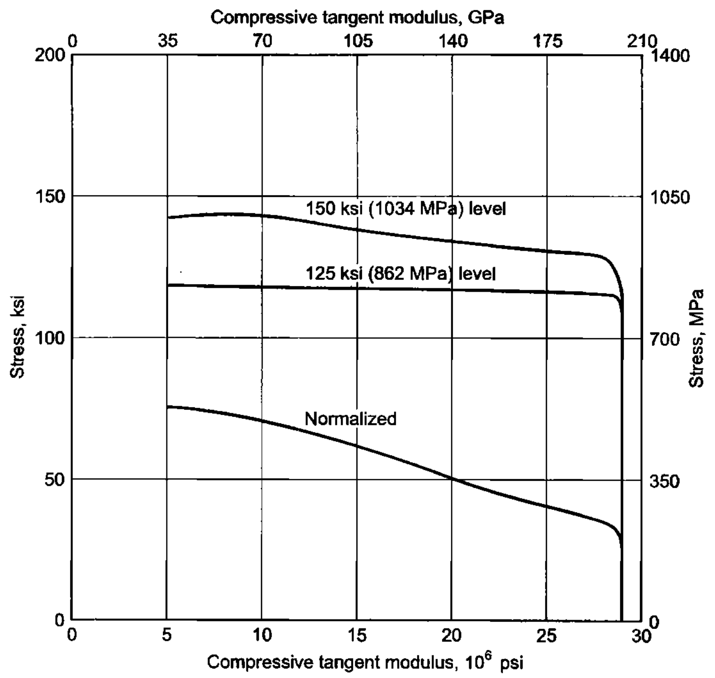
Source: R.I. Stephens, J.H. Chung, A. Fatemi, H.W. Lee, S.G. Lee, C. Vaca-Oleas, and C.M. Wang, Constant and Variable Amplitude Fatigue Behavior of Five Cast Steels at Room Temperature and −45C, *J. Eng. Mater. Technol.*, Vol 106 (No. 1), Jan 1984, p 25–37. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1208, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 14



AS.045 8630 nickel-chromium-molybdenum alloy steel (all products), typical stress-strain curves for various heat treatments

Curves for heat treatments to various strength levels. Composition: Fe-0.3C-0.55Ni-0.5Cr-0.25Mo. UNS G86300

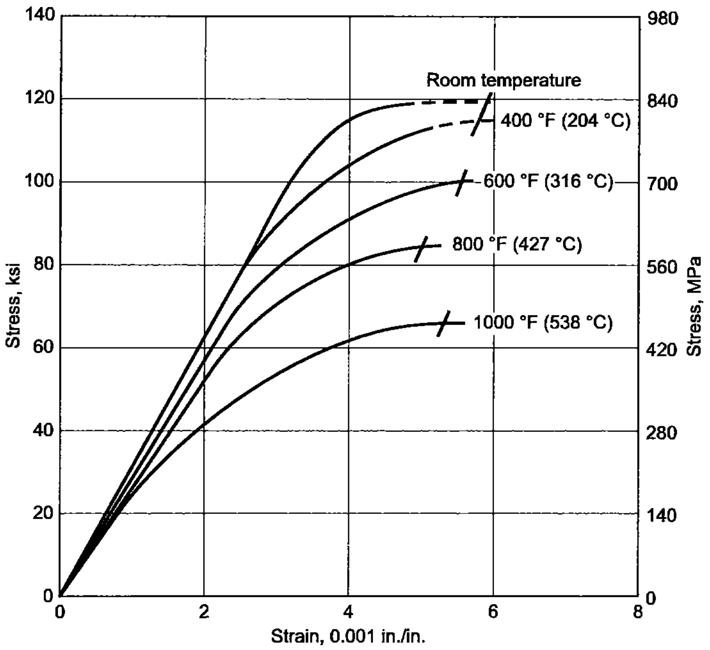
Source: *MIL-HDBK-5H,* Dec 1998, p 2-30



AS.046 8630 nickel-chromium-molybdenum alloy steel (all products), typical compressive tangent modulus curves at room temperature for various heat treatments

Heat treatments indicated by ultimate strength levels. Composition: Fe-0.3C-0.55Ni-0.5Cr-0.25Mo. UNS G86300

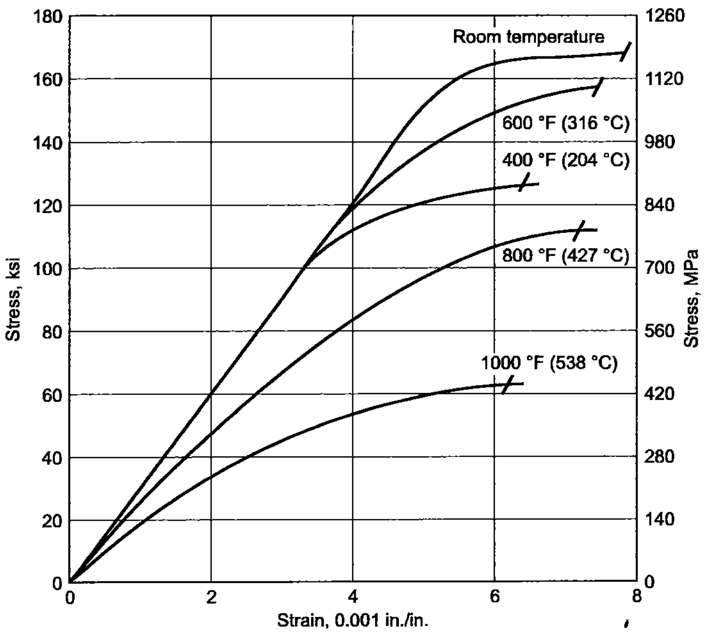
Source: *MIL-HDBK-5H,* Dec 1998, p 2-31



AS.047 8630 nickel-chromium-molybdenum alloy steel sheet, compressive stress-strain curves at room and elevated temperatures

Sheet thickness = 1.626 mm (0.064 in.). Heat treatment: quenched and tempered to room temperature ultimate tensile strength of 827 MPa (120 ksi). Composition: Fe-0.3C-0.55Ni-0.5Cr-0.25Mo. UNS G86300

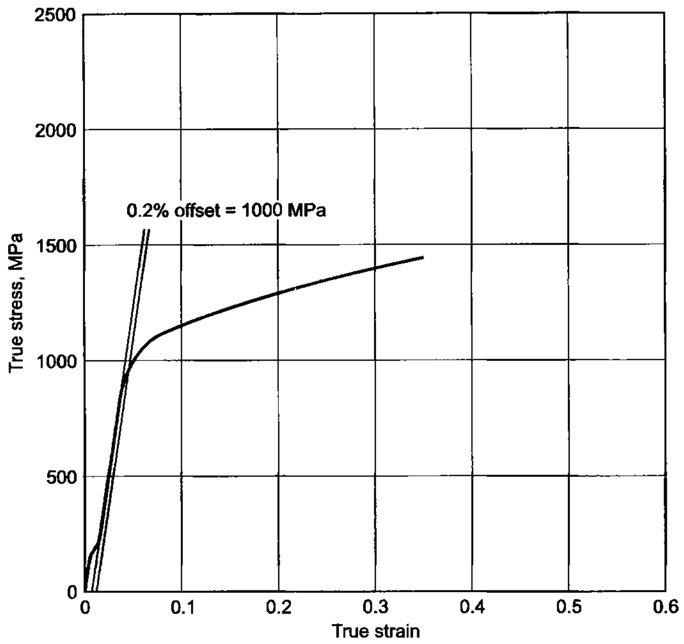
Source: D.D. Doerr, "Determination of Physical Properties of Ferrous and Non-Ferrous Structural Sheet Materials at Elevated Temperatures," WADC AF TR 6517, Pt 2, Armour Research Foundation, April 1954. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1208, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 15



AS.048 8630 nickel-chromium-molybdenum alloy steel sheet, compressive stress-strain curves at room and elevated temperatures

Sheet thickness = 1.626 mm (0.064 in.). Heat treatment: quenched and tempered to room temperature ultimate tensile strength of 1102 MPa (160 ksi). Composition: Fe-0.3C-0.55Ni-0.5Cr-0.25Mo. UNS G86300

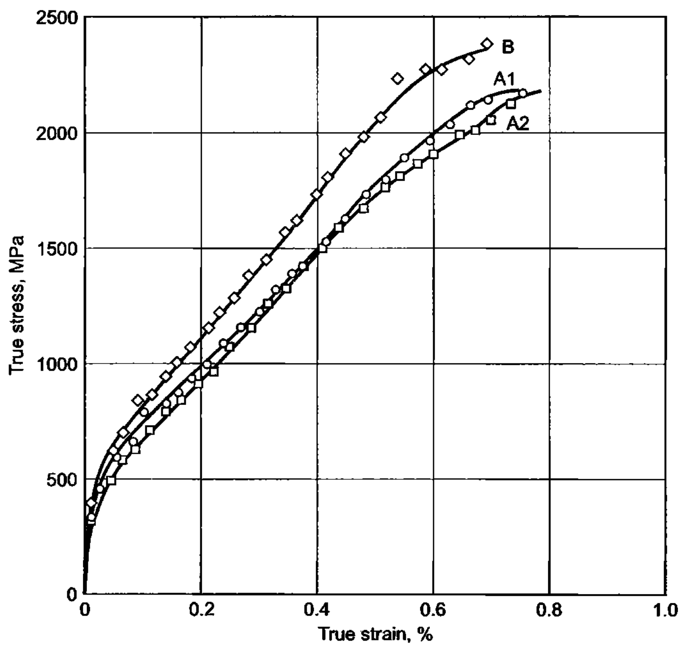
Source: D.D. Doerr, "Determination of Physical Properties of Ferrous and Non-Ferrous Structural Sheet Materials at Elevated Temperatures," WADC AF TR 6517, Pt 2, Armour Research Foundation, April 1954. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1208, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 16



AS.049 9310 nickel-chromium-molybdenum alloy steel gears, true plastic stress-strain curves

Uncarburized 9310 at 230 °C after quenching from 900 °C. 0.2% yield strength = 1000 MPa. Work-hardening rate, $n = 0.17$. Composition prior to carburizing: Fe-0.11C-3.40Ni-1.26Cr-0.13Mo-0.56Mn-0.26Si-0.04Al-0.03Cu-0.01S. UNS G93106

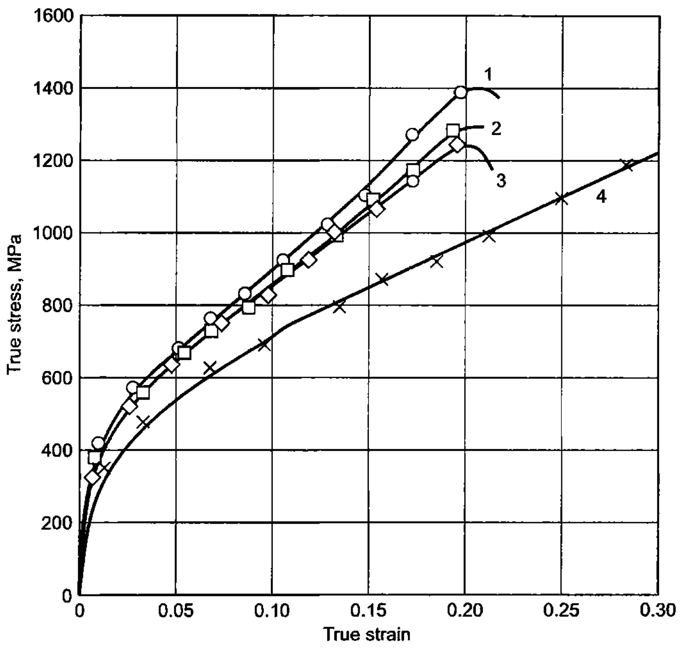
Source: U.J. De Souza and M.F. Amateau, Deformation of Metastable Austenite and Resulting Properties During the Ausform-Finishing of 1pct Carburized AISI 9310 Steel Gears, *Metall. Mater. Trans. A*, Vol 30A (No. 1), Jan 1999, p 186



AS.050 9310 nickel-chromium-molybdenum alloy steel gears, compressive true plastic stress-strain curves

Compressive flow properties of metastable austenite at 230 °C in 1% carburized steel. Strain rate = 0.005/s. Steep and continuous increase in flow stress is sign of high work-hardening rates (n). Type A, $n = 0.56$; type B, $n = 0.55$. Type A specimen 10 mm diam × 2.2 mm thick (0.4 in. diam × 0.086 in. thick), vacuum carburized to 1.06 wt% C. Type B stacked disks 10 mm diam × 15 mm high (0.4 in. diam × 0.6 in. high), carburized in atmosphere to 1.1 wt% prior to stacking. Composition prior to carburizing: Fe-0.11C-3.40Ni-1.26Cr-0.13Mo-0.56Mn-0.26Si-0.04Al-0.03Cu-0.01S. UNS G93106

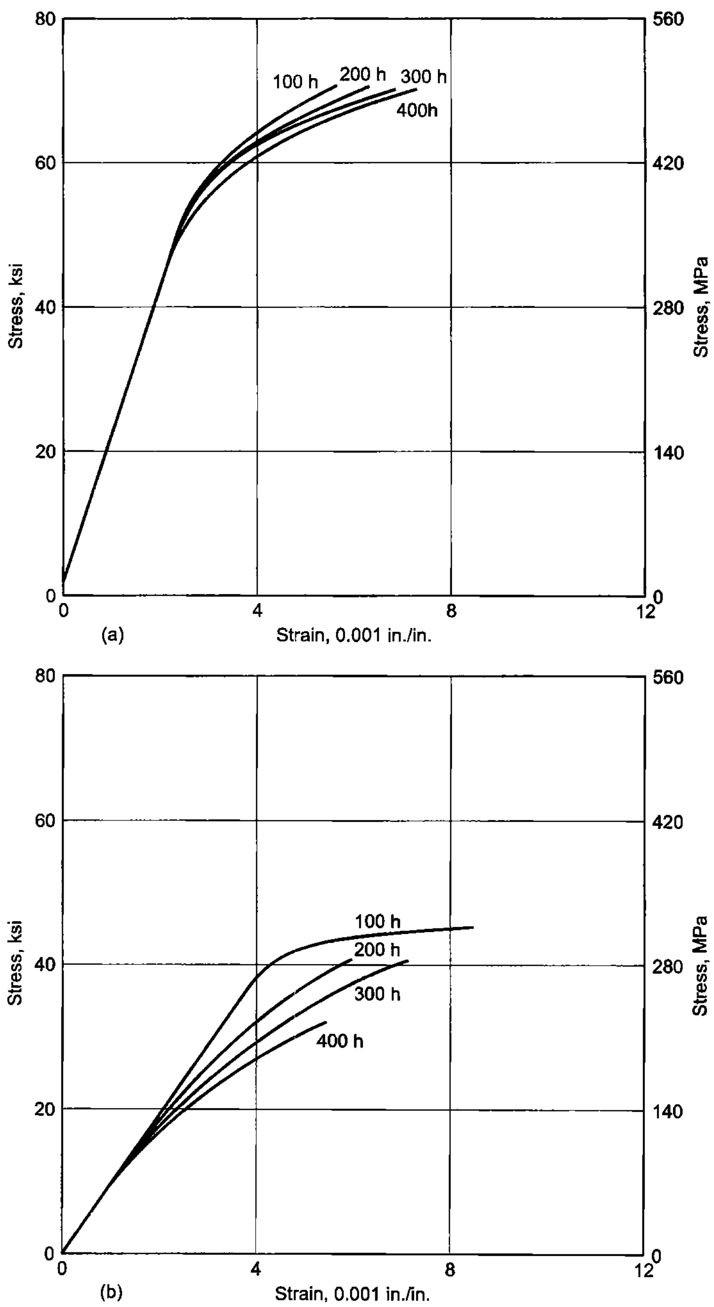
Source: U.J. De Souza and M.F. Amateau, Deformation of Metastable Austenite and Resulting Properties During the Ausform-Finishing of 1pct Carburized AISI 9310 Steel Gears, *Metall. Mater. Trans. A*, Vol 30A (No. 1), Jan 1999, p 186



AS.051 9310 nickel-chromium-molybdenum alloy steel gears, compressive true plastic stress-strain curves

Compressive flow properties of metastable austenite in 1% carburized steel (type A). Type A specimen 10 mm diam × 2.2 mm thick (0.4 in. diam × 0.086 in. thick), vacuum carburized to 1.06 wt% C. Samples were ausformed at different temperatures with the following 0.2% yield strengths: curve 1, 85 °C, 425 MPa; curve 2, 110 °C, 425 MPa; curve 3, 160 °C, 431 MPa; curve 4, 232 °C, 327 MPa. UNS G93106

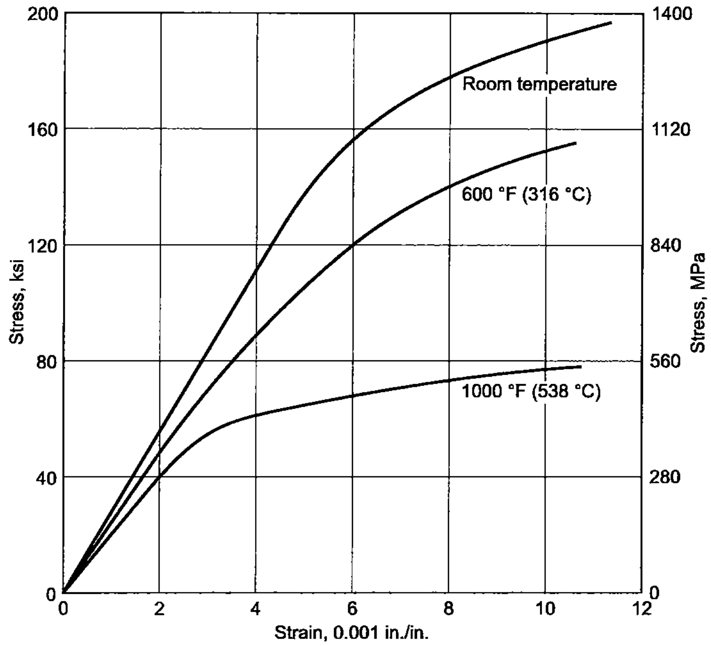
Source: U.J. De Souza and M.F. Amateau, Deformation of Metastable Austenite and Resulting Properties During the Ausform-Finishing of 1pct Carburized AISI 9310 Steel Gears, *Metall. Mater. Trans. A*, Vol 30A (No. 1), Jan 1999, p 189



AS.052 HNM nickel alloy steel sheet, isochronous stress-strain curves at 482 °C (900 °F) (a) and 649 °C (1200 °F) (b)

Solution treated 2050 °F, 15 min, oil quenched, aged 732 °C (1350 °F), 15 h. Composition: Fe-0.3C-9.5Ni-18.5Cr-3.5Mn

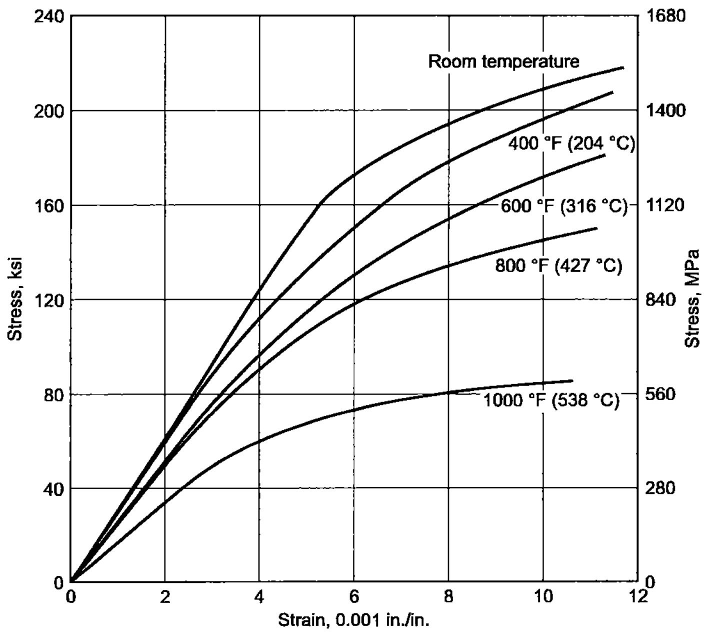
Source: "Crucible HNM," Preliminary Data Sheet, Crucible Steel Co., Issue No. 2, June 1960. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1506, CINDAS/USAF CRDA Handbooks Operation, Purdue University, p 3



AS.053 HY-TUF nickel alloy steel plate, tensile stress-strain curves at room and elevated temperatures

Plate thickness = 6.35 mm (0.25 in.). Silicon-modified steel treated 871 °C (1600 °F), 25 min, oil quenched, 316 °C (600 °F), 0.5 h to ultimate tensile strength of 1517 MPa (220 ksi). Composition: Fe-0.25C-1.8Ni-1.5Si-1.3Mn-0.4Mo. UNS K32550

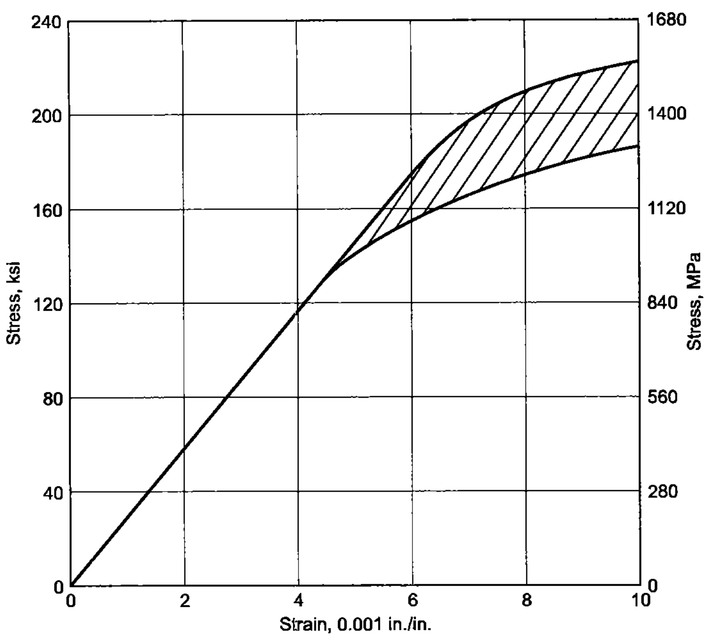
Source: P.J. Hughes, J.E. Inge, and S.B. Prosser, "Tensile and Compressive Stress-Strain Properties of Some High-Strength Sheet Alloys at Elevated Temperatures," NACA TN 3315, Nov 1954. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1214, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 7



AS.054 HY-TUF nickel alloy steel plate, compressive stress-strain curves at room and elevated temperatures

Plate thickness = 6.35 mm (0.25 in.). Silicon-modified steel treated 871 °C (1600 °F), 25 min, oil quenched, 316 °C (600 °F), 0.5 h to ultimate tensile strength of 1517 MPa (220 ksi). Composition: Fe-0.25C-1.8Ni-1.5Si-1.3Mn-0.4Mo. UNS K32550

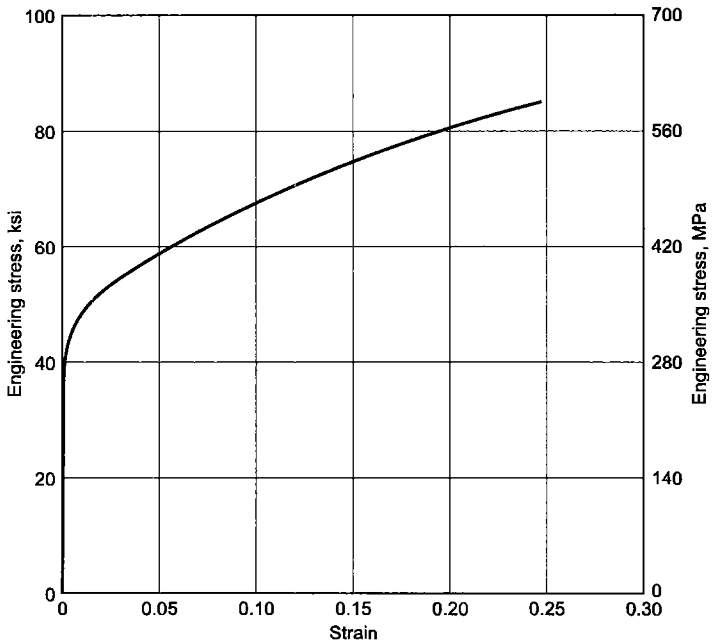
Source: P.J. Hughes, J.E. Inge, and S.B. Prosser, "Tensile and Compressive Stress-Strain Properties of Some High-Strength Sheet Alloys at Elevated Temperatures," NACA TN 3315, Nov 1954. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1214, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 8



AS.055 HY-TUF nickel alloy steel tube, tensile stress-strain curves at room and elevated temperatures

Tube diameter = 53.975 mm (2.125 in.). Hollow section with a diameter-to-thickness ratio of 5 to 40. Ultimate tensile strength of 1496–1703 MPa (217–247 ksi). Data based on 30 tests. UNS K32550

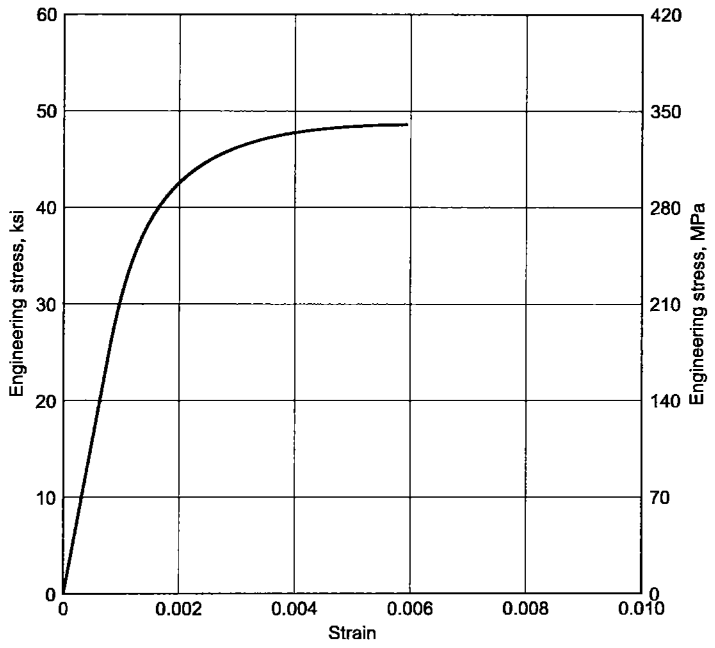
Source: "Stress-Strain Curves for High-Strength Alloy Steel," Rep. No. 732, The Cleveland Pneumatic Tool Co., 25 Feb 1955. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1214, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 4



AS.056 Incoloy 803 annealed nickel alloy steel sheet 3 mm (0.118 in.) longitudinal engineering stress-strain curve (full range)

0.2% yield strength, 324 MPa (47.0 ksi); ultimate tensile strength, 614 MPa (89.1 ksi); elongation, 45.7%. Composition: 37Fe-35Ni-27Cr

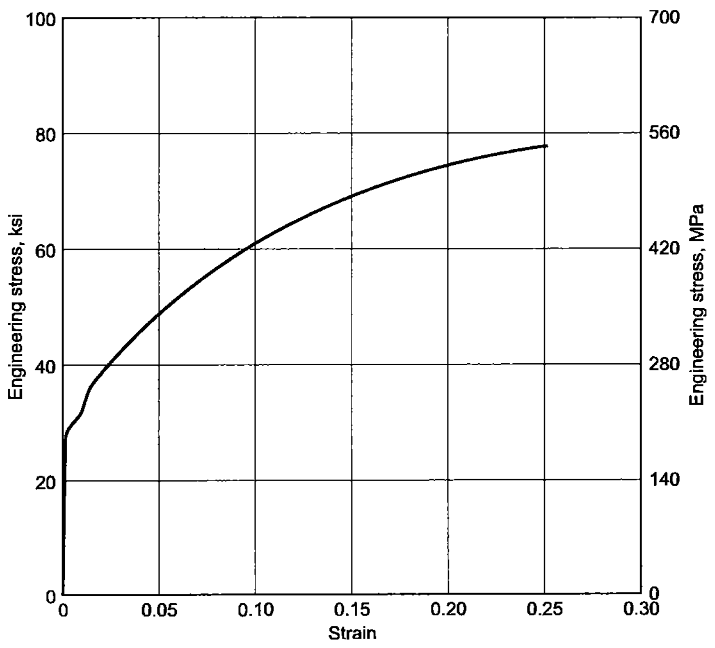
Source: Courtesy of Special Metals Corporation



AS.057 Incoloy 803 annealed nickel alloy steel sheet 3 mm (0.118 in.) longitudinal engineering stress-strain curve (expanded range)

0.2% yield strength, 301 MPa (43.7 ksi); ultimate tensile strength, 614 MPa (89.1 ksi); elongation, 46.4%. Composition: 37Fe-35Ni-27Cr

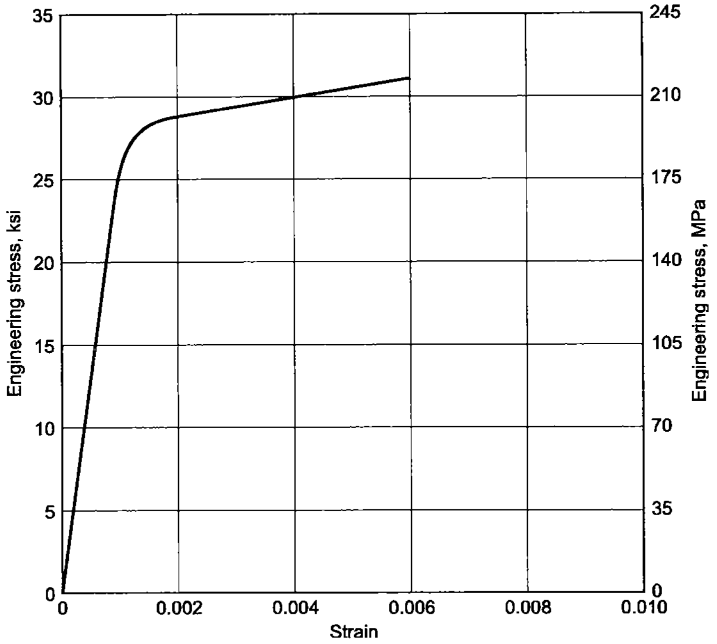
Source: Courtesy of Special Metals Corporation



AS.058 Incoloy 840 annealed nickel alloy steel sheet 0.51 mm (0.020 in.) longitudinal engineering stress-strain curve (full range)

0.2% yield strength, 197 MPa (28.6 ksi); ultimate tensile strength, 552 MPa (80.1 ksi); elongation 40.5%; *n*, 0.371. Composition: 58Fe-21Ni-19Cr0.8Si-0.03C

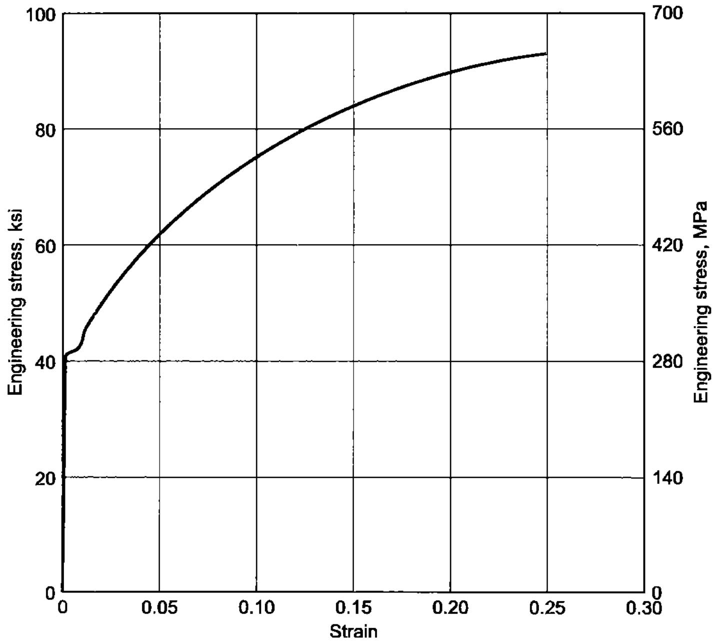
Source: Courtesy of Special Metals Corporation



AS.059 Incoloy 840 annealed nickel alloy steel sheet 0.51 mm (0.020 in.) longitudinal engineering stress-strain curve (expanded range)

0.2% yield strength, 201 MPa (29.2 ksi); ultimate tensile strength, 563 MPa (81.6 ksi); elongation, 38.8%. Composition: 58Fe-21Ni-19Cr-0.8Si-0.03C

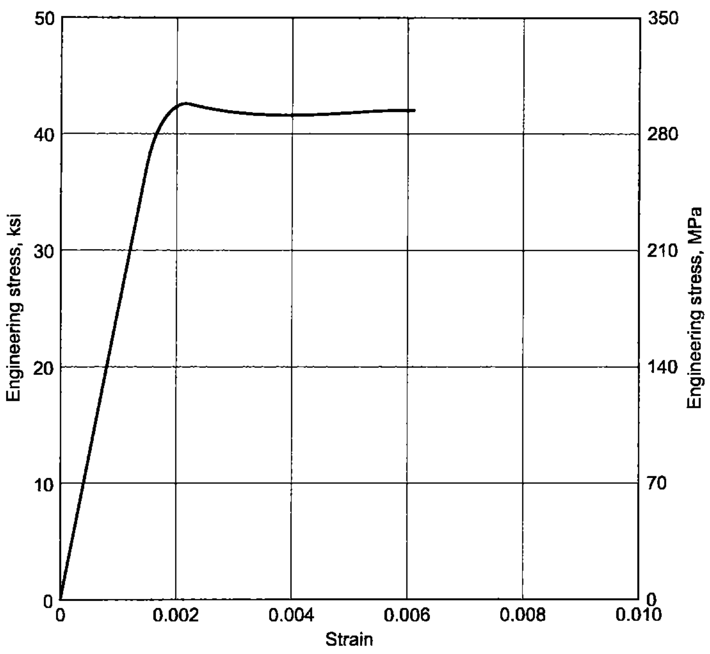
Source: Courtesy of Special Metals Corporation



AS.060 Incoloy A286 annealed nickel alloy steel sheet 1 mm (0.039 in.) longitudinal engineering stress-strain curve (full range)

Iron-base superalloy. 0.2% yield strength, 283 MPa (41.1 ksi); ultimate tensile strength, 652 MPa (94.5 ksi); elongation, 37.8%. Composition: Fe-25.5Ni-14.25Cr-1.25Mo

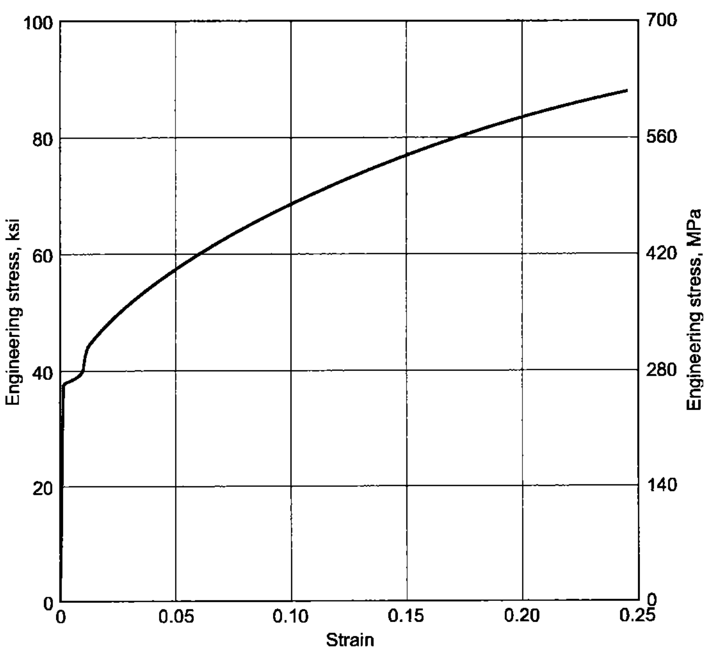
Source: Courtesy of Special Metals Corporation



AS.061 Incoloy A286 annealed nickel alloy steel sheet 1 mm (0.039 in.) longitudinal engineering stress-strain curve (expanded range)

Iron-base superalloy. 0.2% yield strength, 288 MPa (41.7 ksi); ultimate tensile strength, 644 MPa (93.4 ksi); elongation 36.5%. Composition: Fe-25.5Ni-14.25Cr-1.25Mo

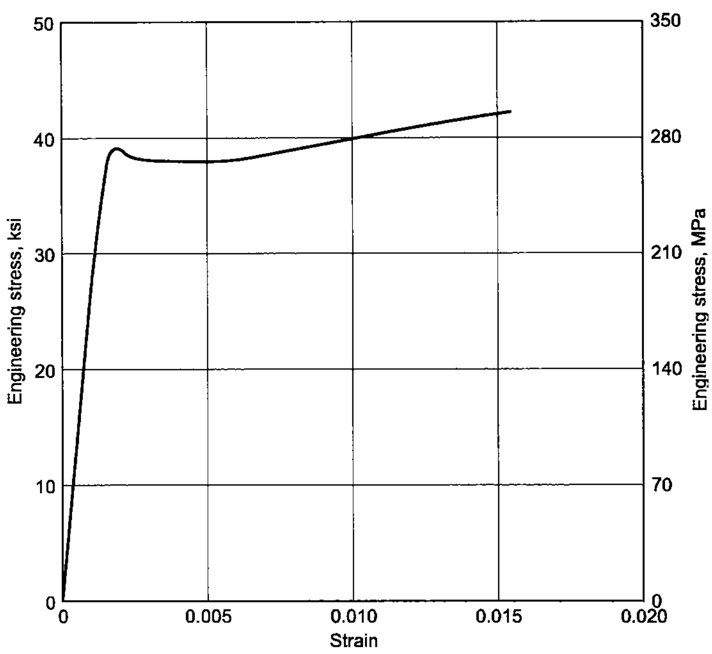
Source: Courtesy of Special Metals Corporation



AS.062 Incoloy 864 annealed nickel alloy steel 0.41 mm (0.016 in.) sheet longitudinal engineering stress-strain curve (full range)

0.2% yield strength, 259 MPa (37.6 ksi); ultimate tensile strength, 658 MPa (95.5 ksi); elongation, 43.6%; n, 0.4435. Composition: 39Fe-21Cr-34Ni-4.2Mo

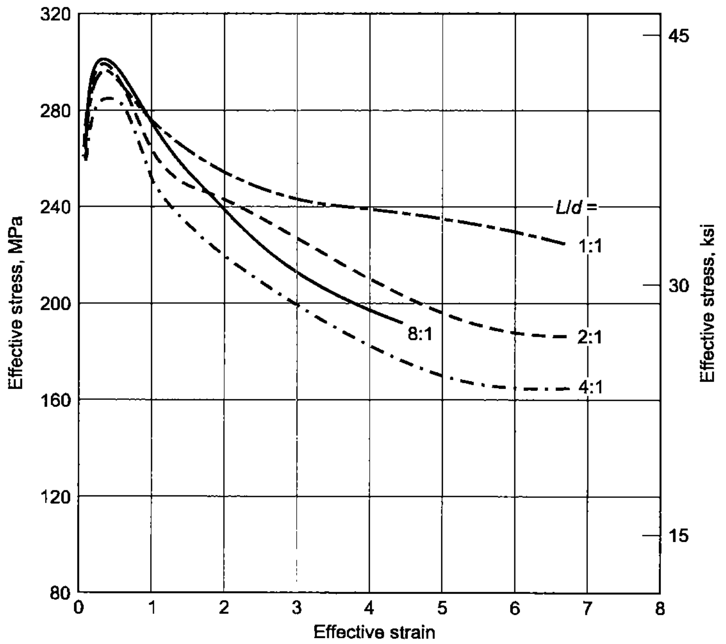
Source: Courtesy of Special Metals Corporation



AS.063 Incoloy 864 annealed nickel alloy steel 0.41 mm (0.016 in.) sheet longitudinal engineering stress-strain expanded range

0.2% yield strength, 262 MPa (38.0 ksi); ultimate tensile strength, 652 MPa (94.5 ksi); elongation 43.6%. Composition: 39Fe-21Cr-34Ni-4.2Mo

Source: Courtesy of Special Metals Corporation

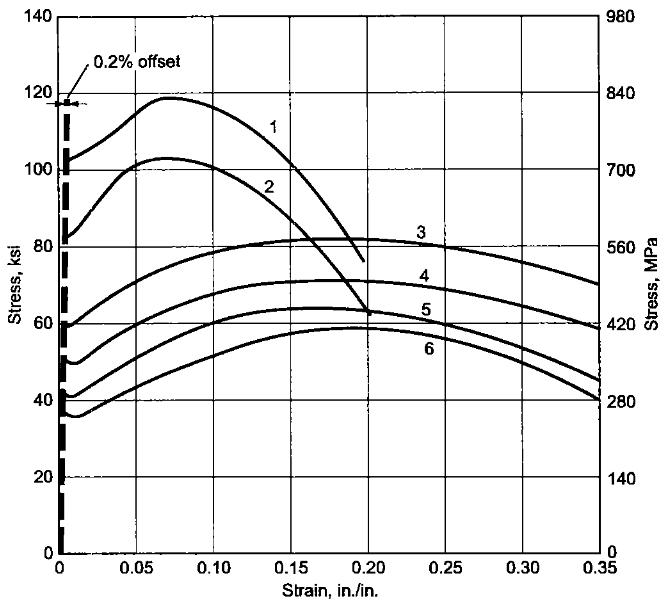


AS.064 3.3% silicon alloy steel, von Mises effective stress-strain curves

Strain rate = 6.5/s. Tested at 700 °C (1290 °F). Stress-strain curves for solid torsion specimens of 3.3% Si steel showing effect of gage length to diameter ratio (*L/d*) on flow stress at high strain rates when adiabatic heating occurs. The flow curves are in terms of von Mises effective stress-strain ($\bar{\sigma} - \bar{\varepsilon}$), defined by $\bar{\sigma} = \sqrt{3}\tau$, and $\bar{\varepsilon} = \Gamma / \sqrt{3}$ where $\tau - \Gamma$ is the shear-stress/shear-strain curve obtained in torsion testing. In both solid bars and tubular specimens, the gage length-to-diameter ratio may have a marked effect on the actual specimen temperature during moderate-speed $\Gamma = 10^{-2}$ to $10\ s^{-1}$ torsion tests because of the effects of heat conduction. Because of this, flow curves derived from data obtained at these rates tend to show a dependence on the length-to-diameter ratio (*L/d*). Flow curves for large *L/d* specimens tend to fall below those for small *L/d* ratios, in which most of the deformation heat is dissipated into the shoulders. Interpretation of fracture strain data from such tests should take into account not only the nominal (initial) test temperature, but also the temperature history during the test.

Source: H.A. Kuhn, Shear, Torsion, and Multiaxial Testing, *Mechanical Testing and Evaluation,* Vol 8, *ASM Handbook,* ASM International, 2000, p 191

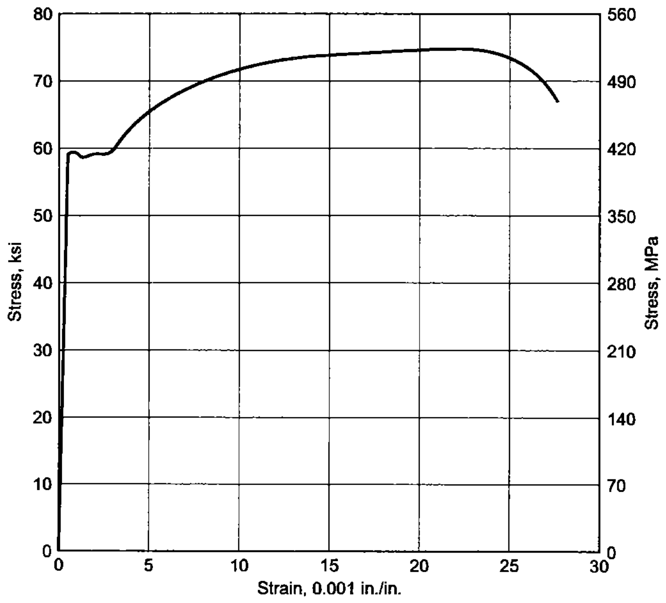
High-Strength Steel (HS)



HS.001 Various HSLA and A36 steel high-strength low-alloy (HSLA) steel, stress-strain curves

Comparison of stress strain curves for alloys with specified minimum values. Curve 1: T-1, T-1 type A, T-1 type B; minimum yield strength (MYS) = 689 MPa (100 ksi). Curve 2: CON-PAC; MYS = 551 MPa (80 ksi). Curve 3: EX-TEN 60; MYS = 413 MPa (60 ksi). Curve 4: COR-TEN, TRI-TEN, EX-TEN 50; MYS = 345 MPa (50 ksi). Curve 5: EX-TEN 42; MYS = 289 MPa (42 ksi). Curve 6: ASTM A36; MYS = 248 MPa (36 ksi). Modulus of elasticity = 200 GPa (29×10^6 psi)

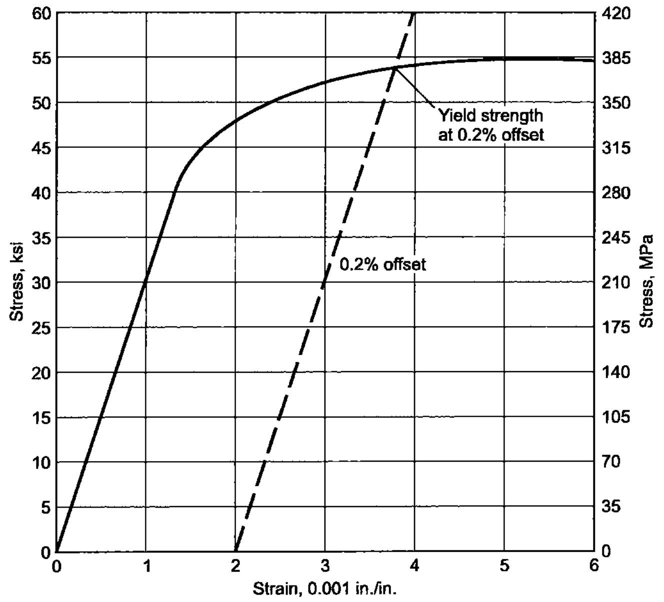
Source: "High-Strength Low-Alloy Steels," U.S. Steel, Oct 1971. As published in *Structural Alloys Handbook,* Vol 1, Battelle Columbus Laboratories, 1980, p 3



HS.002 A242 high-strength low-alloy (HSLA) steel sheet, stress-strain curve (complete range)

USS COR-TEN A sheet. Composition: Fe-0.09C-0.37Mn-0.088P. UNS K11510

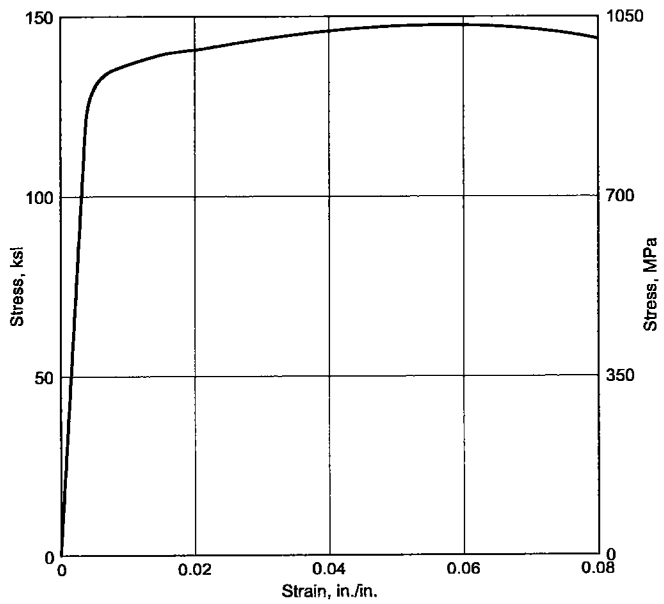
Source: E.A. Dolega, "Investigation of Low Alloy, High Strength Steel as a Missile Fuel Tank," Report BLR 53-56, Bell Aircraft, March 1953. As published in *Structural Alloys Handbook,* Vol 3, CINDAS/Purdue University, 1994, p 6



HS.003 A242 high-strength low-alloy (HSLA) steel sheet, stress-strain curves (expanded range)

USS COR-TEN A sheet. Sheet thickness = 1.778 mm (0.070 in.). Composition: Fe-0.09C-0.37Mn-0.088P. UNS K11510

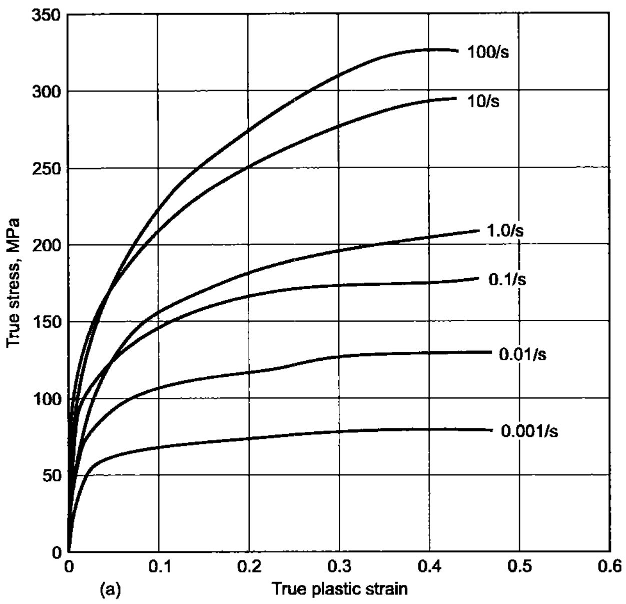
Source: E.A. Dolega, "Investigation of Low Alloy, High Strength Steel as a Missile Fuel Tank," Report BLR 53-56, Bell Aircraft, March 1953. As published in *Structural Alloys Handbook*, Vol 3, CINDAS/Purdue University, 1994, p 6

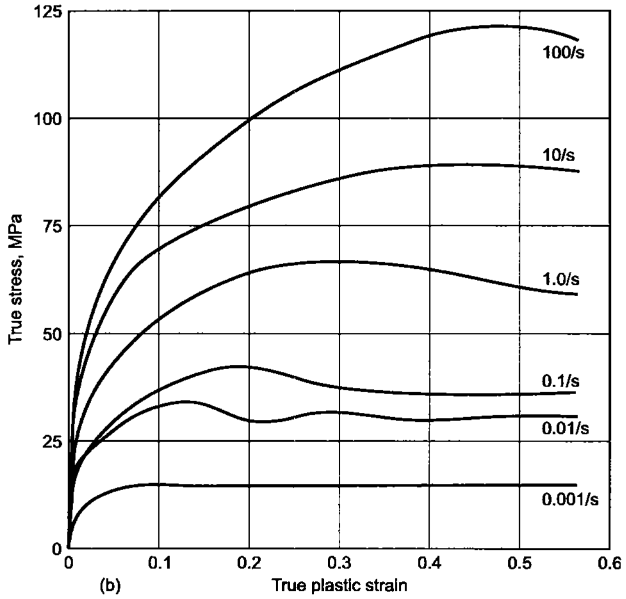


HS.004 Fe-5Ni-Cr-Mo-V high-strength low-alloy (HSLA) steel plate, stress-strain curve

Plate thickness 50 mm (2 in.). Heat treatment: 899 °C (1650 °F), 1 h, water quenched, 816 °C (1500 °F), 1 h, water quenched, 566 °C (1050 °F), 2 h, water quenched. Tensile yield strength = 944 MPa (137 ksi); elastic modulus = 203 GPa (29.5 × 10^6 psi). Composition: Fe-0.11C-5Ni-0.55Cr-0.47Mo-0.07V

Source: L.F. Porter et al., "The Development of an HY 130(T) Steel Weldment," Report 39.018-001, NOBS 88540, U.S. Steel Applied Research Laboratory, 1 July 1966. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1216, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 21

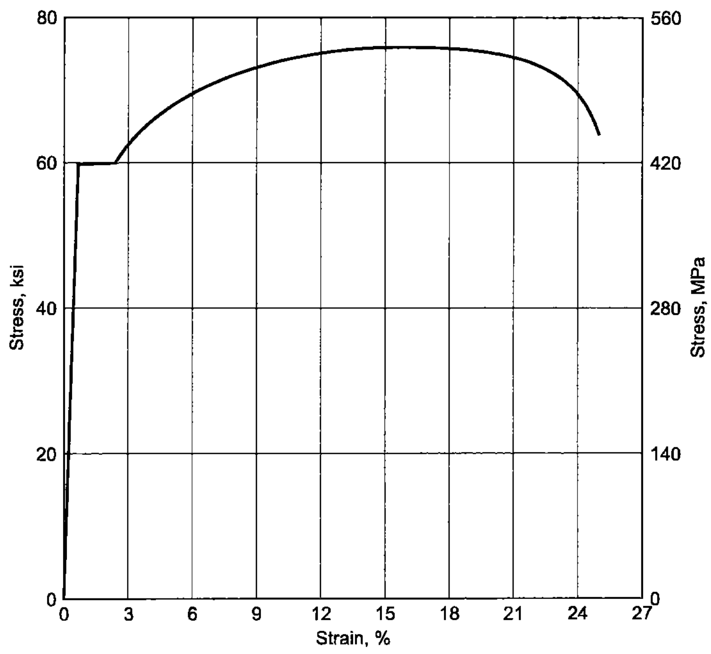




HS.005 Microalloyed high-strength low-alloy (HSLA) steel, compressive true stress-true plastic strain curves at different strain rates

Hot rolled. Thermomechanical processing typically includes rough rolling, 1100–1240 °C (2012–2264 °F), and finish rolling, 810–900 °C (1490–1652 °F), fast cooling to 700 °C (1292 °F), and air cooling. (a) Tested at 900 °C. (b) At 1200 °C. Composition: Fe-0.08C-1.3Mn-0.3Si-0.2Ni-0.08V-0.05Nb-0.015P-0.008S

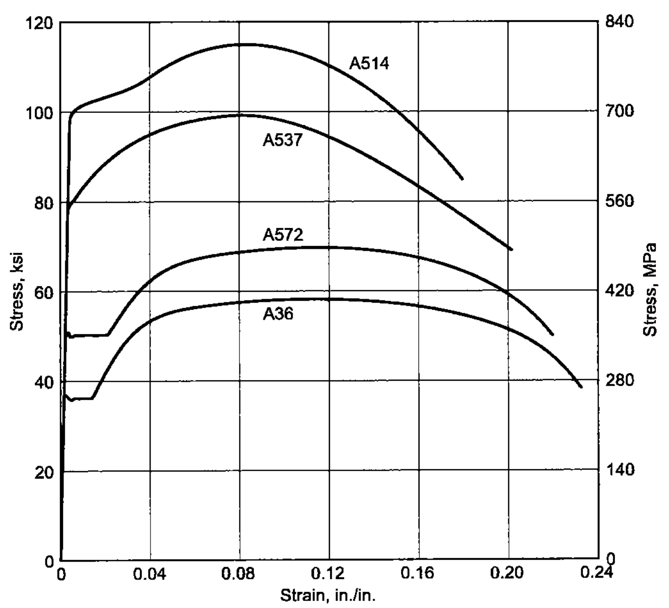
Source: N.S. Mishra, in *Hot Working Guide A Compendium of Processing Maps,* Y.V.R.K Prasad and S. Sasidhara, Ed., ASM International, 1997, p 337



HS.006 A633 grade C high-strength low-alloy (HSLA) steel plate, stress-strain curve (complete range)

Suitable for welded construction. Plate thickness = 19.05 mm (0.75 in.). Typical curve for 203.2 mm (8 in.) test coupon. Yield strength = 435 MPa (63.1 ksi); ultimate tensile strength = 549 MPa (79.7 ksi); elongation = 26.3%. Composition: Fe-0.2C-1.32Mn-0.32Si-0.03Nb. UNS K12000

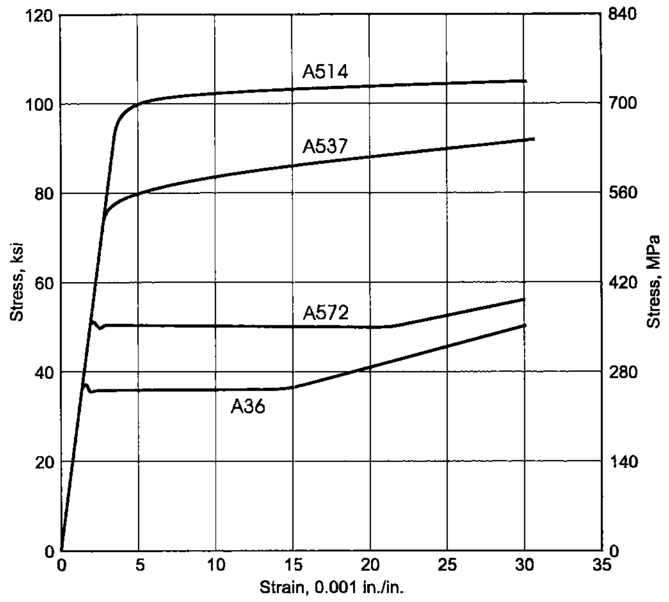
Source: "Plate Selection Guide Book," Bethlehem Steel, Bethlehem, PA, 1985. As published in *Structural Alloys Handbook,* Vol 3, CINDAS/Purdue University, 1994, p 6



HS.007 Various high-strength structural steels, typical stress-strain curves (full range)

Comparison of structural steels with specified minimum tensile properties. Typical yield strengths: A36 carbon steel, 248 MPa (36 ksi); A572 HSLA (grade 50), 345 MPa (50 ksi); A537, 276–414 MPa (40–60 ksi) (depends on class and thickness); A514, 620 or 689 MPa (90 or 100 ksi) (depends on thickness)

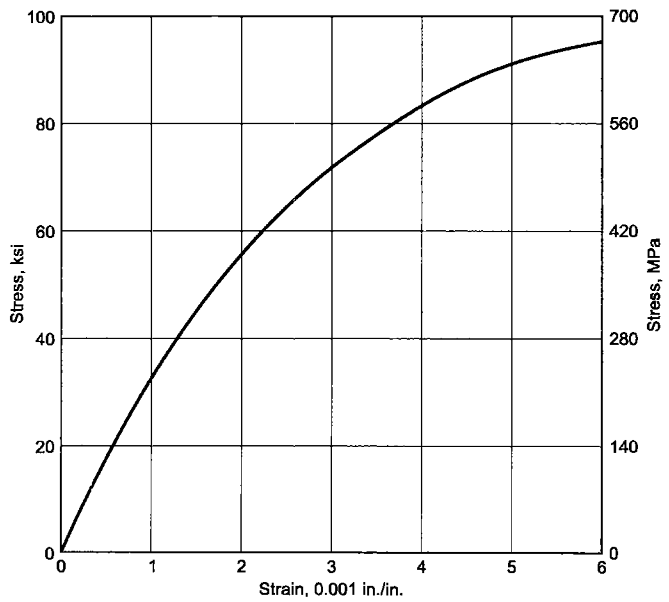
Source: R.L. Brockenbrough and B.G. Johnston, *USS Steel Design Manual,* Jan 1981. As published in *Structural Alloys Handbook,* Vol 3, CINDAS/Purdue University, 1994, p 5



HS.008 Various high-strength structural steels, typical initial stress-strain curves

Comparison of structural steels with specified minimum tensile properties. Typical yield strengths: A36 carbon steel, 248 MPa (36 ksi); A572 HSLA (grade 50), 345 MPa (50 ksi); A537, 276–414 MPa (40–60 ksi) (depends on class and thickness); A514, 620 or 689 MPa (90 or 100 ksi) (depends on thickness)

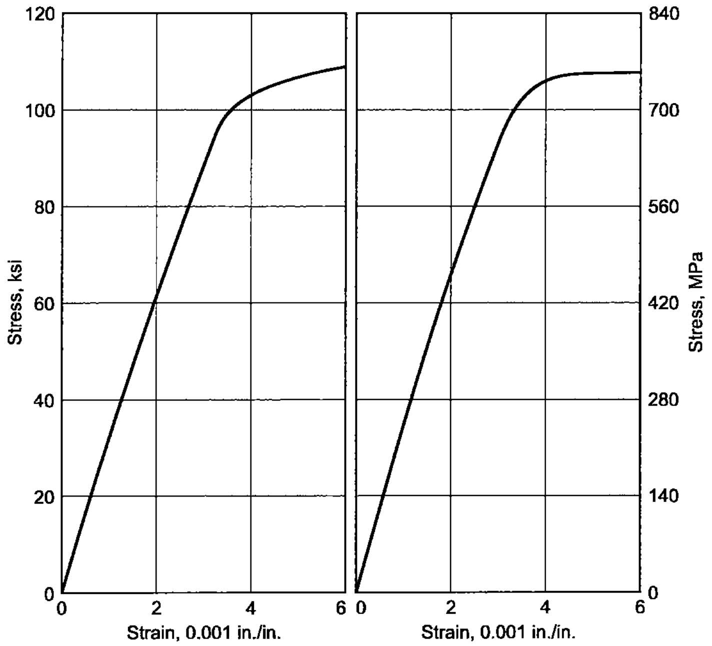
Source: R.L. Brockenbrough and B.G. Johnston, *USS Steel Design Manual*, Jan 1981. As published in *Structural Alloys Handbook*, Vol 3, CINDAS/Purdue University, 1994, p 5



HS.009 ASTM A514 and A517, grade A high-strength structural welded steel plate, typical tensile stress-strain curve

ASTM A514 (high-strength plate suitable for welding); or ASTM A517 (pressure-vessel plate). Typical composition, A514 grade A: Fe-0.18C-0.95Mn-0.65Cr-0.60Si-0.23Mo-0.10Zr. UNS K11856

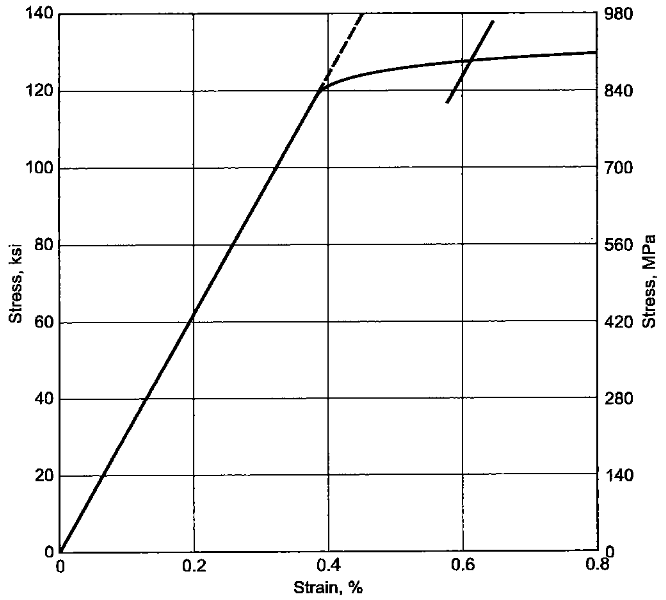
Source: "Evaluation of Great Lakes Steel Corp. Steel Alloy NAXTRA 100," Report A240, McDonnell Aircraft Corp., Dec 1963. As published in *Structural Alloys Handbook*, Vol 3, CINDAS/Purdue University, 1994, p 9



HS.010 A514 and A517, grade A high-strength structural steel plate, typical tensile stress-strain curves

Test direction: left, longitudinal; right, transverse. Typical for Grade A from either ASTM A514 (high-strength plate suitable for welding), or ASTM A517 (pressure-vessel plates). Typical composition, A514 grade A: Fe-0.18C-0.95Mn-0.65Cr-0.60Si-0.23Mo-0.10Zr. UNS K11856

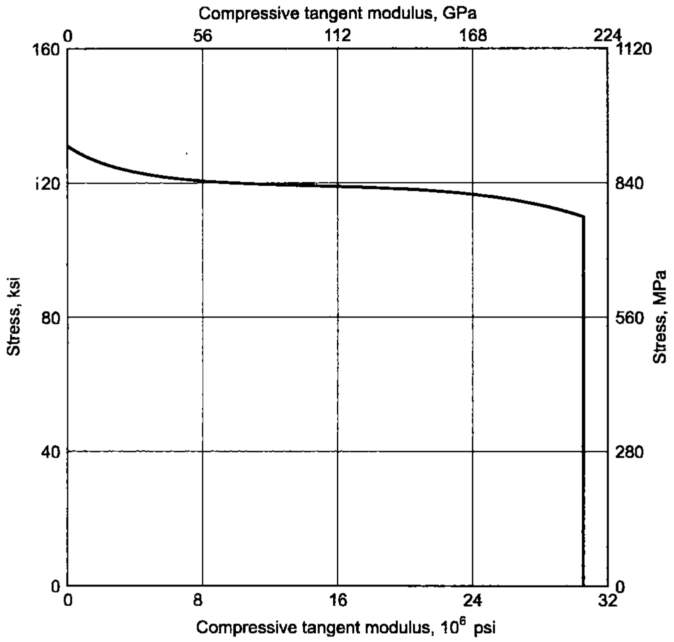
Source: "Evaluation of Great Lakes Steel Corp. Steel Alloy NAXTRA 100," Report A240, McDonnell Aircraft Corp., Dec 1963. As published in *Structural Alloys Handbook*, Vol 3, CINDAS/Purdue University, 1994, p 9



HS.011 T-1 (ASTM A517, grades B, F, H) high-strength structural steel pressure-vessel plate, typical compressive stress-strain curve

Compressive yield strength = 876 MPa (127 ksi); modulus of elasticity in compression = 208 GPa (30.2 × 10^6 psi). Composition: varies with grade. UNS K11630, K11576, K11646

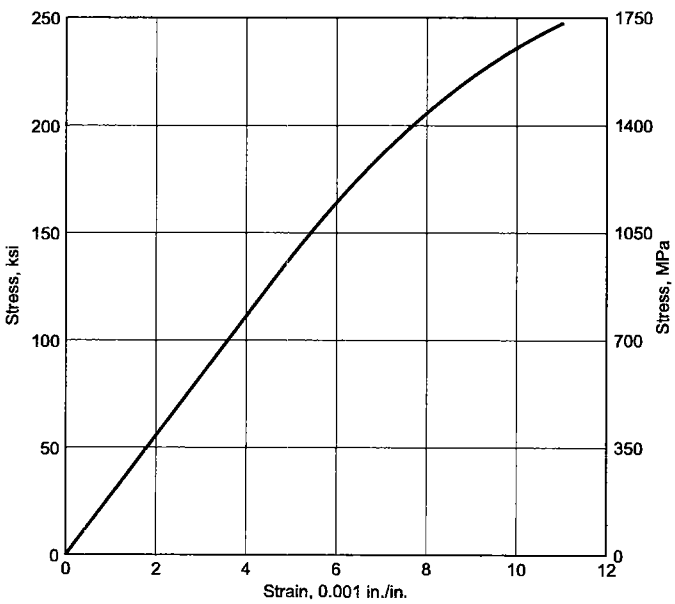
Source: D.J. Carney, U.S. Steel Corp., personal communication with W.J. Brown, 27 Jan 1972. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1103, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 8



HS.012 T-1 (ASTM A517, grades B, F, H) high-strength structural steel pressure-vessel plate, typical compressive tangent modulus curve

Compressive yield strength = 876 MPa (127 ksi); modulus of elasticity in compression = 208 GPa (30.2×10^6 psi). Composition: varies with grade. UNS K11630, K11576, K11646

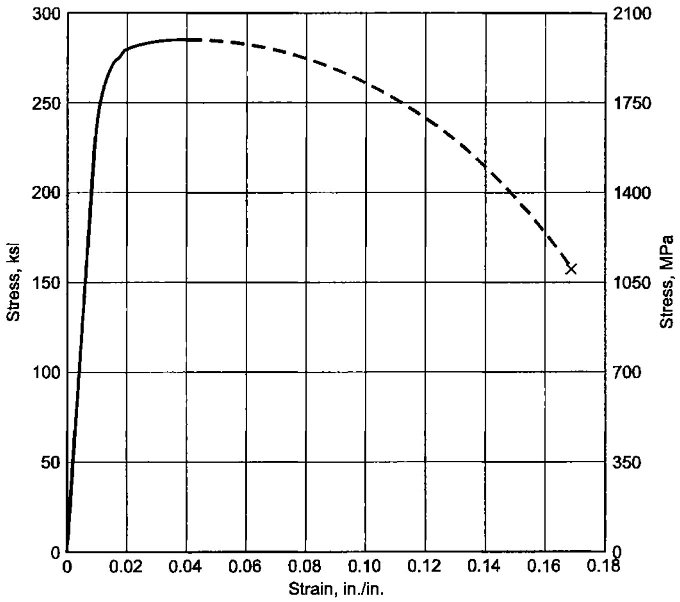
Source: D.J. Carney, U.S. Steel Corp., personal communication with W.J. Brown, 27 Jan 1972. As published in *Aerospace Structural Metals Handbook,* Vol 1, Code 1103, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



HS.013 AerMet 100 high-strength structural steel bar, typical tensile stress-strain curve at room temperature

Bar thickness = ≤254 mm (≤10.000 in.). Test direction: longitudinal (L) and short transverse (ST). Heat treated to 1930–2068 MPa (280–300 ksi). Ramberg-Osgood parameters: n(L) = 6.8, n(ST) = 6.8. Composition: Fe-0.23C-13.4Co-3.1Cr-1.2Mo-11.1Ni

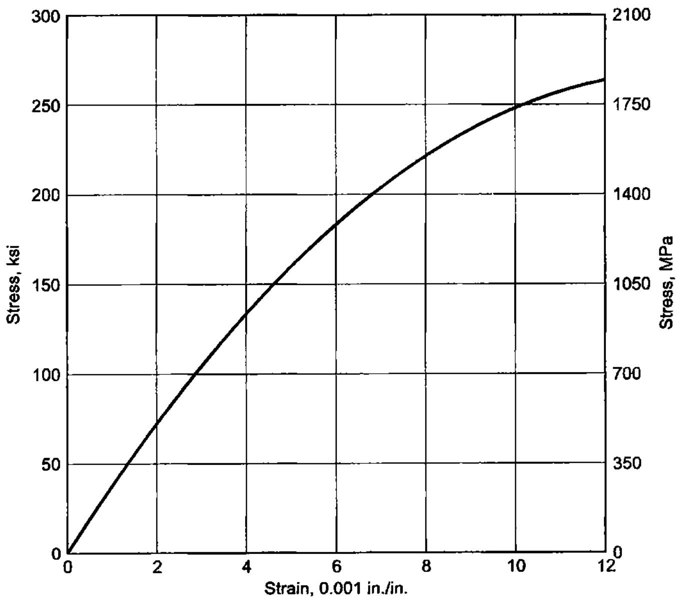
Source: *MIL-HDBK-5H,* Dec 1998, p 2-110



HS.014 AerMet 100 high-strength structural steel bar, typical tensile stress-strain curve at room temperature

Test direction: longitudinal. Bar thickness = 127 mm (5.000 in.). Based on one heat. Heat treated to 1930–2068 MPa (280–300 ksi). Composition: Fe-0.23C-13.4Co-3.1Cr-1.2Mo-11.1Ni

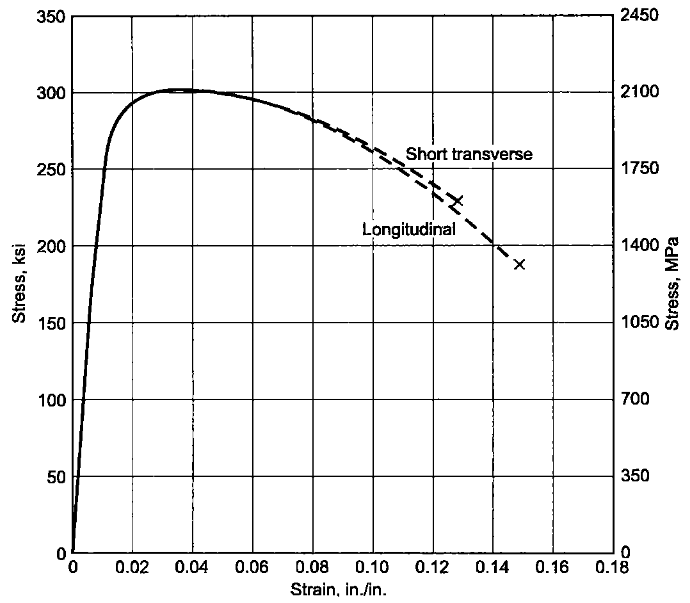
Source: *MIL-HDBK-5H,* Dec 1998, p 2-112



HS.015 AerMet 100 high-strength structural steel bar, typical tensile stress-strain curve (full range) at room temperature

Bar thickness = ≤254 mm (≤10.000 in.). Test direction: longitudinal (L) and short transverse (ST). Heat treated to 1999–2137 MPa (290–310 ksi). Ramberg-Osgood parameters: $n(L) = 15.9$, $n(ST) = 16.1$. Composition: Fe-0.23C-13.4Co-3.1Cr-1.2Mo-11.1Ni

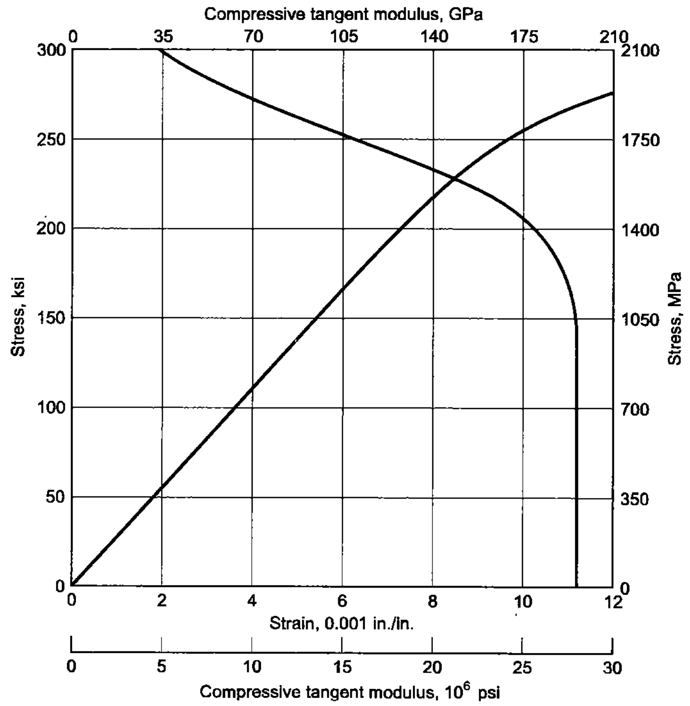
Source: *MIL-HDBK-5H,* Dec 1998, p 2-113



HS.016 AerMet 100 high-strength structural steel bar, typical tensile stress-strain curve (full range) at room temperature

Bar thickness = 127 mm (5.000 in.). Heat treated to 1999–2137 MPa (290–310 ksi). Based on one heat. Composition: Fe-0.23C-13.4Co-3.1Cr-1.2Mo-11.1Ni

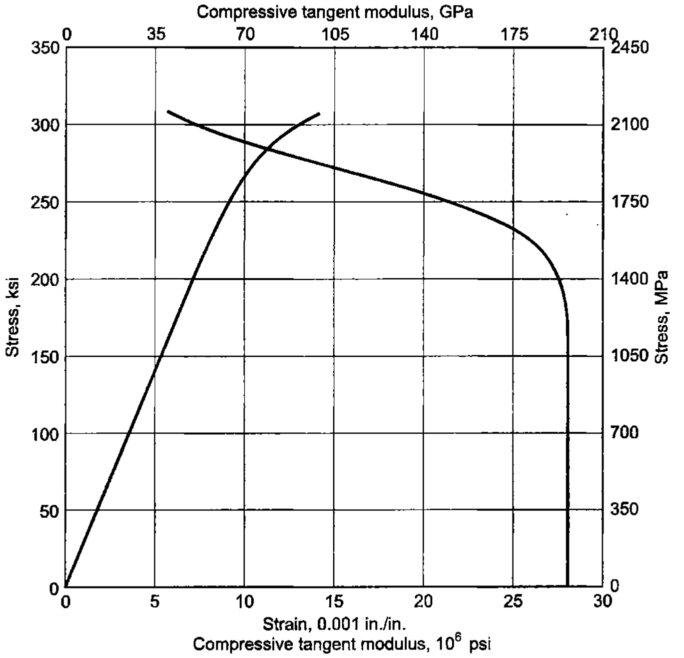
Source: *MIL-HDBK-5H,* Dec 1998, p 2-115



HS.017 AerMet 100 high-strength structural steel bar, typical compressive stress-strain and compressive tangent modulus curves at room temperature

Bar thickness = ≤254 mm (≤10.000 in.). Test direction: longitudinal (L) and short transverse (ST). Heat treated to 1930–2068 MPa (280–300 ksi). Ramberg-Osgood parameters: n(L) = 11, n(ST) = 12. Composition: Fe-0.23C-13.4Co-3.1Cr-1.2Mo-11.1Ni

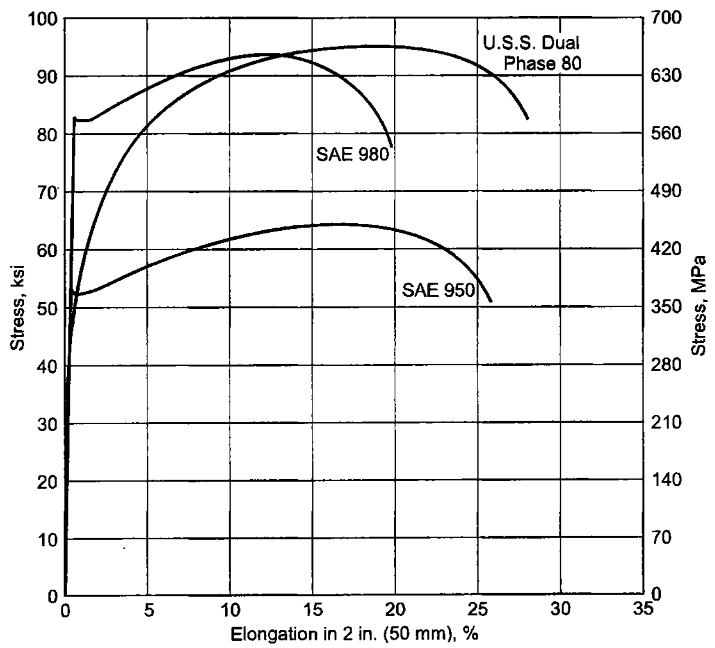
Source: *MIL-HDBK-5H,* Dec 1998, p 2-111



HS.018 AerMet 100 high-strength structural steel bar, typical compressive stress-strain and compressive tangent modulus curves at room temperature

Bar thickness = ≤254 mm (≤10.000 in.). Test direction: longitudinal(L) and short transverse (ST). Heat treated to 1999–2137 MPa (290–310 ksi). Ramberg-Osgood parameters: n(L) = 9.6, n(ST) = 13. Composition: Fe-0.23C-13.4Co-3.1Cr-1.2Mo-11.1Ni

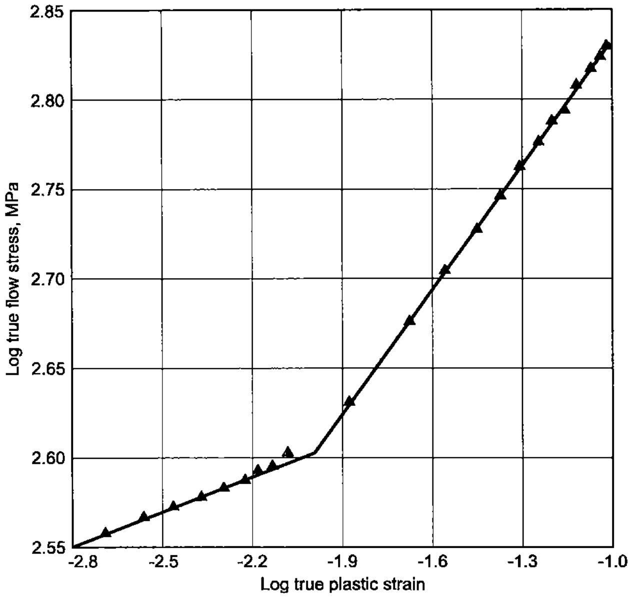
Source: *MIL-HDBK-5H,* Dec 1998, p 2-114



HS.019 U.S.S. Dual-phase 80 high-strength low-alloy (HSLA) steel sheet, typical tensile stress-strain curve, compared with other steels

Ultimate tensile strength = 660 MPa (95 ksi). Yield strength for coils = 340 MPa (50 ksi); for cut leveled lengths = 390 MPa (56 ksi). Composition: Fe-0.15C-1.75Mn-0.75Si-0.025P-0.020S-0.02V. All maximum values except V which is the minimum

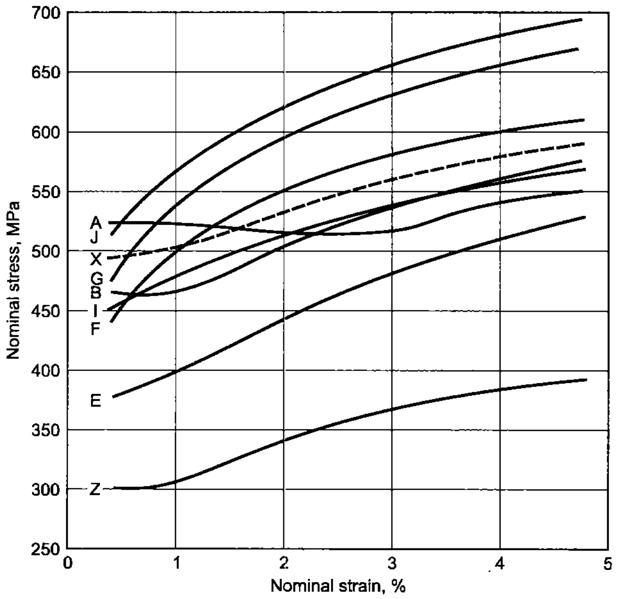
Source: SA-352, *Alloy Digest,* Dec 1978



HS.020 C5 dual-phase high-strength low-alloy (HSLA) steel sheet, log true flow stress-log true plastic strain curve

Sheet thickness = 3 mm. Curve shows a double n behavior with the transition at about 0.01 strain. Composition: Fe-0.04C-1.28Si-1Mn-0.59Cr-0.40Mo

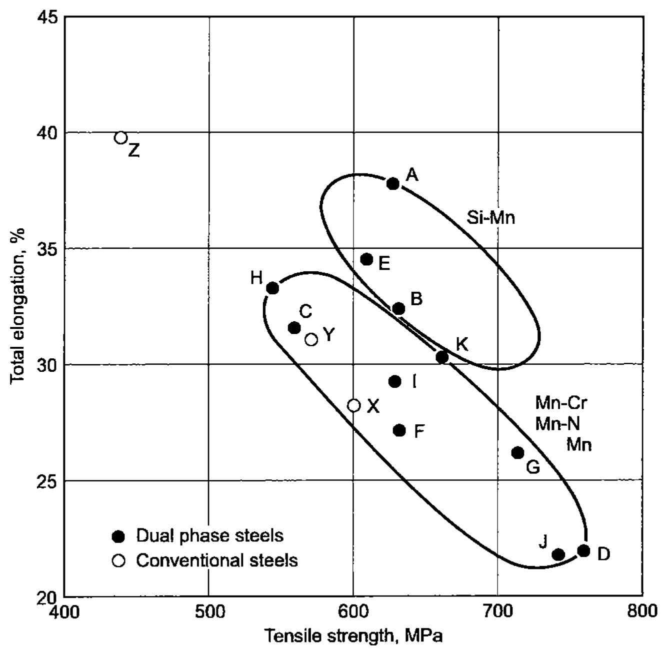
Source: M.R. Krishnadev et al., Formability of the Next Generation of High-Strength Low-Alloy Steels: The Effects of Low Temperatures and Processing Conditions, *Formability of Metallic Materials—2000 A.D.*, STP 753, J.R. Newby and B.A. Niemeier, Ed., ASTM, 1982, p 253



HS.021 High-strength low-alloy (HSLA) steel sheet, comparison of nominal stress-strain curves for a variety of alloys

All specimens hot rolled 1.99–2.53 mm thick. Specimen A: Si-Mn; yield strength (YS) = 519 MPa, strain-hardening exponent (n) = 0.181. Specimen B: Si-Mn; YS = 458 MPa, n = 0.188. Specimen E: Si-Mn (heat treated); YS = 374 MPa, n = 0.223. Specimen F: Mn-Cr; YS = 428 MPa, n = 0.144. Specimen G: Mn-Cr; YS = 453 MPa, n = 0.147. Specimen I: Mn-N; YS = 439 MPa, n = 0.154. Specimen J: Mn-N; YS = 484 MPa, n = 0.145. Specimen X: conventional Nb; YS = 500 MPa, n = 0.126. Specimen Z: commercial; YS = 300 MPa, n = 0.189

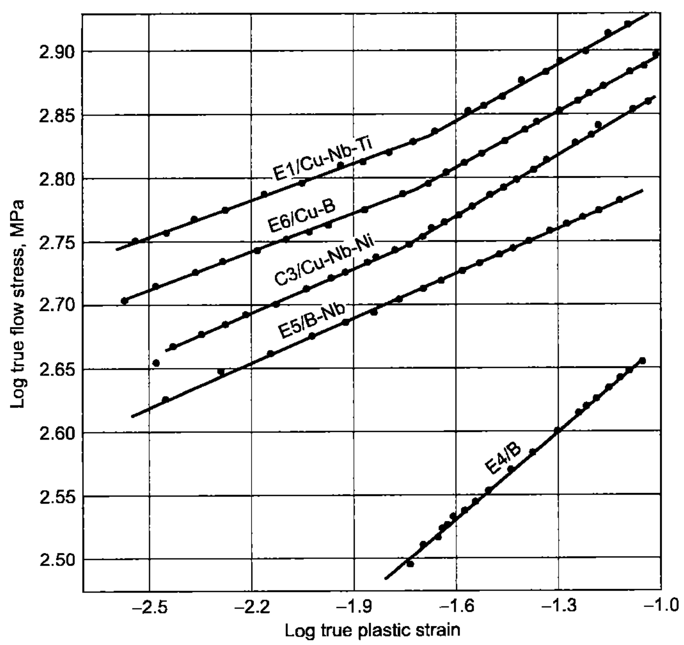
Source: I. Aoki, T. Horita, and T. Herai, Formability and Application of New Hot-Rolled High-Strength Sheet Steels, *Formability of Metallic Materials—2000 A.D.*, STP 753, J.R. Newby and B.A. Niemeier, Ed., ASTM, 1982, p 239



HS.022 High-strength low-alloy (HSLA) steel sheet, comparison of tensile strength and elongation for a variety of alloys

All specimens hot rolled 1.99–2.53 mm thick. Specimen A: Si-Mn; yield strength (YS) = 519 MPa, elongation (e) = 37.5%. Specimen B: Si-Mn; YS = 458 MPa, e = 32.1%. Specimen C: Mn (heat treated); YS = 333 MPa, e = 32.5%. Specimen D: Mn; YS = 467 MPa, e = 23.6%. Specimen E: Si-Mn; YS = 374 MPa, 34.3%. Specimen F: Mn-Cr; YS = 428 MPa, e =37.3%. Specimen G: Mn-Cr; YS = 453 MPa, e = 25.8%. Specimen H: Mn-Cr; YS = 395 MPa, e = 32.8%. Specimen I: Mn-N; YS = 439 MPa, e = 29.0%. Specimen J: Mn-N; YS = 484 MPa, e = 21.6%. Specimen X: conventional Nb; YS = 500 MPa, e = 27.8%. Specimen Y: conventional Si-Mn; YS = 400 MPa, e = 31.5%. Specimen Z: commercial; YS = 300 MPa, e = 39.7%

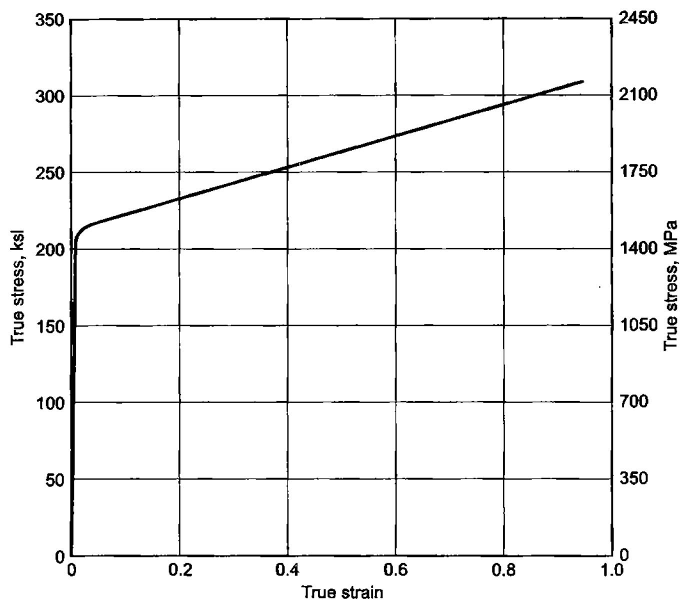
Source: I. Aoki, T. Horita, and T. Herai, Formability and Application of New Hot-Rolled High-Strength Sheet Steels, *Formability of Metallic Materials—2000 A.D.*, STP 753, J.R. Newby and B.A. Niemeier, Ed., ASTM, 1982, p 233



HS.023 High-strength low-alloy (HSLA) steel sheet, log true flow stress-log true plastic strain curves

Experimental steels E1, E4, E5, and E6 are compared with a commercial grade. E1 is a weathering steel, the other three are boron steels. C3 is a ferritic commercial HSLA Arctic steel with copper used for precipitation strengthening. Curve shows a double n behavior of the alloys strengthened with copper. Strengthening with niobium produces single n behavior.

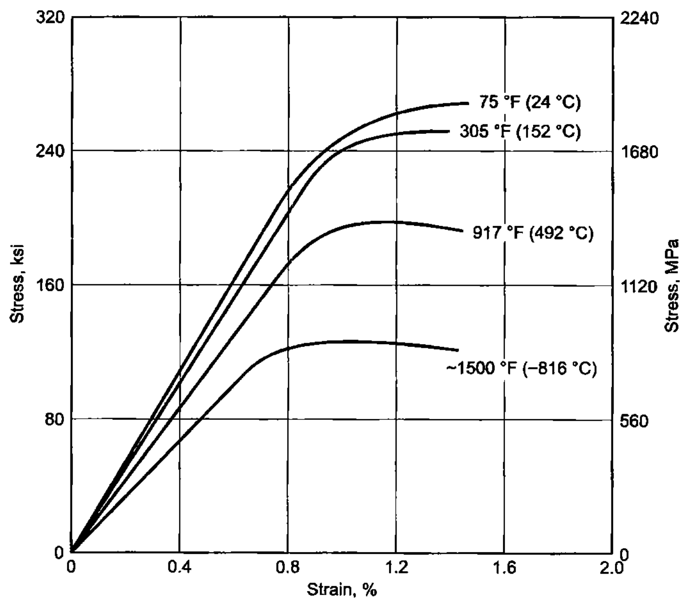
Source: M.R. Krishnadev et al., Formability of the Next Generation of High-Strength Low-Alloy Steels: The Effects of Low Temperatures and Processing Conditions, *Formability of Metallic Materials—2000 A.D.*, STP 753, J.R. Newby and B.A. Niemeier, Ed., ASTM, 1982, p 259



HS.024 200 high-strength maraging steel, true stress-strain curve

Heat treatment: 816 °C (1500 °F), 1 h, air cooled, 482 °C (900 °F), 3 h. Composition: Fe-18Ni-8.5Co-3.3Mo-0.2Ti-0.1Al

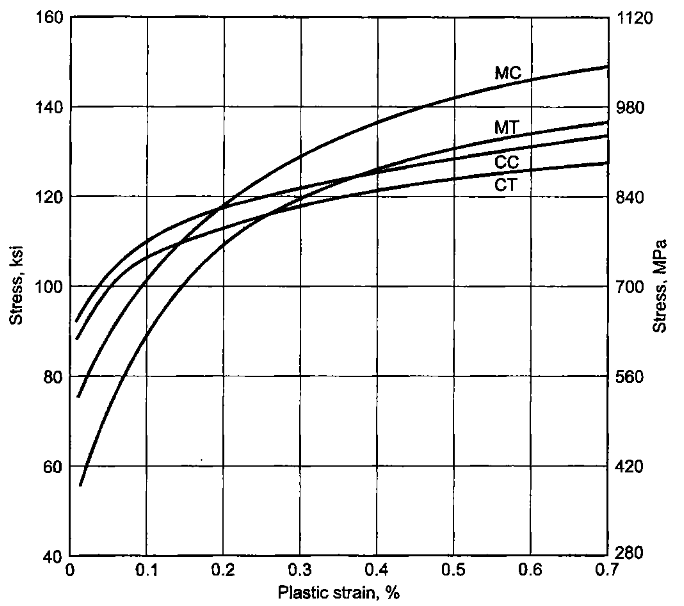
Source: "18% Nickel Maraging Steels," Data Bulletin, International Nickel Co., Nov 1964, p 11. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1223, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 7



HS.025 T-250 high-strength maraging steel bar, stress-strain curves at room and elevated temperatures

Bar thickness = 16.5 mm (0.65 in.). Heat treatment: 85% cold formed, 482 °C (900 °F), 4 h. Composition: Fe-18.5Ni-3.0Mo-1.4Ti-0.1Al (Co free)

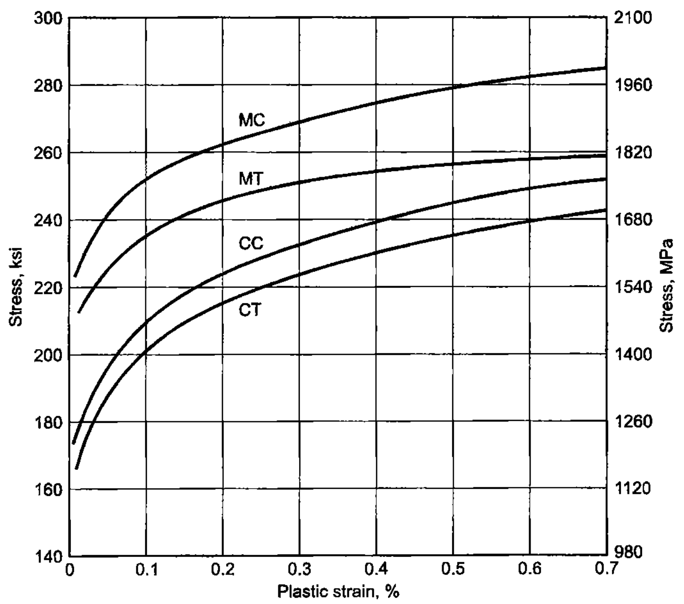
Source: Personal communication from W.B. Austin, Hercules Inc., McGregor, TX, 14 Nov 1989. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1228, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 14



HS.026 18Ni (250) high-strength maraging steel plate, monotonic and cyclic stress-strain curves

Test direction: longitudinal. Specimen size = 6.35 mm (0.25 in.) diam, 18.03 mm (0.71 in.) long. Heat treatment: austenitized 927 °C (1700 °F), solution annealed 804 °C (1480 °F). Strain rate = 6.097 mm/min (0.24 in./min). Test condition: monotonic tension, MT; monotonic compression, MC; cyclic tension, CT; cyclic compression, CC. Composition: Fe-18Ni-7.5Co-5Mo-Ti-Al

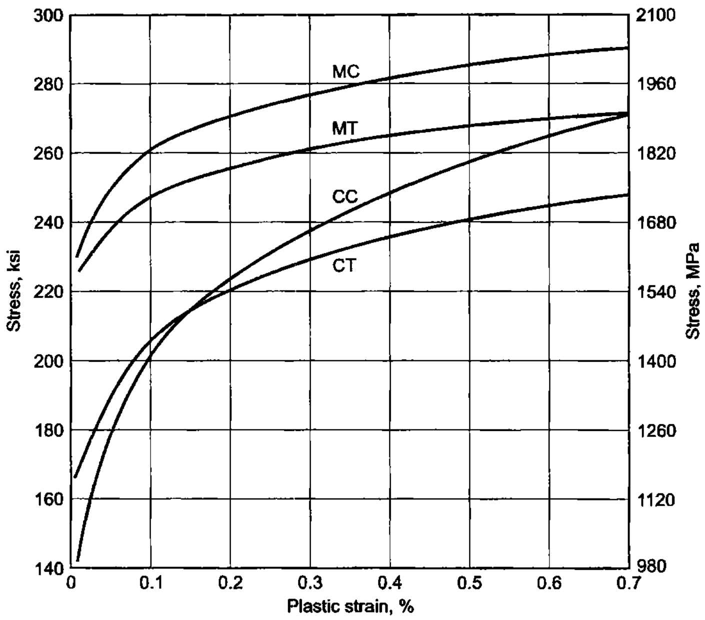
Source: W.B. Jones and J.C. Swearengen, Mechanical Stability of Ultrahigh Strength Steels, *Mater. Sci. Eng.*, Vol 41 (No. 2), Dec 1979, p 225–235. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1220, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 21



HS.027 18Ni (250) high-strength maraging steel plate, monotonic and cyclic stress-strain curves

Test direction: longitudinal. Specimen size = 6.35 mm (0.25 in.) diam, 18.03 mm (0.71 in.) long. Heat treatment: austenitized 927 °C (1700 °F), solution annealed 804 °C (1480 °F), aged 482 °C (900 °F), 4 h, air cooled. Strain rate = 6.097 mm/min (0.24 in./min). Test condition: monotonic tension, MT; monotonic compression, MC; cyclic tension, CT; cyclic compression, CC. Composition: Fe-18Ni-7.5Co-5Mo-Ti-Al

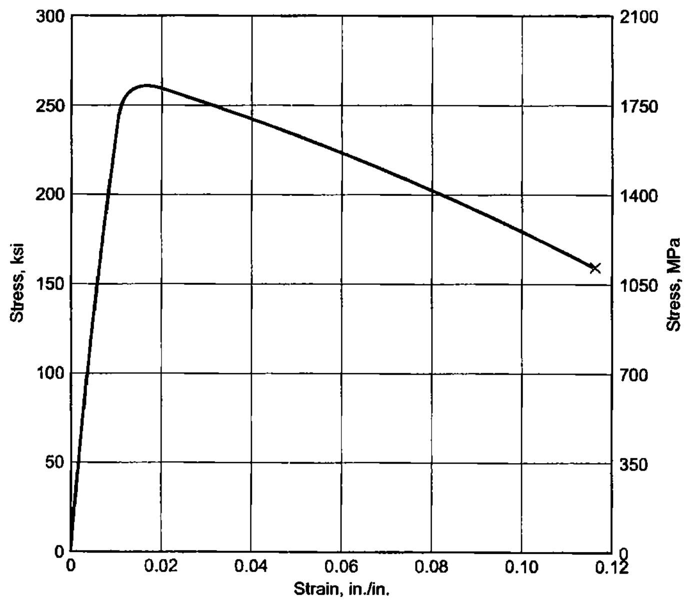
Source: W.B. Jones and J.C. Swearengen, Mechanical Stability of Ultrahigh Strength Steels, *Mater. Sci. Eng.*, Vol 41 (No. 2), Dec 1979, p 225–235. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1220, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 21



HS.028 18Ni (250) high-strength maraging steel plate, monotonic and cyclic stress-strain curves

Test direction: longitudinal. Specimen size = 6.35 mm (0.25 in.) diam, 18.03 mm (0.71 in.) long. Heat treatment: austenitized 927 °C (1700 °F), solution annealed 804 °C (1480 °F), aged 482 °C (900 °F), 8 h, air cooled. Strain rate = 6.097 mm/min (0.24 in./min). Test condition: monotonic tension, MT; monotonic compression, MC; cyclic tension, CT; cyclic compression, CC. Composition: Fe-18Ni-7.5Co-5Mo-Ti-Al

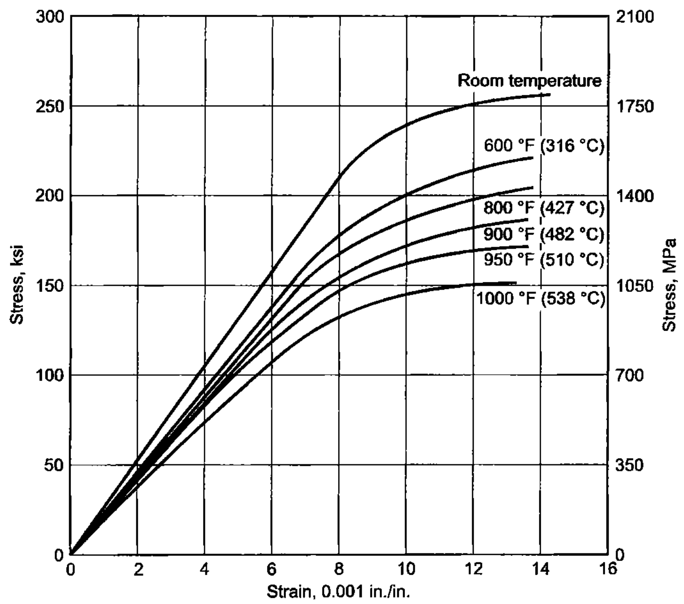
Source: W.B. Jones and J.C. Swearengen, Mechanical Stability of Ultrahigh Strength Steels, *Mater. Sci. Eng.*, Vol 41 (No. 2), Dec 1979, p 225–235. As published in *Aerospace Structural Metals Handbook,* Vol 1, Code 1220, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 21



HS.029 18Ni (250) high-strength maraging steel bar, stress-strain curve (full range)

Consumable vacuum arc remelted. Heat treatment: annealed 816 °C (1500 °F), 30 min, air cooled, aged 482 °C (900 °F), 3 h. Composition: Fe-18Ni-7.5Co-5Mo-Ti-Al

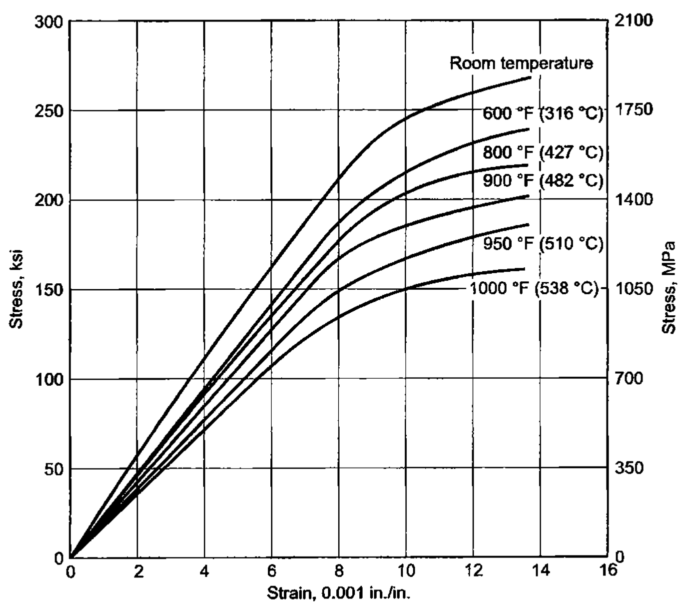
Source: "Vascomax 18 Percent Nickel Ultrahigh Strength Maraging Steels," VASCO, Latrobe, PA, 1966. As published in *Aerospace Structural Metals Handbook,* Vol 1, Code 1220, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 21



HS.030 18Ni (250) high-strength maraging steel bar, tensile stress-strain curves at room and elevated temperatures

Air melted. Heat treatment: annealed 816 °C (1500 °F), 30 min, air cooled, aged 482 °C (900 °F), 3 h. Composition: Fe-18Ni-7.5Co-5Mo-Ti-Al

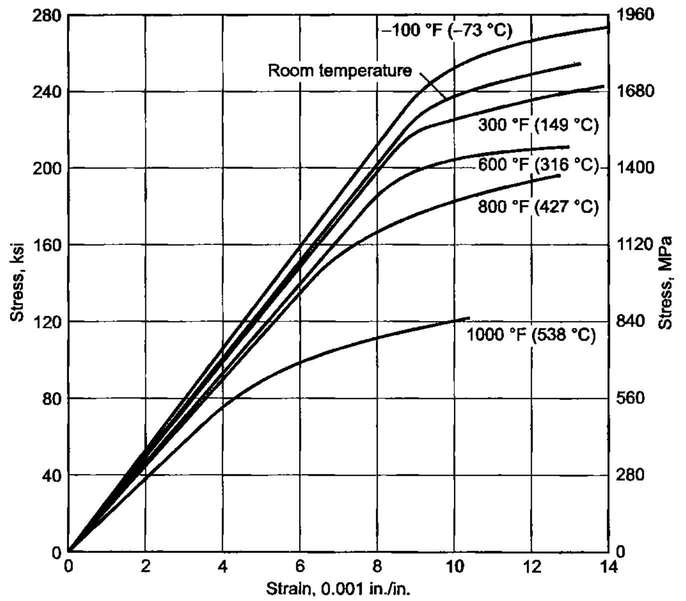
Source: "Vascomax 18 Percent Nickel Ultrahigh Strength Maraging Steels," VASCO, Latrobe, PA, 1966. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1220, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 43



HS.031 18Ni (250) high-strength maraging steel bar, tensile stress-strain curves at room and elevated temperatures

Consumable vacuum arc remelted. Heat treatment: annealed 816 °C (1500 °F), 30 min, air cooled, aged 482 °C (900 °F), 3 h. Composition: Fe-18Ni-7.5Co-5Mo-Ti-Al

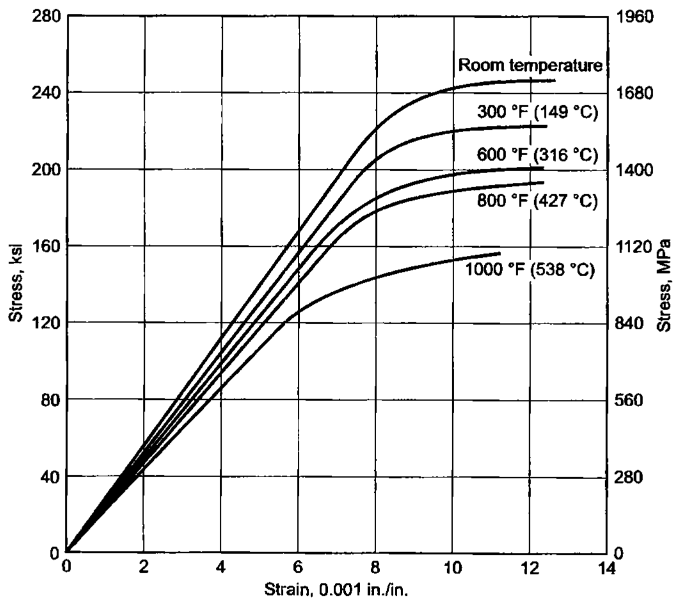
Source: "Vascomax 18 Percent Nickel Ultrahigh Strength Maraging Steels," VASCO, Latrobe, PA, 1966. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1220, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 44



HS.032 18Ni (250) high-strength maraging steel, typical tensile stress-strain curves at room, low, and elevated temperatures

Consumable vacuum arc remelted. Heat treatment: mill annealed 816 °C (1500 °F), aged 482 °C (900 °F), 3 h. Exposure time at test temperature = 0.5 h. Composition: Fe-18Ni-7.5Co-5Mo-Ti-Al

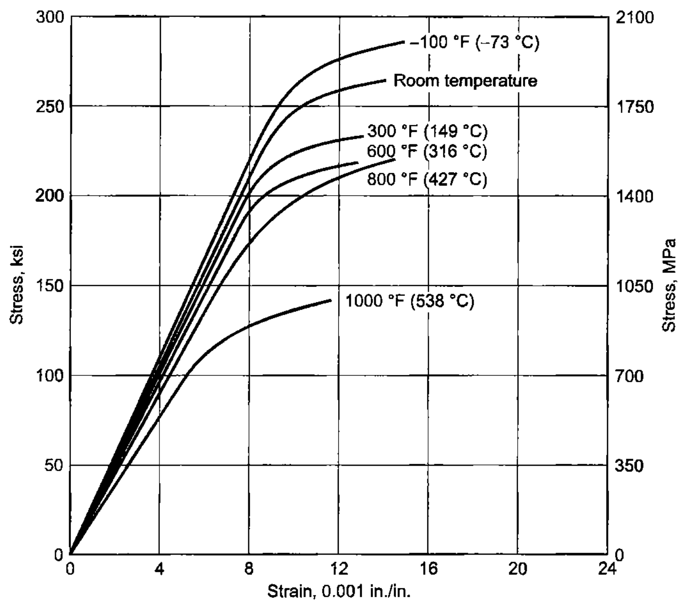
Source: A.F. Hoenie, J.A. Lumm, R.J. Shelton, and R.A. Wallace, "Determination of Mechanical Property Design Values for 18NiCoMo 250 and 300 Grade Maraging Steels," AFML-TR-65-197, July 1965. As published in *Aerospace Structural Metals Handbook,* Vol 1, Code 1220, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 44



HS.033 18Ni (250) high-strength maraging steel sheet, typical compressive stress-strain curves at room and elevated temperatures

Consumable vacuum arc remelted. Heat treatment: mill annealed 816 °C (1500 °F), aged 482 °C (900 °F), 3 h. Exposure time at test temperature = 0.5 h. Composition: Fe-18Ni-7.5Co-5Mo-Ti-Al

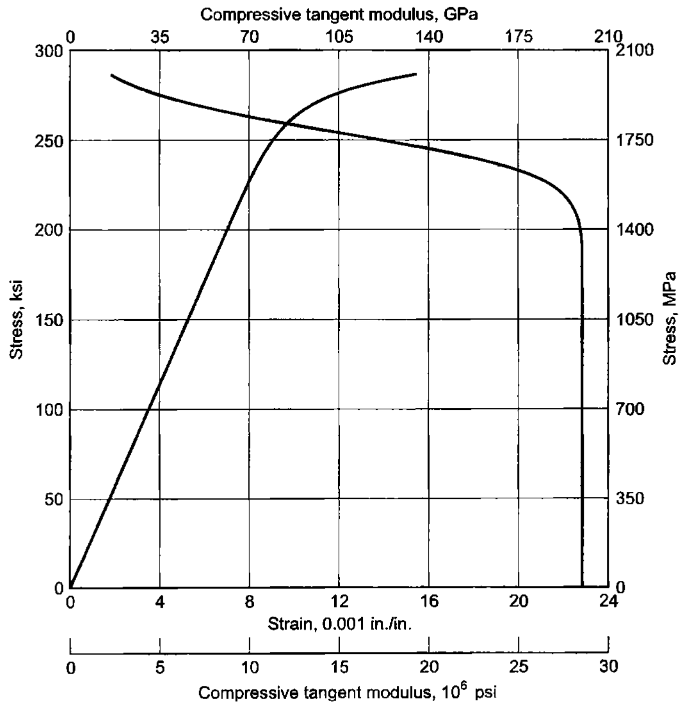
Source: A.F. Hoenie, J.A. Lumm, R.J. Shelton, and R.A. Wallace, "Determination of Mechanical Property Design Values for 18NiCoMo 250 and 300 Grade Maraging Steels," AFML-TR-65-197, July 1965. As published in *Aerospace Structural Metals Handbook,* Vol 1, Code 1220, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 48



HS.034 18Ni (250) high-strength maraging steel bar, typical stress-strain curves at room, low, and elevated temperatures

Test direction: longitudinal. Consumable vacuum arc remelted. Heat treatment: annealed, aged 482 °C (900 °F). Exposure time at test temperature = 0.5 h. RT, room temperature. Ramberg-Osgood parameters: *n*(−100 °F) = 24, *n*(RT) = 26, *n*(300 °F) = 29, *n*(600 °F) = 26, *n*(800 °F) = 11, *n*(1000 °F) = 11. Composition: Fe-18Ni

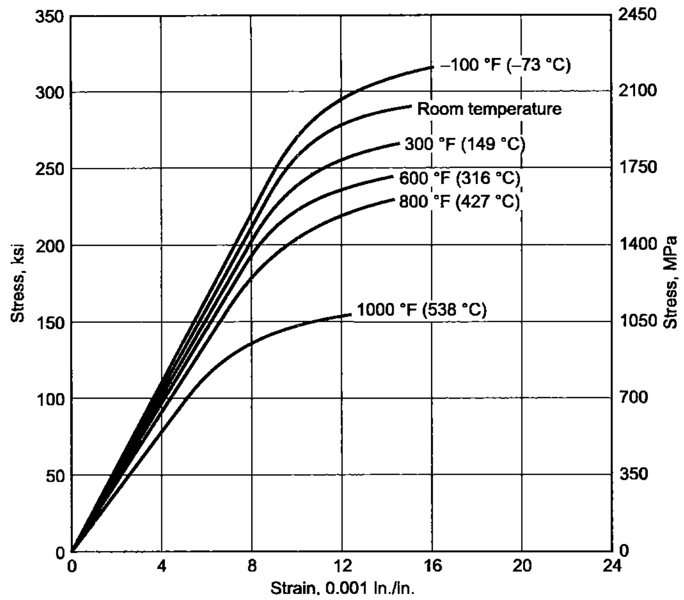
Source: *MIL-HDBK-5H,* Dec 1998, p 2-101



HS.035 18Ni (250) high-strength maraging steel bar, typical compressive stress-strain and tangent modulus curves at room and elevated temperatures

Test direction: longitudinal. Consumable vacuum arc remelted. Heat treatment: annealed, aged 482 °C (900 °F). Exposure time at test temperature = 0.5 h. RT, room temperature. Ramberg-Osgood parameter: *n*(RT, compressive) = 22. Composition: Fe-18Ni

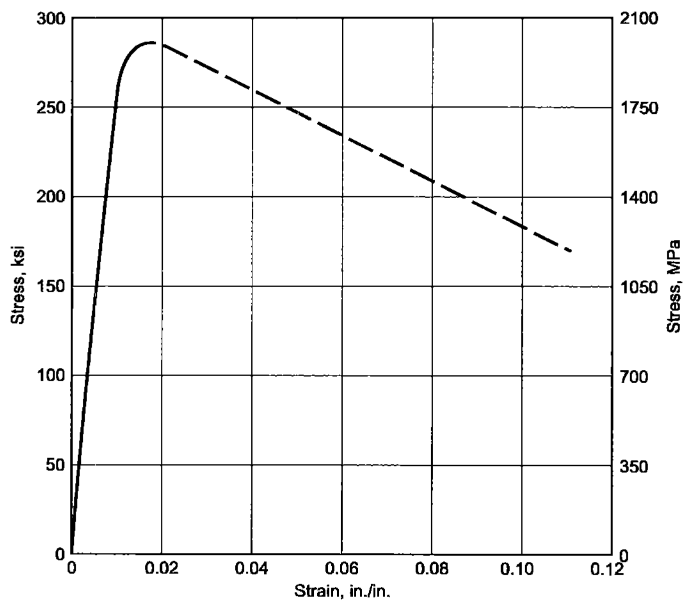
Source: *MIL-HDBK-5H,* Dec 1998, p 2-102



HS.036 18Ni (250) high-strength maraging steel bar, typical tensile stress-strain curves at room and elevated temperatures

Consumable vacuum arc remelted. Heat treatment: Annealed, aged 482 °C (900 °F). Exposure time at test temperature = 0.5 h. RT, room temperature. R'amberg-Osgood parameters: n(−100 °F) = 19, n(RT) = 22, n(300 °F) = 17, n(600 °F) = 17, n(800 °F) = 12, n(1000 °F) = 11. Composition: Fe-18Ni

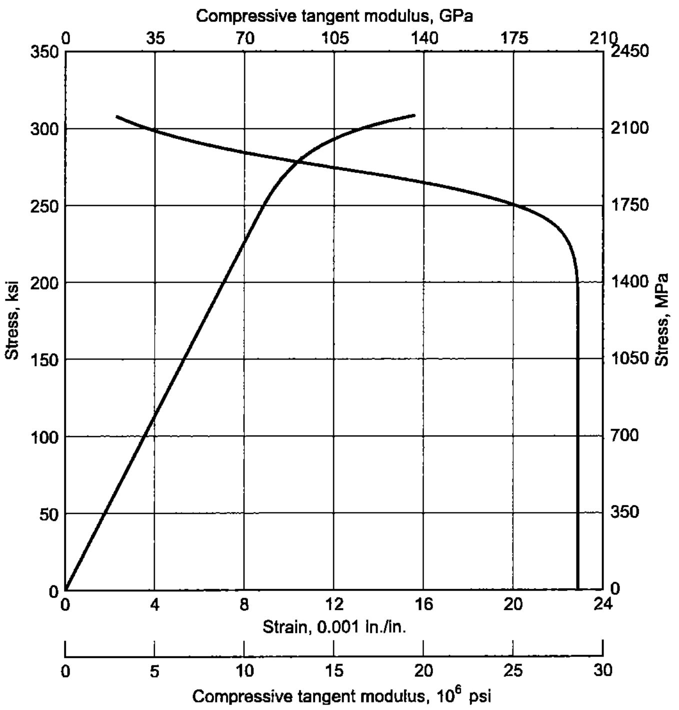
Source: *MIL-HDBK-5H*, Dec 1998, p 2-101



HS.037 18Ni (280) high-strength maraging steel bar, typical tensile stress-strain curve at room temperature (full range)

Test direction: longitudinal. Consumable vacuum arc remelted. Heat treatment: annealed, aged 482 °C (900 °F). Composition: Fe-18Ni

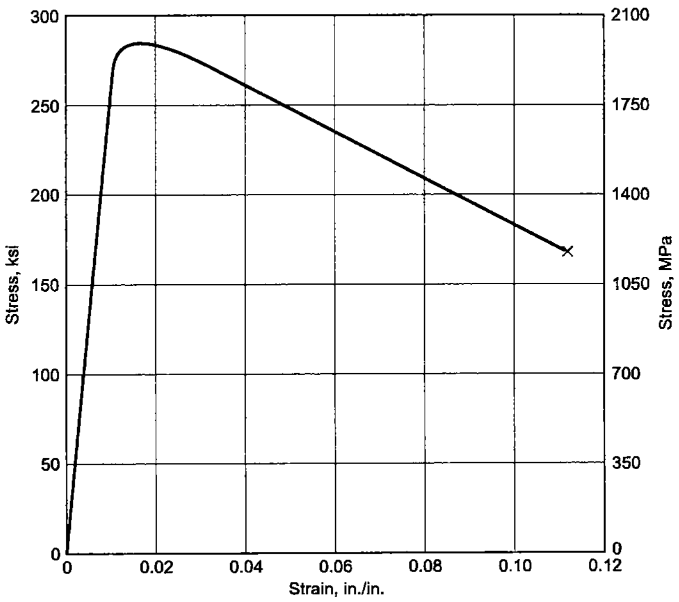
Source: *MIL-HDBK-5H*, Dec 1998, p 2-104



HS.038 18Ni (280) high-strength maraging steel bar, typical compressive stress-strain and tangent modulus curves at room temperature

Test direction: longitudinal. Consumable vacuum arc remelted. Heat treatment: annealed, aged 482 °C (900 °F). Exposure time at test temperature = 0.5 h. RT, room temperature. Ramberg-Osgood parameter: n(RT, compressive) = 21. Composition: Fe-18Ni

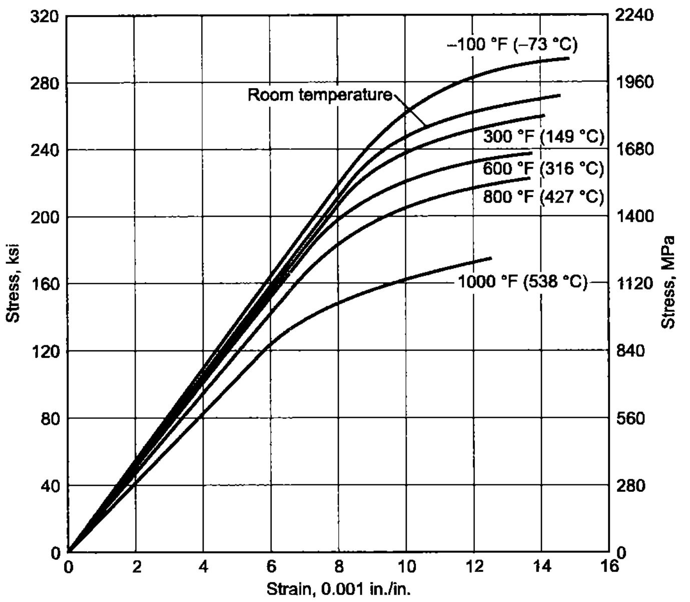
Source: *MIL-HDBK-5H,* Dec 1998, p 2-103



HS.039 18Ni (300) high-strength maraging steel bar, typical stress-strain curve

Consumable vacuum arc remelted. Heat treatment: mill annealed 816 °C (1500 °F), 0.5 h, air cooled, aged 482 °C (900 °F), 3 h. Composition: Fe-18Ni-9Co-5Mo-Ti-Al

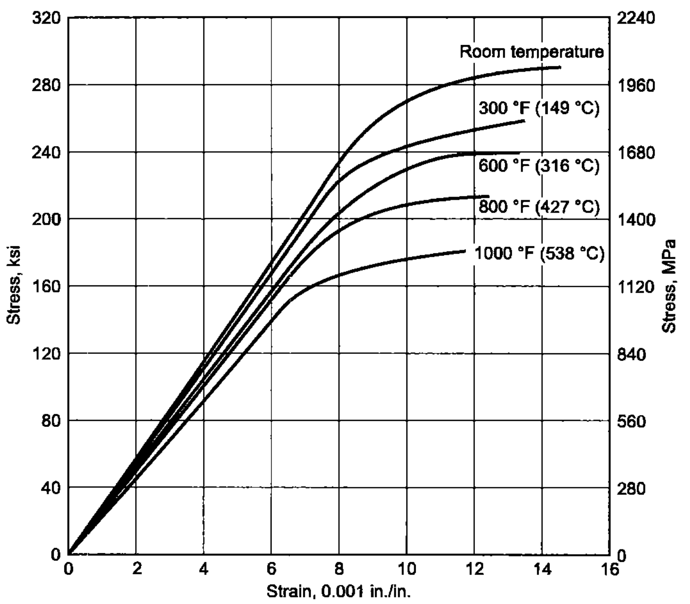
Source: "Vascomax 18 Percent Nickel Ultra High Strength Maraging Steels," VASCO, Latrobe, PA, 1966. As published in *Aerospace Structural Metals Handbook,* Vol 1, Code 1225, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 17



HS.040 18Ni (300) high-strength maraging steel bar, tensile stress-strain curves at room, low, and elevated temperatures

Consumable vacuum arc remelted. Heat treatment: mill annealed 816 °C (1500 °F), 0.5 h, air cooled, aged 482 °C (900 °F), 3 h. Exposure time at test temperature = 0.5 h. Composition: Fe-18Ni-9Co-5Mo-Ti-Al

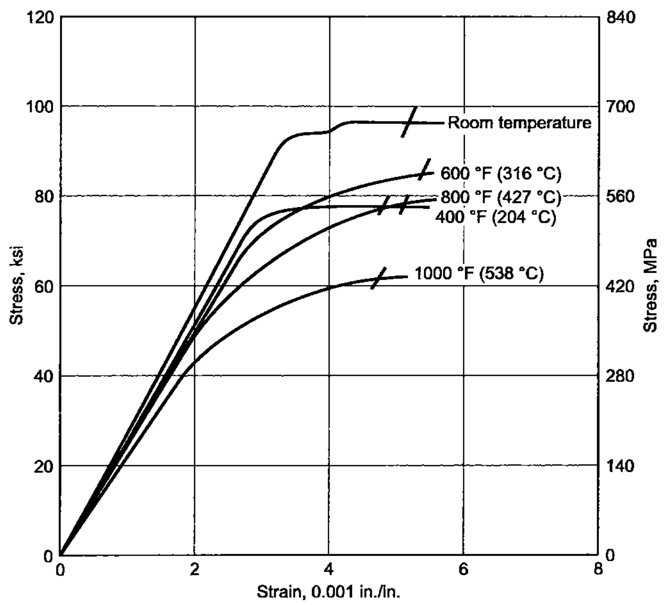
Source: A.F. Hoenie, J.A. Lumm, R.J. Shelton, and R.A. Wallace, "Determination of Mechanical Property Design Values for 18Ni-Co-Mo 250 and 300 Grade Maraging Steels," AFML-TR-65-197, July 1965, p 65. As published in *Aerospace Structural Metals Handbook,* Vol 1, Code 1225, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 27



HS.041 18Ni (300) high-strength maraging steel bar, compressive stress-strain curves at room and elevated temperatures

Consumable vacuum arc remelted. Heat treatment: mill annealed 816 °C (1500 °F), 0.5 h, air cooled, aged 482 °C (900 °F), 3 h. Exposure time at test temperature = 0.5 h. Composition: Fe-18Ni-9Co-5Mo-Ti-Al

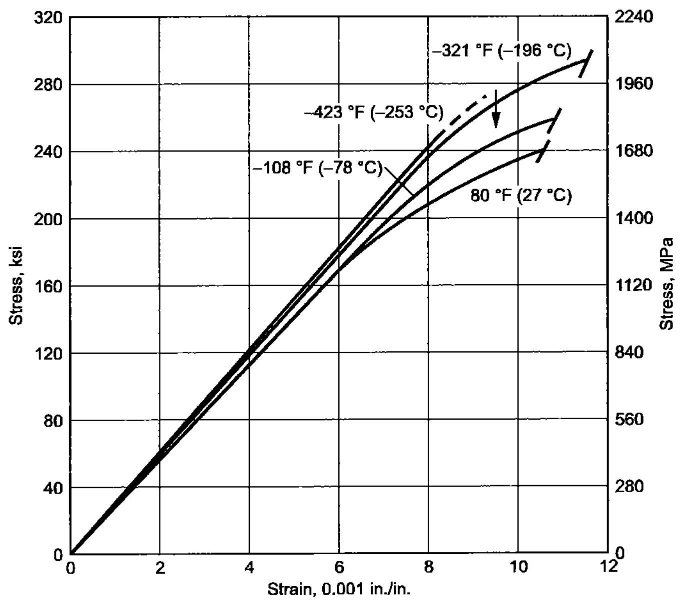
Source: A.F. Hoenie, J.A. Lumm, R.J. Shelton, and R.A. Wallace, "Determination of Mechanical Property Design Values for 18Ni-Co-Mo 250 and 300 Grade Maraging Steels," AFML-TR-65-197, July 1965, p 65. As published in *Aerospace Structural Metals Handbook,* Vol 1, Code 1225, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 32



HS.042 17-22A(S) ultrahigh-strength steel sheet, tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Sheet thickness = 1.575 mm (0.062 in.). Heat treatment: 954 °C (1750 °F), 0.25 h, oil quenched, tempered 704 °C (1300 °F), 1 h. Exposures at temperature = 0.5–1000 h. Composition: Fe-0.3C-1.3Cr-0.5Mo-0.25V. UNS K14675

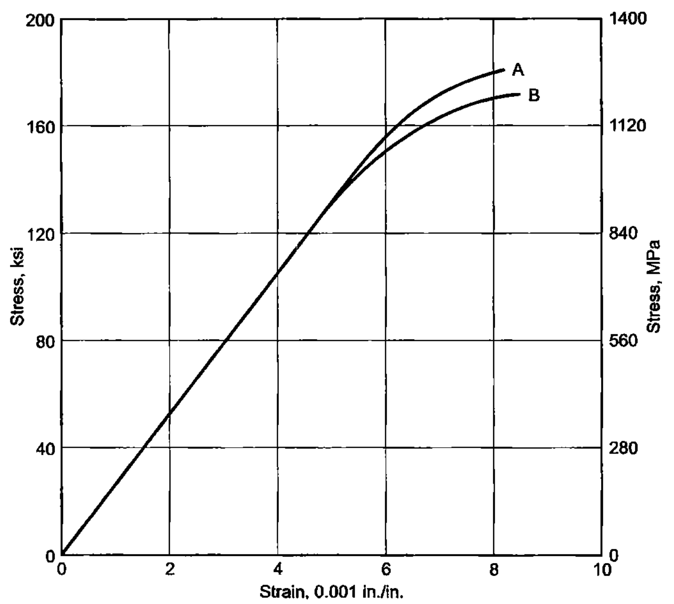
Source: J.R. Kattus, J.B. Preston, and H.L. Lessley, "Determination of Tensile, Compressive, Bearing, and Shear Properties of Sheet Steels at Elevated Temperatures," WADC Technical Report 58-365, Nov 1958. As published in *Aerospace Structural Metals Handbook,* Vol 1, Code 1210, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 8



HS.043 300M ultrahigh-strength steel bar, tensile stress-strain curves at room and low temperatures

Bar thickness = 25.4 mm (1 in.). Heat treatment: 871 °C (1600 °F), 4 h, oil quenched, 316 °C (600 °F), 4 + 4 h. Composition: Fe-0.4C-1.8Ni-1.6Si-0.8Cr-0.4Mo-V

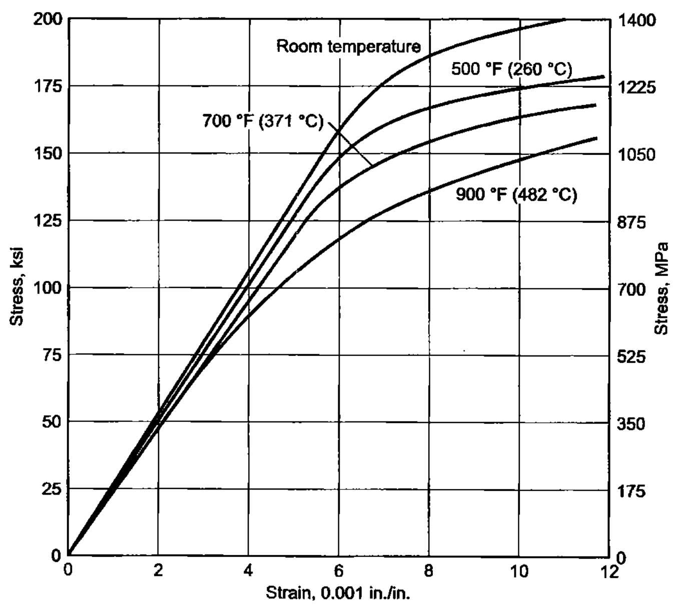
Source: S.L. Pendleberry, R.F. Simeng, and E.K. Walker, "Fracture Toughness and Crack Propagation of 300M Steel," Technical Report DS-68-18, Contract FA67-WA-1812, Lockheed-California Co., Aug 1968. As published in *Aerospace Structural Metals Handbook,* Vol 1, Code 1217, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 25



HS.044 9Ni-4Co-0.20C ultrahigh-strength steel plate, stress-strain curves with effect of tempering temperatures

Plate thickness = 25.4 mm (1 in.). Consumable electrode vacuum process, carbon deoxidation (CEVM (C-deox)). Heat treatment: 913 °C (1675 °F), 1 h, air cooled, 843 °C (1550 °F), 1 h, oil quenched + tempered, 2 h, air cooled. Tempered at: curve A, 538 and 566 °C (1000 and 1050 °F); curve B, 482 °C (900 °F). Composition: Fe-0.20C-9Ni-4Co-Cr-Mo-V

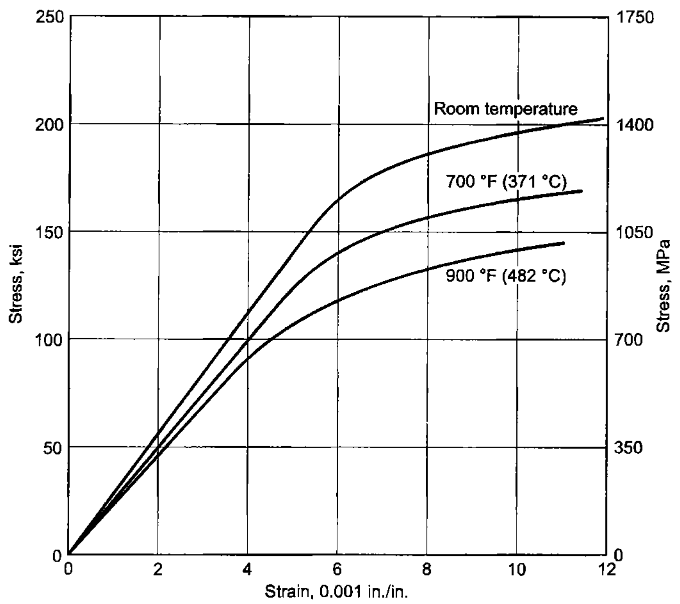
Source: A.H. Rosenstein, M.R. Gross, W.G. Schreitz, and G.A. Wacker, "Metallurgical Investigation of 9Ni-4Co-.2C Steel," Report 2678, Naval Research and Development, July 1968. As published in *Aerospace Structural Metals Handbook,* Vol 1, Code 1221, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 47



HS.045 9Ni-4Co-0.20C ultrahigh-strength forged steel bar, compressive stress-strain curves at room and elevated temperatures

Test direction: transverse. Bar size = 57.15 × 152.4 × 213.36 mm (2.25 × 6 × 84 in.). Heat treatment: 899 ° C (1650 °F), 1 h, air cooled, 816 °C (1500 °F), 1 h, oil quenched, tempered 552 °C (1025 °F), 6 h, air cooled. Composition: Fe-0.20C-9Ni-4Co-Cr-Mo-V

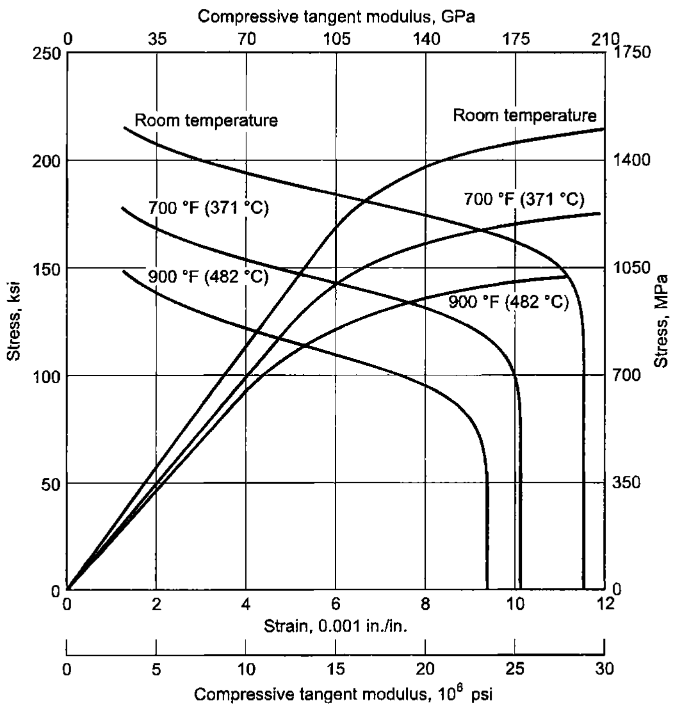
Source: O.L. Deel and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," AFML-TR-72-196, Vol II, Sept 1972. As published in *Aerospace Structural Metals Handbook,* Vol 1, Code 1221, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 65



HS.046 9Ni-4Co-0.20C ultrahigh-strength steel plate, typical tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal and long transverse. Plate thickness = 25.4–101.6 mm (1.000–4.000 in.). RT, room temperature. Exposure at temperature = 0.5 h. Ramberg-Osgood parameters: n(RT) = 14, n(700 °F) = 13, n(900 °F) = 7.7. Composition: Fe-9Ni-4Co-0.20C

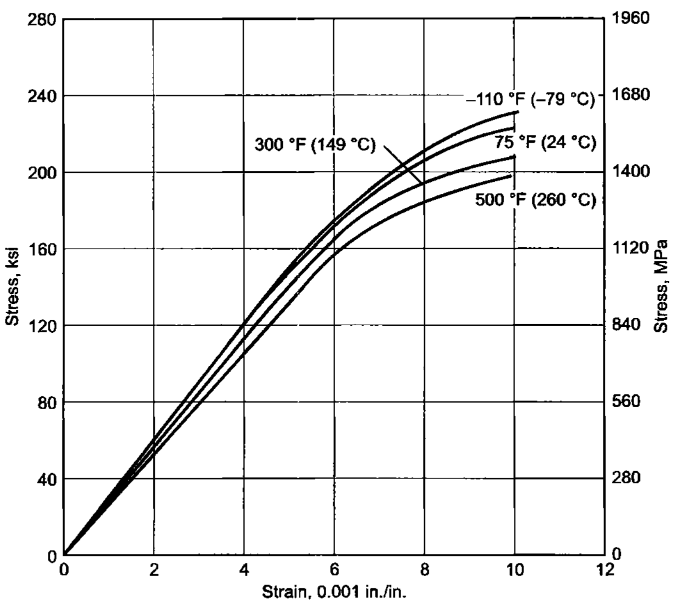
Source: *MIL-HDBK-5H,* Dec 1998, p 2-79



HS.047 9Ni-4Co-0.20C ultrahigh-strength steel plate, typical compressive stress-strain curves at room and elevated temperatures

Test direction: longitudinal and long transverse. Plate thickness = 25.4–101.6 mm (1.000–4.000 in.). RT, room temperature. Exposure at temperature = 0.5 h. Ramberg-Osgood parameters: n(RT) = 15, n(700 °F) = 12, n(900 °F) = 9.0. Composition: Fe-9Ni-4Co-0.20C

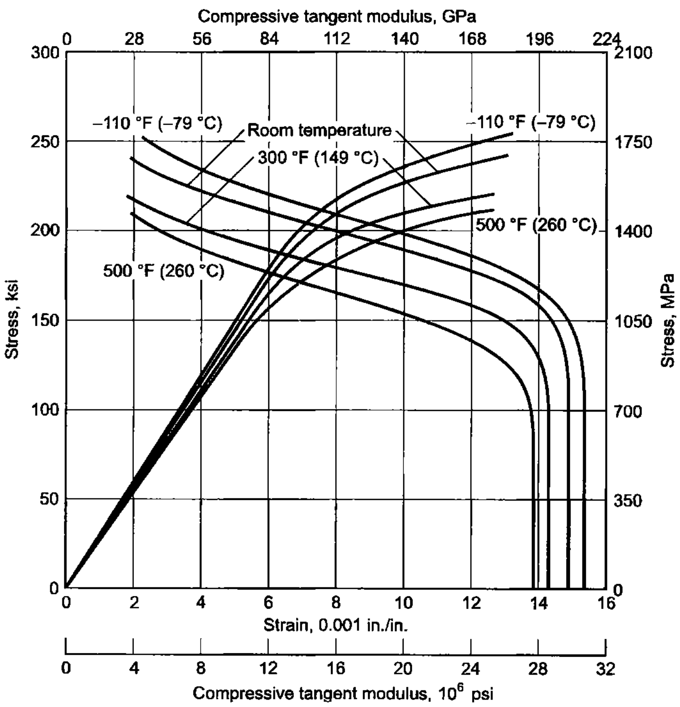
Source: *MIL-HDBK-5H,* Dec 1998, p 2-79



HS.048 9Ni-4Co-0.30C ultrahigh-strength forged steel billet, typical compressive stress-strain curves at various temperatures

Test direction: longitudinal, long transverse, and short transverse. Billet size = 76.2 × 228.6 × 609.6 mm (3 × 9 × 24 in.). Consumable electrode vacuum process, carbon deoxidation (CEVM (C-deox)). Heat treatment: 871–927 °C (1600–1700 °F), 1 h, air cooled, 621 ± 14 °C (1150 ± 25 °F), × h min, 843 ± 14 °C (1550 ± 25 °F), 1 h, oil quenched, −73 °C (−100 °F), 2 h, 510 ± 14 °C (950 ± 25 °F), 2 + 2 h, air cooled. Curves based on average of 3 heats.

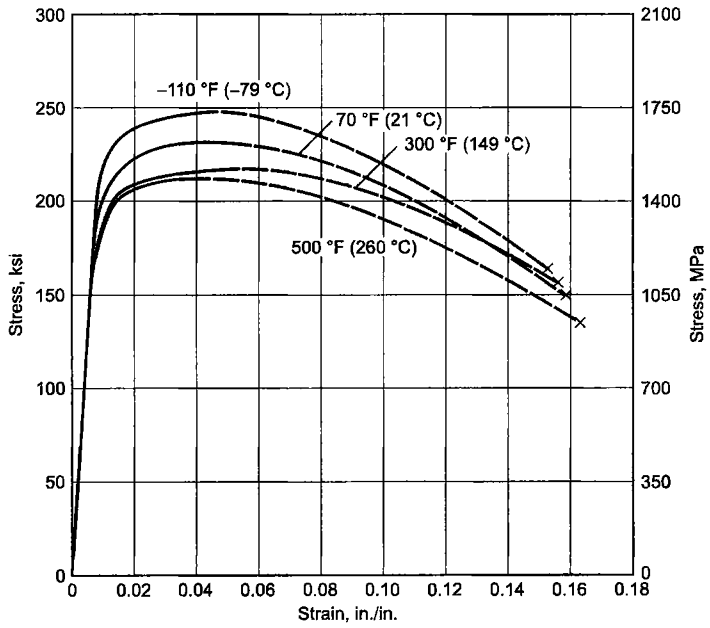
Source: D.F. Bulloch, T.W. Eichenberger, and J.L. Guthrie, "Evaluation of the Mechanical Properties of 9Ni-4Co Steel Forgings," AFML Contract AF 33615-67-C-1724, AFML TR 68-57, The Boeing Co., March 1968. As published in *Aerospace Structural Metals Handbook,* Vol 1, Code 1221, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 65



HS.049 9Ni-4Co-0.30C ultrahigh-strength steel hand forging, typical compressive stress-strain and compressive tangent modulus curves at various temperatures

Forging thickness = 76.2 mm (3.000 in.). For all directions. Exposure at temperature = 0.5 h. RT, room temperature. Ramberg-Osgood parameters: n(−110 °F) = 11, n(RT) = 12, n(300 °F) = 12, n(500 °F)= 10. Composition: Fe-9Ni-4Co-0.30C

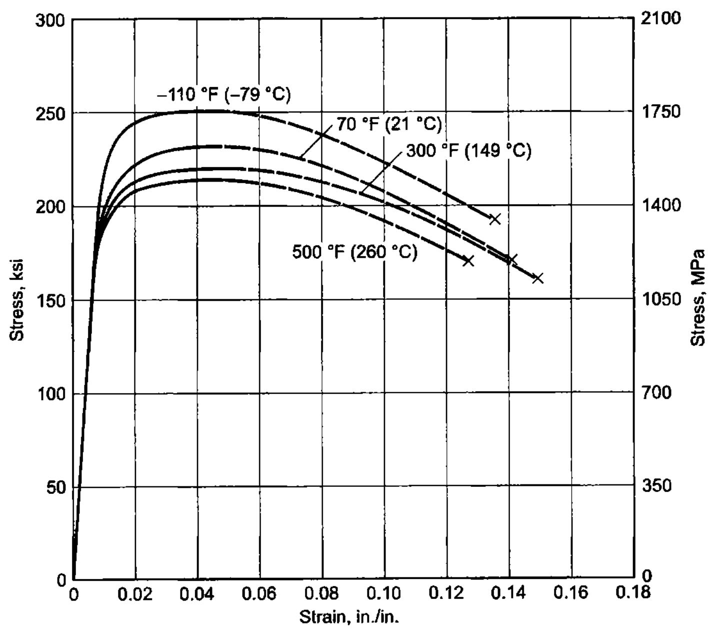
Source: *MIL-HDBK-5H,* Dec 1998, p 2-87



HS.050 9Ni-4Co-0.30C ultrahigh-strength steel hand forging, typical tensile stress-strain curves (full range) at various temperatures

Test direction: longitudinal. Forging thickness = 76.2 mm (3.000 in.). Exposure at temperature = 0.5 h. Composition: Fe-9Ni-4Co-0.30C

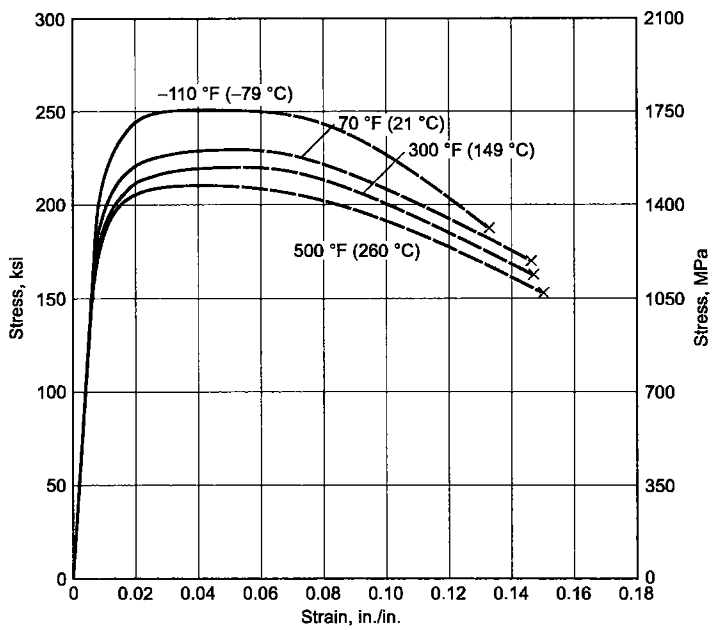
Source: *MIL-HDBK-5H,* Dec 1998, p 2-88



HS.051 9Ni-4Co-0.30C ultrahigh-strength steel hand forging, typical tensile stress-strain curves (full range) at various temperatures

Test direction: long transverse. Forging thickness = 76.2 mm (3.000 in.). Exposure at temperature = 0.5 h. Composition: Fe-9Ni-4Co-0.30C

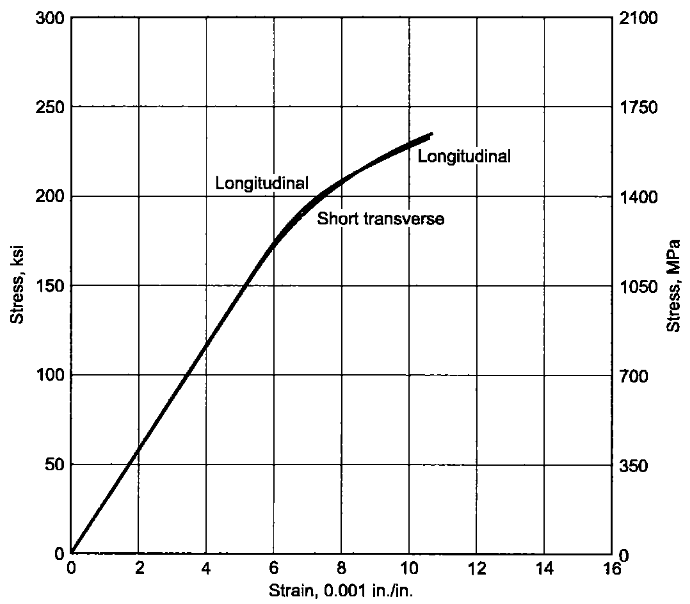
Source: *MIL-HDBK-5H,* Dec 1998, p 2-89



HS.052 9Ni-4Co-0.30C ultrahigh-strength steel hand forging, typical tensile stress-strain curves (full range) at various temperatures

Test direction: short transverse. Exposure at temperature = 0.5 h. Composition: Fe-9Ni-4Co-0.30C

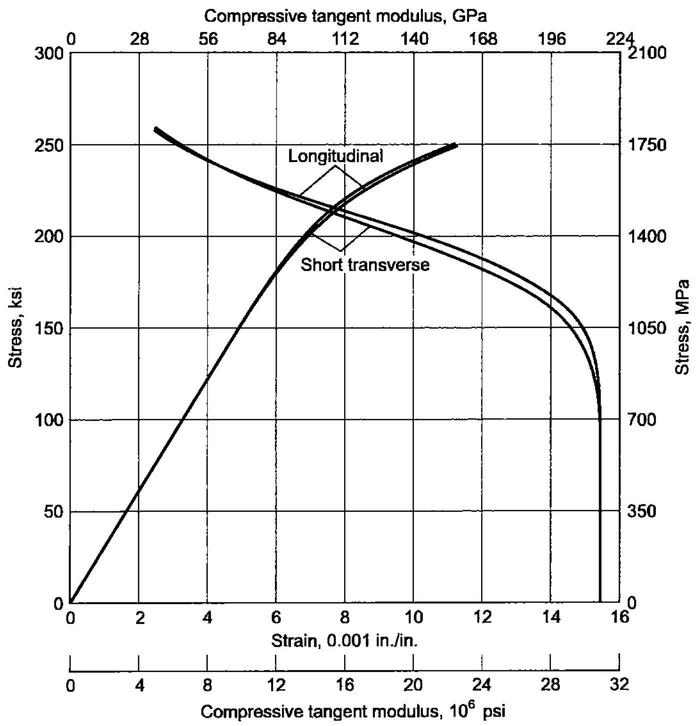
Source: *MIL-HDBK-5H*, Dec 1998, p 2-90



HS.053 AF1410 ultrahigh-strength steel bar, typical tensile stress-strain curves at room temperature

Bar thickness = ≤107.95 mm (≤4.250 in.). Ramberg-Osgood parameters: n(longitudinal) = 11, n(short transverse) = 9.1. UNS K92571

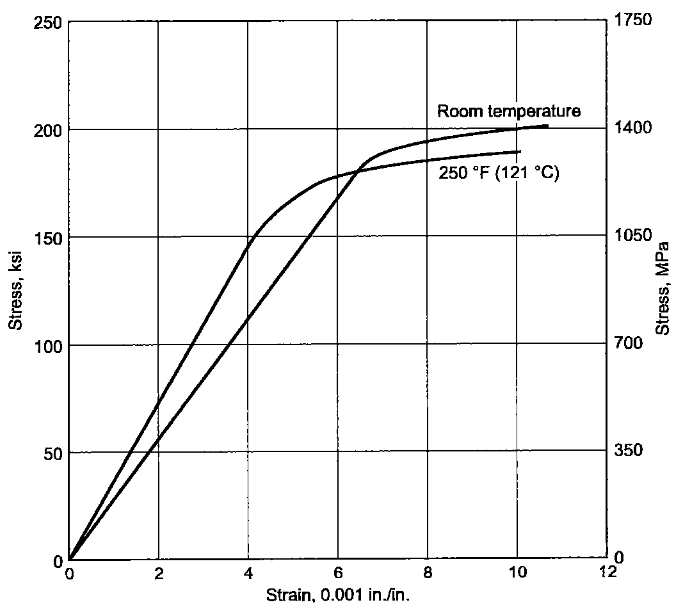
Source: *MIL-HDBK-5H*, Dec 1998, p 2-107



HS.054 AF1410 ultrahigh-strength steel bar, typical compressive stress-strain and compressive tangent modulus curves at room temperature

Bar thickness = ≤107.95 mm (≤4.250 in.). Ramberg-Osgood parameters: *n*(longitudinal) = 9.0, *n*(short transverse) = 10. UNS K92571

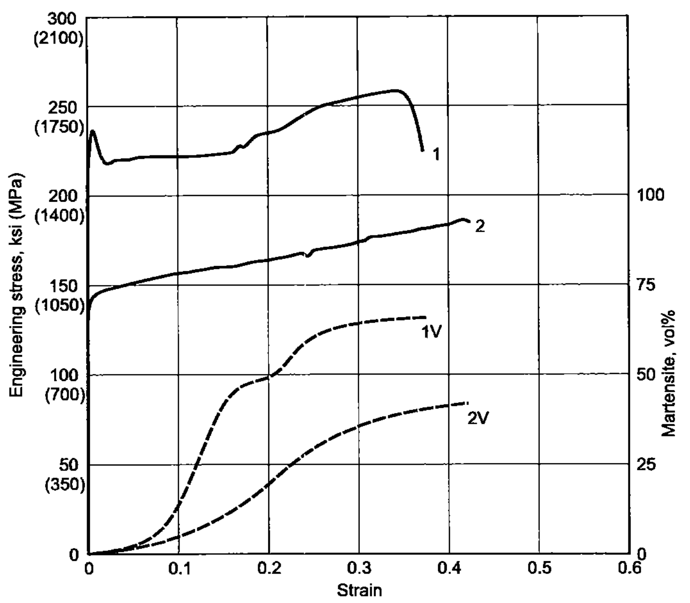
Source: *MIL-HDBK-5H*, Dec 1998, p 2-107



HS.055 D6A, D6AC ultrahigh-strength steel plate, typical stress-strain curves at room and elevated temperature

D6A, air melted; D6AC, consumable electrode vacuum melted (CVM). Heat treatment: 899 °C (1650 °F), 1 h, solution quenched, 204 °C (400 °F), 10 min, air cooled, 604 °C (1120 °F), 4 h, air cooled. Composition: Fe-0.46C-1.0Cr-1.0Mo-0.55Ni. UNS K24728

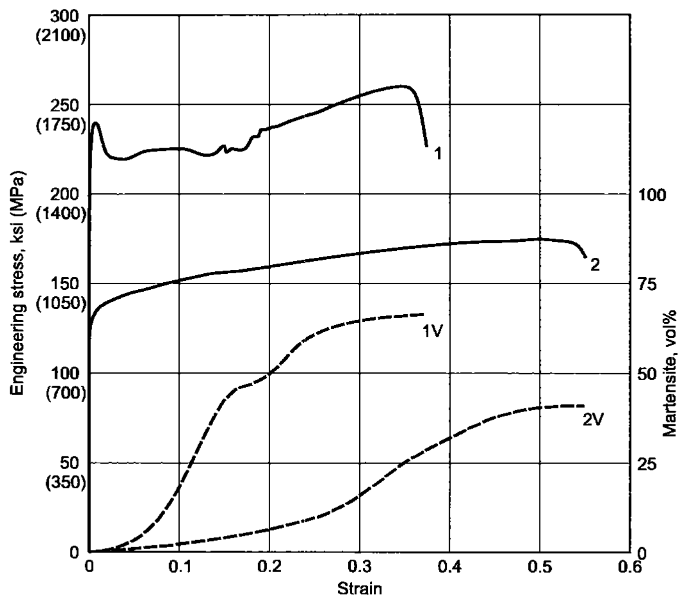
Source: Private Communication, G.R. Sipple, General Motors Allison Division with W.F. Brown, Jr., 1965. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1213, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 34



HS.056 Transformation-induced plasticity (TRIP) high-strength steel plate, engineering stress-strain curves at 25 °C of alloy deformed at 450 °C and martensite volume versus strain

Test direction: longitudinal. Curve 1: hot forged to 9.525 mm (0.375 in.). Plate then austenitized at 1200 °C, 3 h, in 4% H atmosphere, brine quenched, and flat rolled 80% to 1.905 mm (0.075 in.) at 450 °C. Curve 2: hot forged to 2.54 mm (0.10 in.) with similar treatment and reduced to 1.905 mm (0.075 in.) (20%) at 450 °C. Test specimen size = 3.175 × 1.905 × 25.4 mm (0.125 × 0.075 × 1 in.) gage length. Curve 1V and 2V: vol% martensite versus strain curve for these alloys. Composition: Fe-9Cr-8Ni-3Mn-3Si-4Mo-0.25C

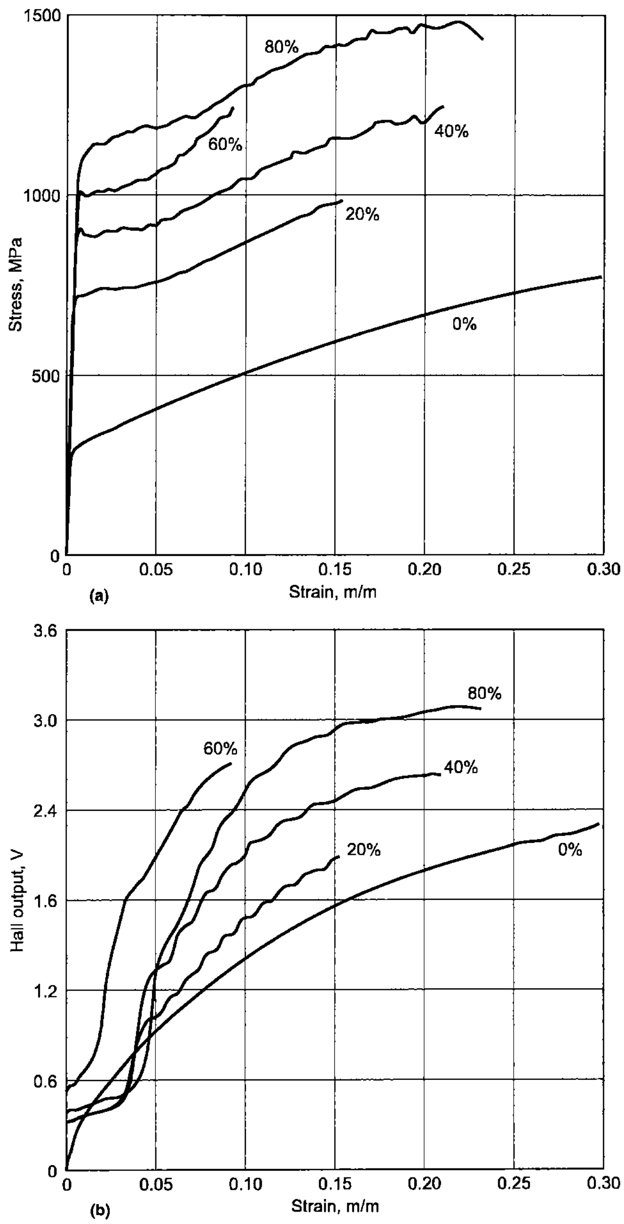
Source: G.R. Chanani, S.D. Antolovich, and W.W. Gerberich, Fatigue Crack Propagation in Trip Steels, *Metall. Trans.*, Vol 3, Oct 1972, p 2664



HS.057 Transformation-induced plasticity (TRIP) high-strength steel plate, engineering stress-strain curves at 25 °C of alloy deformed at 250 °C and martensite volume versus strain

Test direction: longitudinal. Curve 1: hot forged to 9.525 mm (0.375 in.). Plate then austenitized at 1200 °C, 3 h, in 4% H atmosphere, brine quenched, and flat rolled 80% to 1.905 mm (0.075 in.) at 250 °C. Curve 2: hot forged to 2.54 mm (0.10 in.) with similar treatment and reduced to 1.905 mm (0.075 in.) (20%) at 250 °C. Test specimen size = 3.175 × 1.905 × 25.4 mm (0.125 × 0.075 × 1 in.) gage length. Curve 1V and 2V: vol% martensite versus strain curve for these alloys. Composition: Fe-9Cr-8Ni-3Mn-3Si-4Mo-0.25C

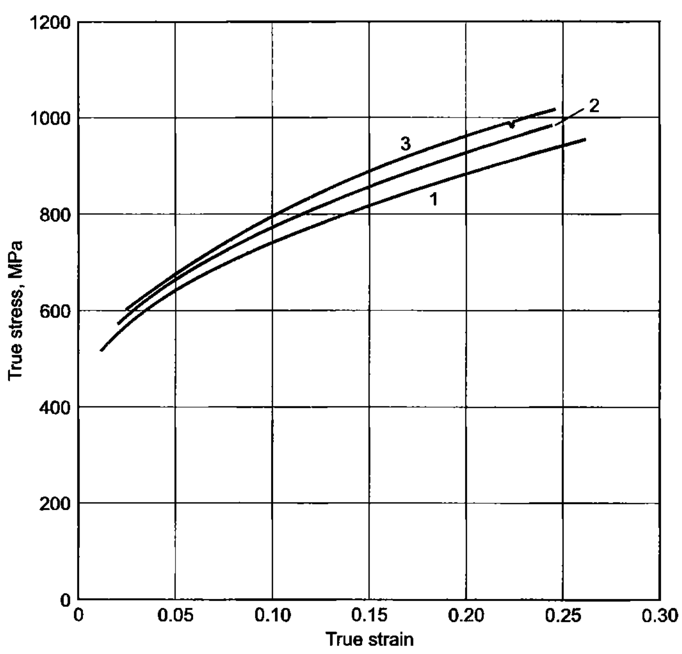
Source: G.R. Chanani, S.D. Antolovich, and W.W. Gerberich, Fatigue Crack Propagation in Trip Steels, *Metall. Trans.*, Vol 3, Oct 1972, p 2664



HS.058 Fe-8.4Cr-8.4Ni transformation-induced plasticity (TRIP) high-strength steel strip, stress-strain and Hall voltage output-strain curves

TRIP steels can be used as strain sensors. (a) Room-temperature stress-strain curves for specimens as wrought (0%), 20, 40, 60, and 80% reduction at 450 °C warm rolling. The magnetic properties of the material change irreversibly as austenite to martensite transformation occurs. (b) As the magnetic susceptibility changes dramatically, an accurate history of the peak strain can be derived from the Hall effect voltages shown on lower curves. Composition: Fe-8.4Cr-8.4Ni-2.1Mn-0.26C

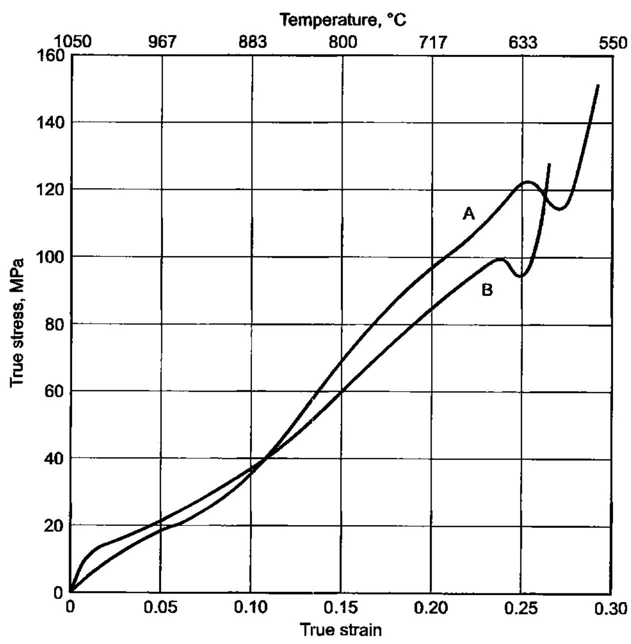
Source: J.S. Dunning, Characterization of TRIP Steels as Strain Monitor Materials, *Microstructural Science*, Vol 25, Proc. 30th Annual Technical Meeting of the International Metallographic Society, IMS & ASM International, July 1997, p 417



HS.059 Transformation-induced plasticity (TRIP) high-strength steel strip, true stress-strain curves with effect of niobium content

Strip thickness = 2 mm. After 60% rolling reduction, tests were conducted with 0.8 mm sheet. Material was annealed, 780 °C, 180 s, transformed, 400 °C, 400 s. Niobium adds about 15 MPa strength/0.01% without significantly changing the shape of curve. Curve 1, 0% Nb; curve 2, 0.02% Nb; curve 3, 0.04% Nb. Composition: Fe-0.17C-1.4Mn-1.5Si + Nb as shown

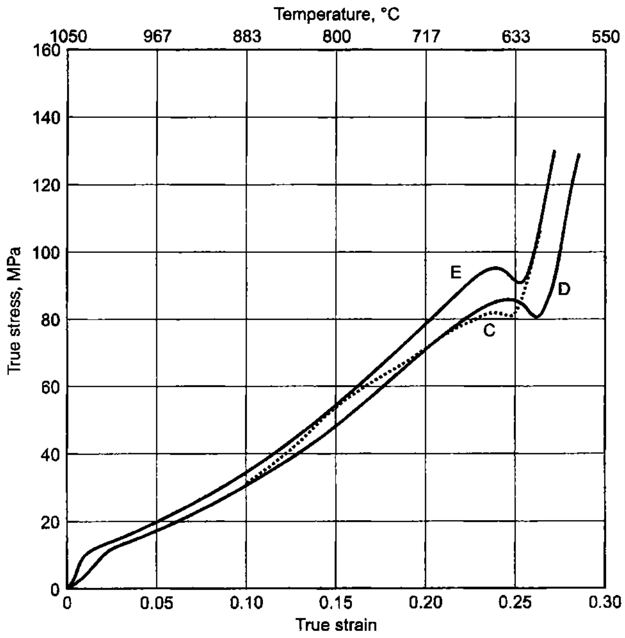
Source: K. Hulka, W. Bleck, and K. Papamantellos, Relationship between Heat Treatment Conditions, Microstructure, and Properties of Niobium Microalloyed TRIP Steel, *41st Mechanical Working and Steel Processing Conf. Proc.*, Vol 37, Iron & Steel Society, 1999, p 75



HS.060 Transformation-induced plasticity (TRIP) high-strength steel, continuous-cooling compression true stress-strain curves

This type of test examines transformation behavior. Note portion of curve with negative slope indicating material has softened. Other less dramatic slope changes exist and indicate other transformations. Cooling rate = 0.5 °C/s. Strain rate = 0.0003/s. Composition: steel A, Fe-0.22C-1.55Mn-1.55Si-0.035Nb-0.028Al (N, 20–40 ppm); steel B, Fe-0.19C-1.54Mn-1.50Si-0.024Al (N, 20–40 ppm)

Source: A.Z. Hanzaki, R. Pandi, P.D. Hadgson, and S. Yue, Continuous Cooling Deformation Testing of Steels, *Metall. Trans. A*, Vol 24A, Dec 1993, p 2661

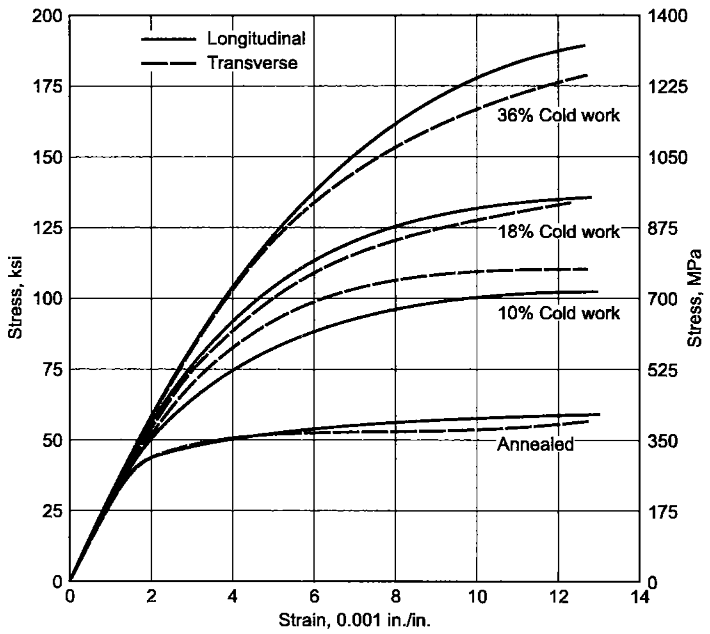


HS.061 Transformation-induced plasticity (TRIP) high-strength steel, continuous-cooling compression true stress-strain curves

This type of test examines transformation behavior. Note portion of curve with negative slope indicating material has softened. Other less dramatic slope changes exist and indicate other transformations. Cooling rate = 0.5 °C/s. Strain rate = 0.0003/s. Composition: steel C, Fe-0.145C-1.50Mn-1.55Si-0.027Al (N, 20–40 ppm); steel D, Fe-0.18C-1.50Mn-0.93Si-0.024Al (N, 20–40 ppm); steel E, Fe-0.21C-1.50Mn-1.10Si-0.027Al (N, 20–40 ppm)

Source: A.Z. Hanzaki, R. Pandi, P.D. Hadgson, and S. Yue, Continuous Cooling Deformation Testing of Steels, *Metall. Trans. A*, Vol 24A, Dec 1993, p 2661

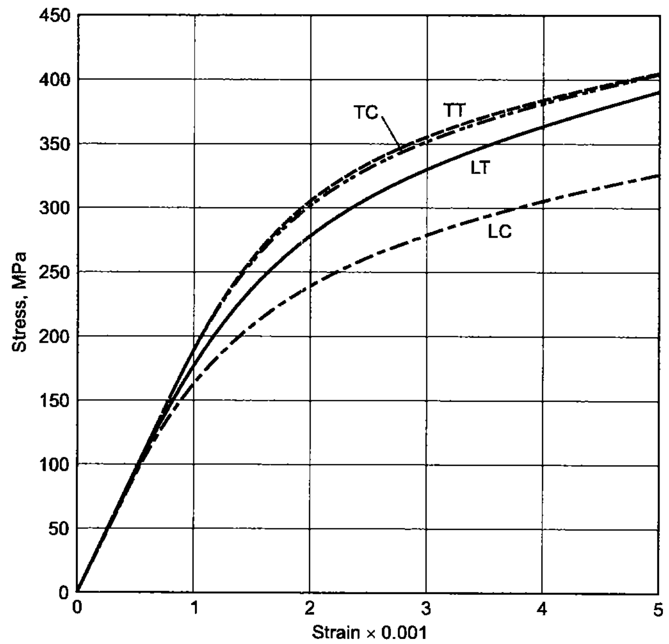
Stainless Steel (SS)



SS.001 201 stainless steel, stress-strain curves showing effect of cold work

Test direction: longitudinal and transverse. Composition: Fe-17Cr-6.5Mn-4.5Ni. UNS S20100

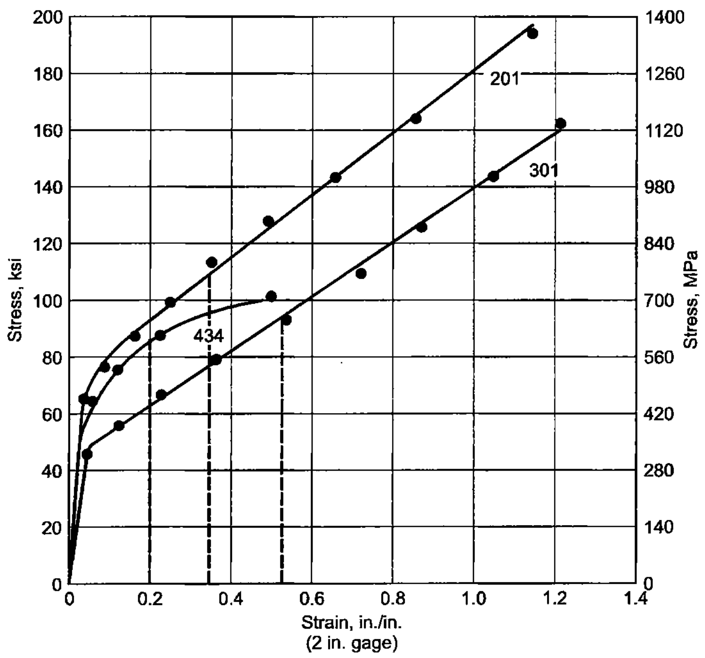
Source: P.D. Harvey, *Engineering Properties of Steel,* American Society for Metals, 1982



SS.002 201 stainless steel sheet, tensile and compressive stress-strain curves

Six tests were made in each orientation on cold-rolled specimens. Curves: LT, longitudinal tensile; LC, longitudinal compressive; TT, transverse tensile; TC: transverse compressive. Elastic modulus: LT, 195.7 GPa; TT, 196.7 GPa; LC, 189.7 GPa; TC, 197.0 GPa. Yield strength (0.2%): LT, 359.6 MPa; TT, 383.1 MPa; LC, 295.8 MPa; TC, 380.2 MPa. Ultimate tensile strength: LT, 745 MPa; TT, 730 MPa. Composition: Fe-17Cr-6.5Mn-4.5Ni. UNS S20100

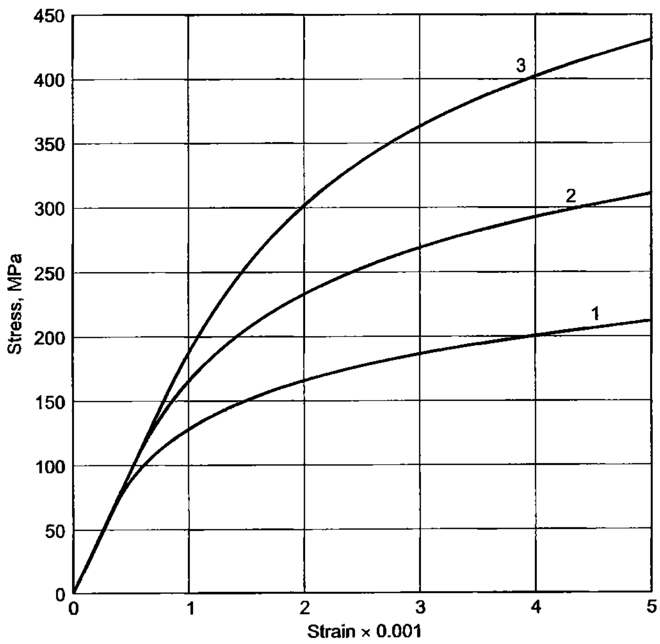
Source: P. Van Der Merwe and G.J Van Den Berg, The Advantages of Using Cr-Mn Steels Instead of Cr-Ni Steels in Cold-Formed Design, *High Manganese High Nitrogen Austenitic Steels,* R.A. Lula, Ed., Conf. Proc., 10–15 Oct 1987 (Cincinnati, OH) and 2–4 Nov 1992 (Chicago, IL), ASM International, 1992, p 129



SS.003 201, 301, 434 stainless steel sheet, stress-strain curves used in case study

Comparison of true stress-strain for coiled strips of ferritic (434) and austenitic (201, 301) alloys. Higher work-hardening rates of austenitic grades indicate improved deep-drawing capability. Localized reduction, necking, is retarded. Vertical dashed lines are the points of maximum uniform strain, above which the localized deformation takes place. The load corresponding to this point is the maximum load.

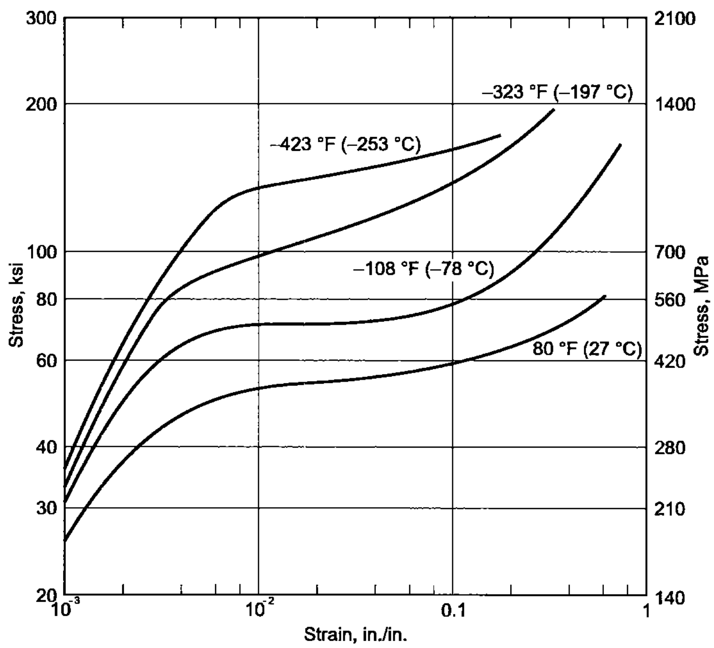
Source: E.R. Cunningham, Cold Forming Stainless Steels and Other Specialty Grades, *Source Book on Cold Forming,* American Society for Metals, 1975, p 126



SS.004 201-1, 201-2, 301, 304 stainless steel sheet, compressive stress-strain curves for various annealed alloys

Test direction: longitudinal. Curve 1, types 201-1, 301, 304. Curve 2, type 201-2. Curve 3, type 205. Initial elastic modulus = 193 GPa, all curves. Longitudinal compressive yield strength: type 201-1, 185 MPa; type 201-2, 280 MPa; type 205, 405 MPa; type 301, 185 MPa; type 304, 185 MPa

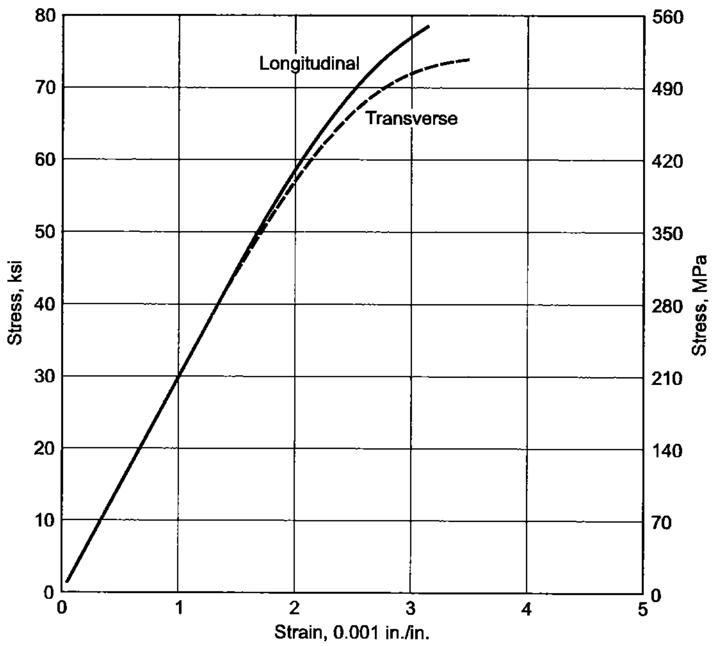
Source: P. Van Der Merwe and G.J Van Den Berg, The Advantages of Using Cr-Mn Steels Instead of Cr-Ni Steels in Cold-Formed Design, *High Manganese High Nitrogen Austenitic Steels,* R.A. Lula, Ed., Conf. Proc., 10–15 Oct 1987 (Cincinnati, OH) and 2–4 Nov 1992 (Chicago, IL), ASM International, 1992, p 130



SS.005 202 (UNS S20200) annealed stainless steel bar, stress-strain curves at room and low temperatures

Bar diameter = 6.426 mm (0.253 in.). Composition: Fe-18Cr-8.75Mn-5Ni. UNS S20200

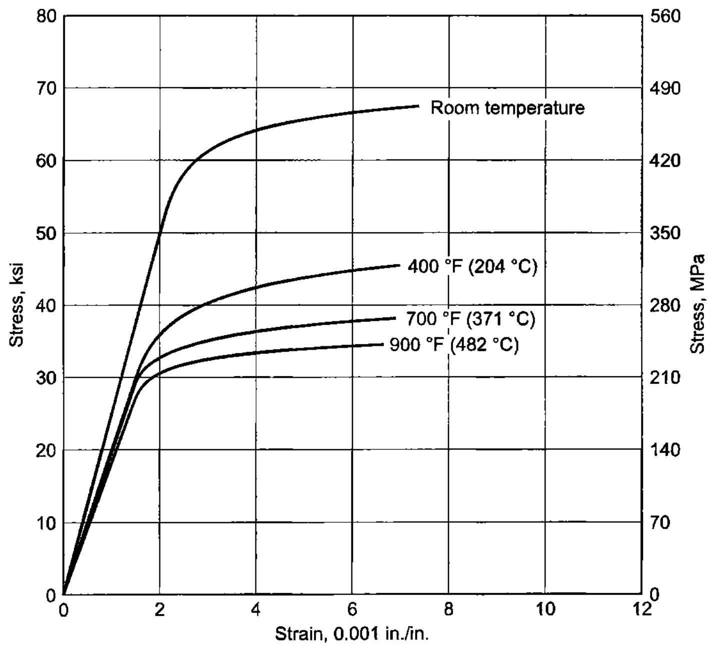
Source: C.J. Gunter and R.P. Reed, "Mechanical Properties of Four Austenitic Stainless Steels at Temperatures between 300 and 20 K," National Bureau of Standards, Cryogenic Engineering Laboratory, 1960. As published in *Structural Alloys Handbook*, Vol 2, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1994, p 51



SS.006 21-6-9 annealed stainless steel, stress-strain curves

Test direction: longitudinal and transverse. Composition: Fe-low C-20.25Cr-9Mn-6.5Ni-0.28N. UNS S21900

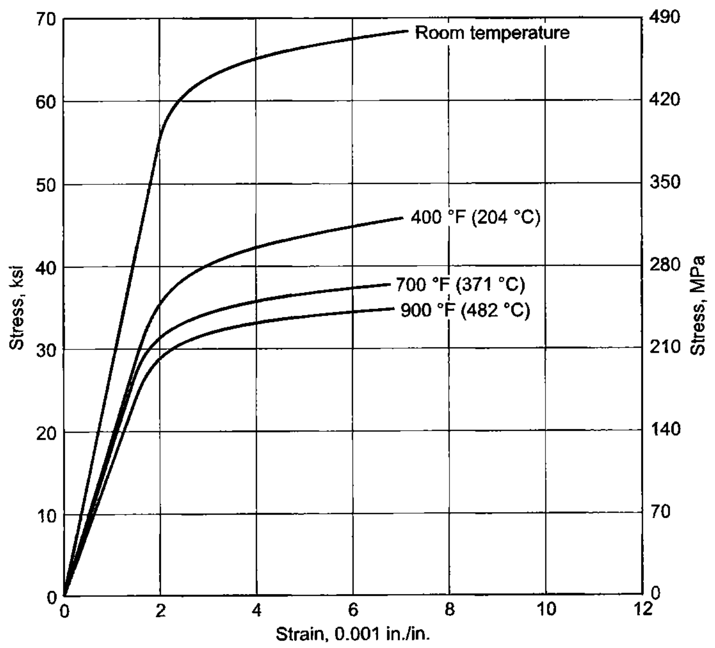
Source: "Armco 21-6-9 Stainless Steel," Product Data Brochure S-26c, Armco Steel Corp., Baltimore, MD, April 1969. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1314, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 18



SS.007 21-6-9 annealed stainless steel sheet, stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Composition: Fe-20.25Cr-9Mn-6.5Ni-0.28N. UNS S21900

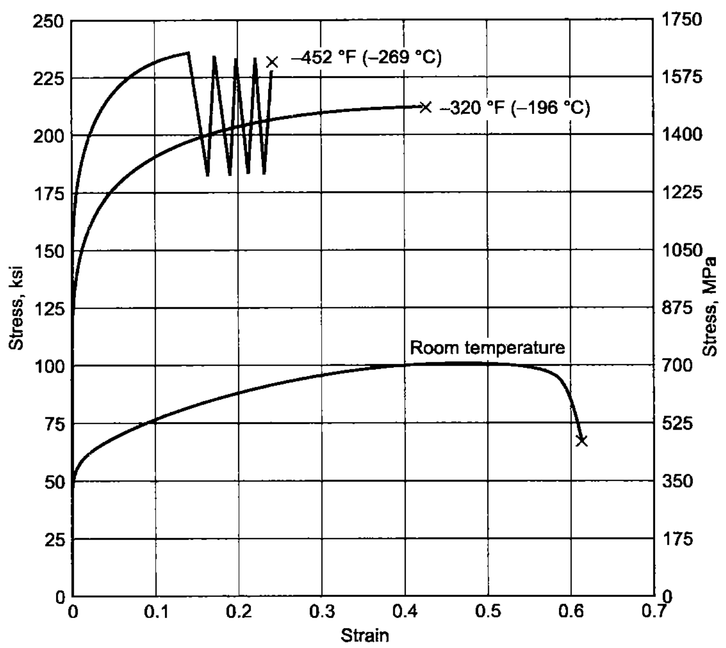
Source: O. Deel, P. Ruff, and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," AFML TR-73-114, AD:762305, Battelle Columbus Laboratories, Columbus, OH, June 1973. As published in *Structural Alloys Handbook,* Vol 2, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1994, p 49



SS.008 21-6-9 annealed stainless steel sheet, stress-strain curves at room and elevated temperatures

Test direction: transverse. Composition: Fe-20.25Cr-9Mn-6.5Ni-0.28N. UNS S21900

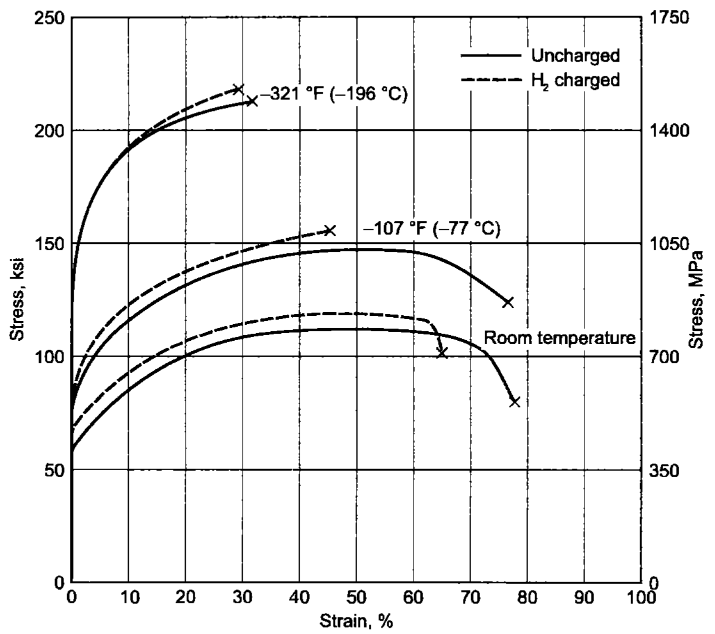
Source: O. Deel, P. Ruff, and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," AFML TR-73-114, AD:762305, Battelle Columbus Laboratories, Columbus, OH, June 1973. As published in *Structural Alloys Handbook,* Vol 2, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1994, p 50



SS.009 21-6-9 stainless steel, stress-strain curves at room and low temperatures

Composition: Fe-20.25Cr-9Mn-6.5Ni-0.28N. UNS S21900

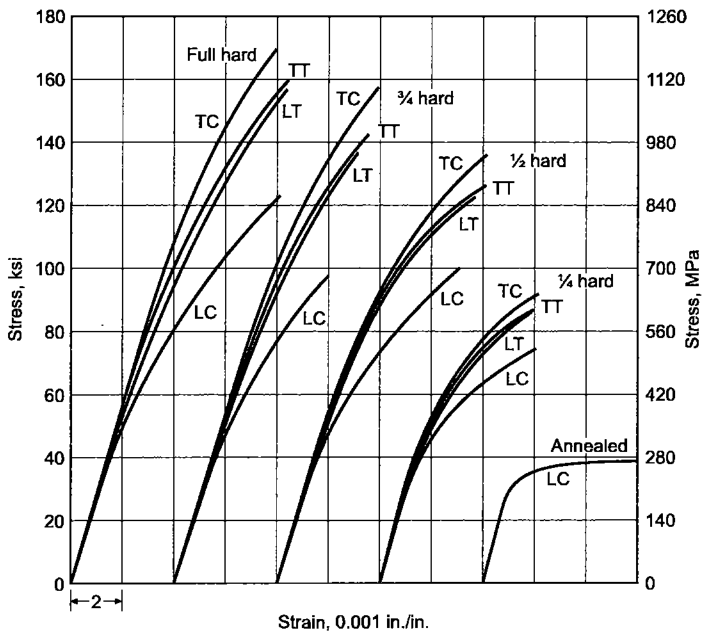
Source: M.B. Kasen, R.E. Schramm, and D.T. Read, "Semi-Annual Report of Materials Research in Support of Super Conducting Machinery," ARPA Order-2569, AD-B063554, National Bureau of Standards, Cryogenics Division, Boulder, CO, Oct 1976. As published in *Structural Alloys Handbook,* Vol 2, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1994, p 50



SS.010 21-6-9 stainless steel plate, stress-strain behavior of uncharged and hydrogen-charged alloys at room and low temperatures

Specimens annealed 1050 °C (1922 °F), 2 h. Hydrogen charged 573 °C (1063 °F), 14 days, 69 MPa (10 ksi) H_2. Strain rate = 0.00045/s. Composition: Fe-low C-20.25Cr-9Mn-6.5Ni-0.28N. UNS S21904

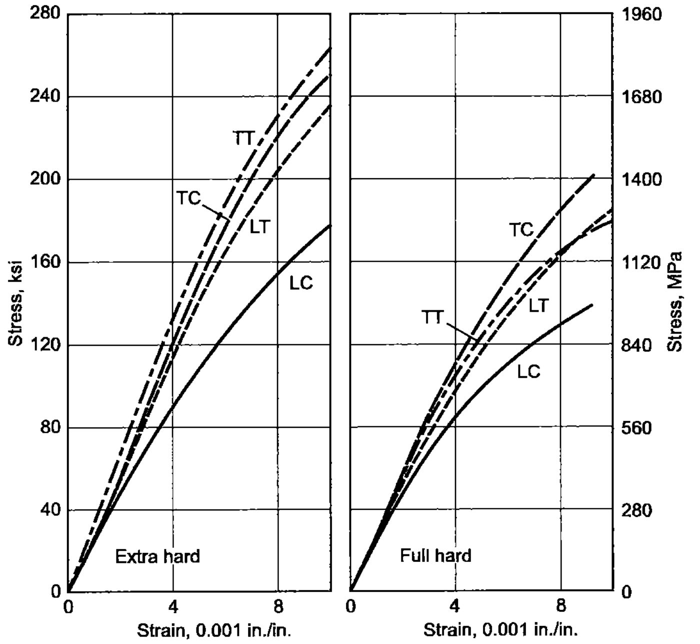
Source: J.H. Holbrook and A.J. West, The Effect of Temperature and Strain Rate on the Tensile Properties of Hydrogen-Charged 304L, 21-6-9, and JBK 75, *Proc. Hydrogen Effects in Metals,* 26–31 Aug 1980 (Moran, WY), TMS/AIME, 1981, p 655–663. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1314, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 22



SS.011 301 stainless steel sheet and strip, stress-strain curves at different tempers

Test direction: longitudinal and transverse. Curves: LT, longitudinal tensile; LC, longitudinal compressive; TT, transverse tensile; TC: transverse compressive. Composition: Fe-18Cr-8Ni. UNS S30100

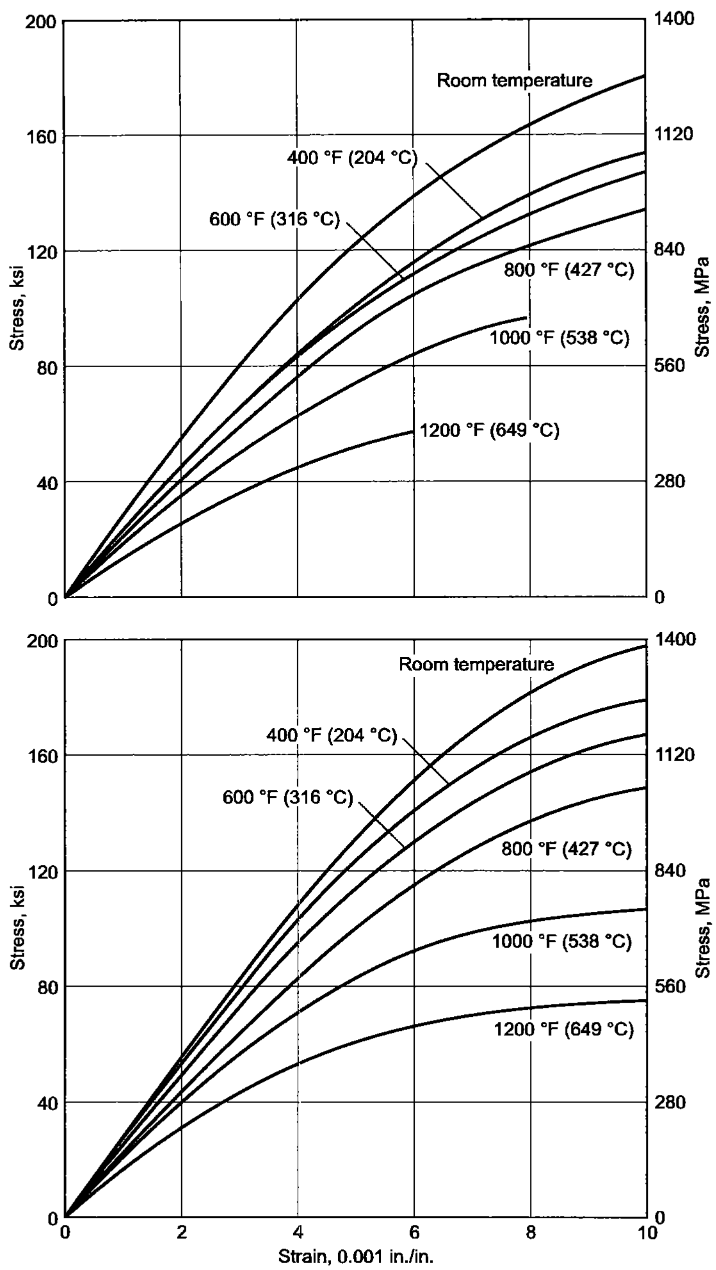
Source: M. Watter and R.A. Lincoln, "Strength of Stainless Steel Structural Members as Function of Design," Allegheny Ludlum Steel Corp., 1950. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1301, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 22



SS.012 301 stainless steel sheet, stress-strain curves at different tempers

Test direction: longitudinal and transverse. Sheet and strip cold rolled to full hard and extra-hard tempers. Curves: LT, longitudinal tensile; LC, longitudinal compressive; TT, transverse tensile; TC: transverse compressive. Composition: Fe-18Cr-8Ni. UNS S30100

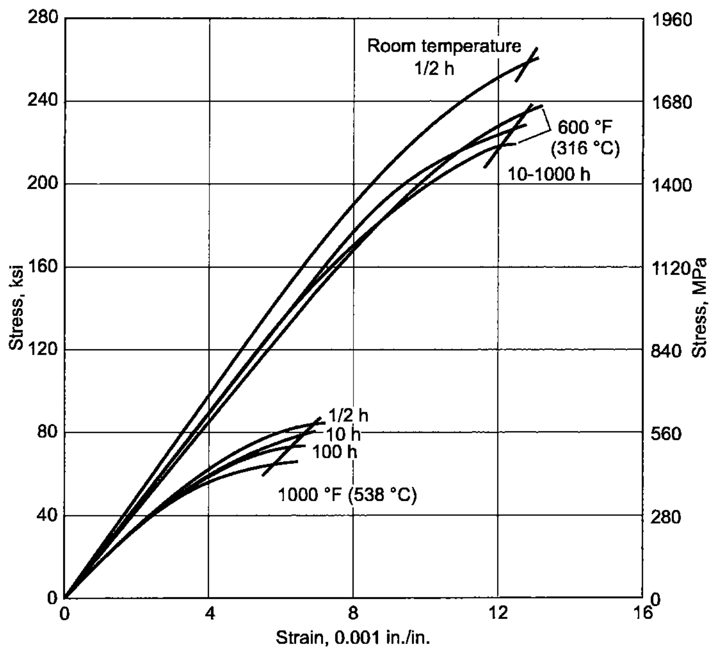
Source: "High Strength Cold Rolled Stainless Steels," Data Sheet, Allegheny Ludlum Steel Corp., 1958. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1301, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 22



SS.013 301 stainless steel sheet, tensile stress-strain curves at various temperatures

Average of longitudinal and transverse. Top: 0.508 mm (0.020 in.) sheet full hard, 40% reduction. Bottom: 0.813 mm (0.032 in.) sheet full hard, stress relief 427 °C (800 °F), 8 h. Composition: Fe-18Cr-8Ni. UNS S30100

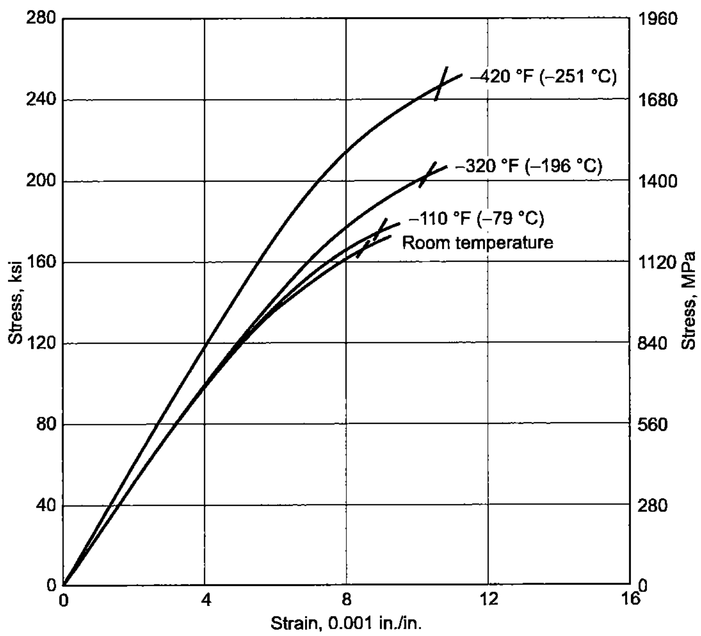
Source: "High Strength Cold Rolled Stainless Steels," Data Sheet, Allegheny Ludlum Steel Corp., 1958. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1301, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 30



SS.014 301 stainless steel sheet, tensile stress-strain curves at various temperatures and exposure times

60% cold-reduced sheet, 1.27 mm (0.050 in.) thick. Composition: Fe-18Cr-8Ni. UNS S30100

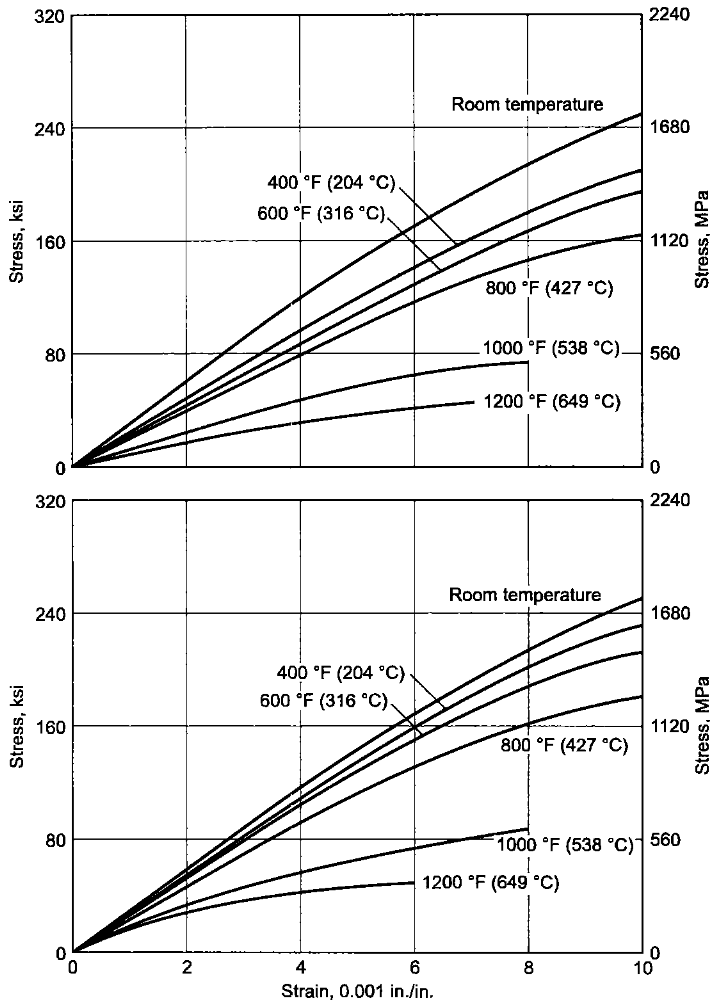
Source: M.M. Lemcoe and A. Trevim, Jr., "Determination of the Effects of Elevated Temperature Materials Properties of Several High Temperature Alloys," ASD-TDR-61-529, June 1962. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1301, CINDAS/ USAF CRDA Handbooks Operation, Purdue University, 1995, p 30



SS.015 301 stainless steel sheet, tensile stress-strain curves at room and low temperatures

Extra hard cold-rolled sheet, 1.524 mm (0.060 in.) thick. Composition: Fe-18Cr-8Ni. UNS S30100

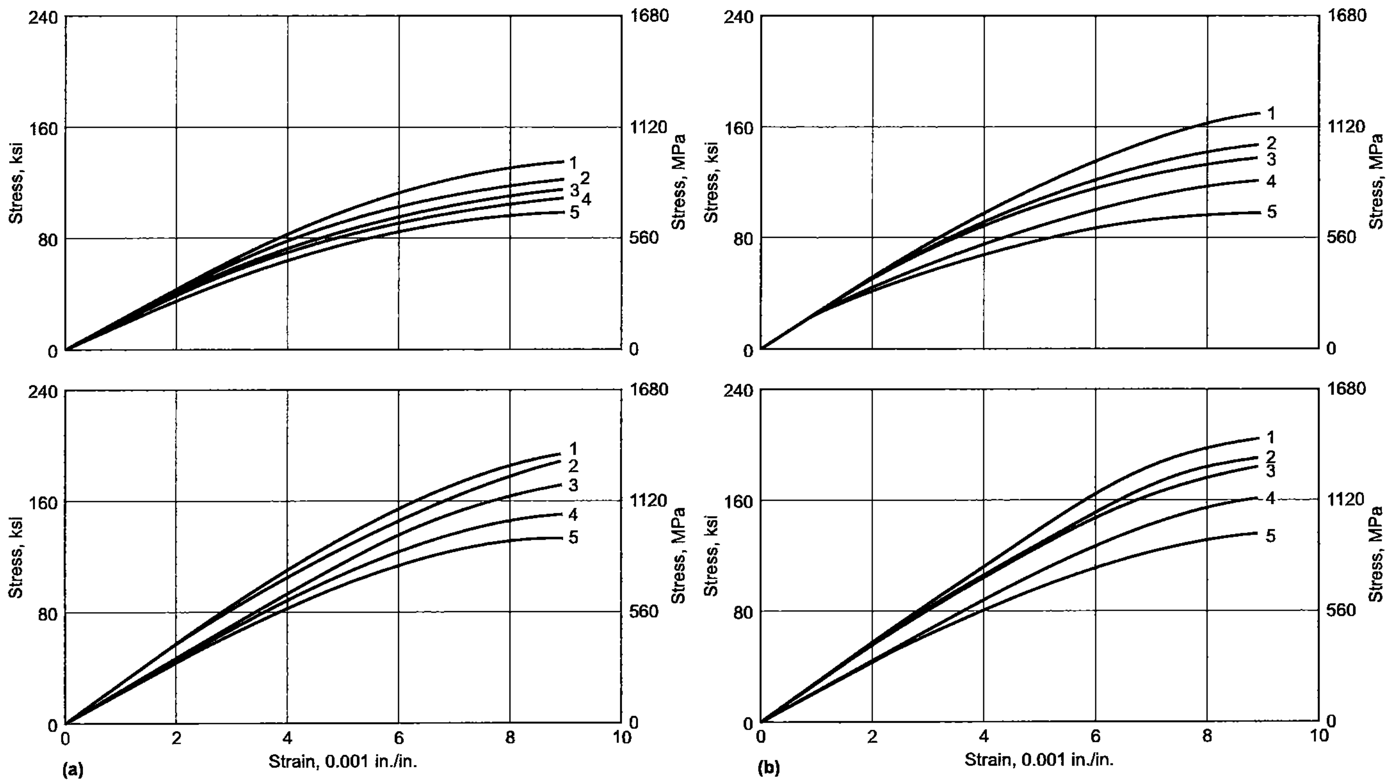
Source: L.P. Rue, J.E. Campbell, and W.F. Simmons, "The Evaluation and the Effects of Very Low Temperatures on the Properties of Aircraft and Missile Metals," WADD-TR-60-254, Feb 1960. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1301, CINDAS/ USAF CRDA Handbooks Operation, Purdue University, 1995, p 31



SS.016 301 stainless steel sheet, tensile stress-strain curves at room and elevated temperatures

Average of longitudinal and transverse. Top: sheet extra hard, 65% reduction. Bottom: extra hard, stress relief 399 °C (750 °F), 8 h. Composition: Fe-18Cr-8Ni. UNS S30100

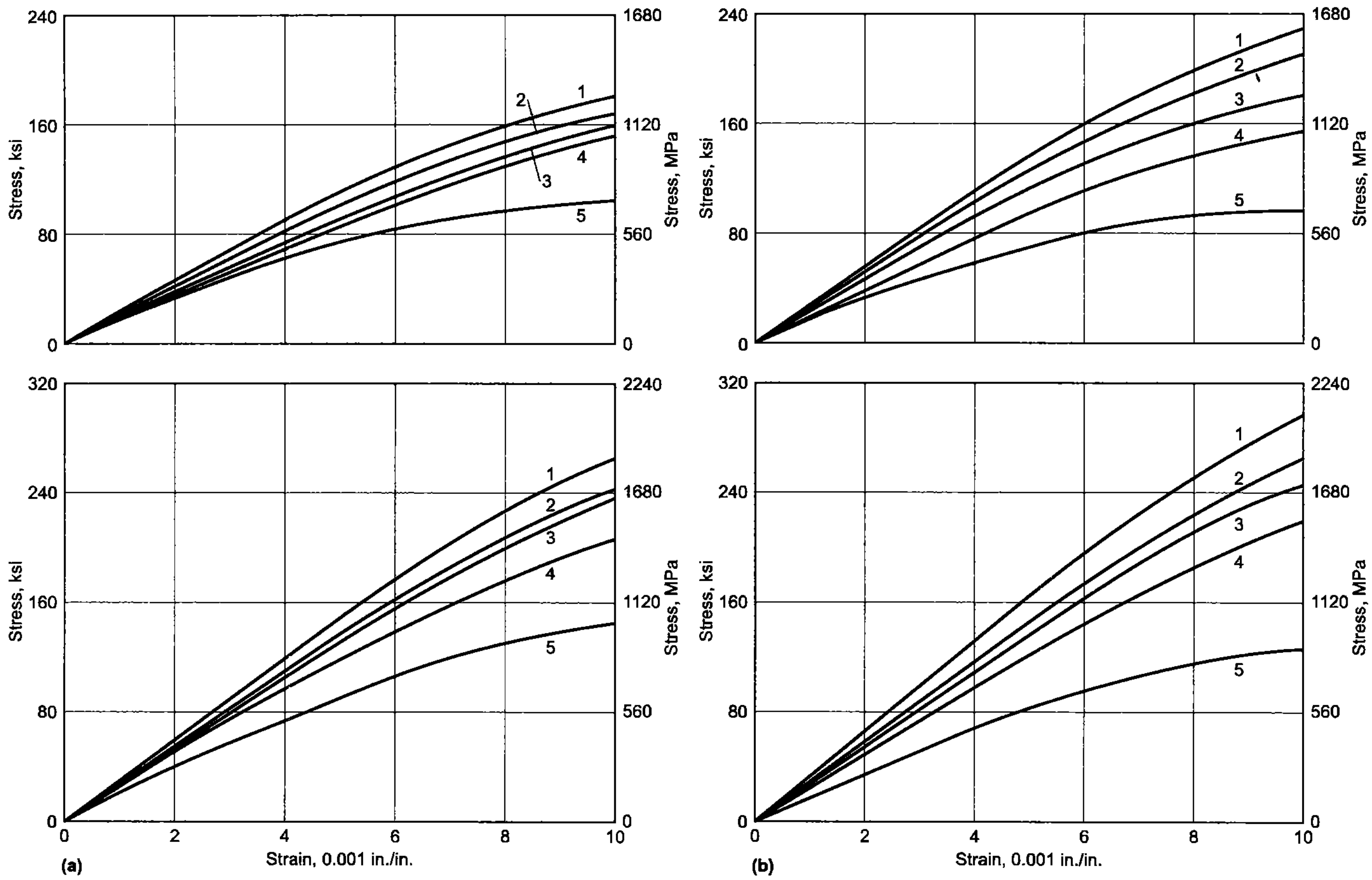
Source: "High Strength Cold Rolled Stainless Steels," Data Sheet, Allegheny Ludlum Steel Corp., 1958. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1301, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 31



SS.017 301 stainless steel sheet, compressive stress-strain curves at room and elevated temperatures

(a) Full hard sheet. Top: longitudinal; bottom: transverse. (b) Full hard sheet, stress relief 427 °C (800 °F), 8 h. Top: longitudinal; bottom: transverse. Curve 1, room temperature; curve 2, 204 °C (400 °F); curve 3, 316 °C (600 °F); curve 4, 427 °C (800 °F); curve 5, 538 °C (1000 °F). Composition: Fe-18Cr-8Ni. UNS S30100

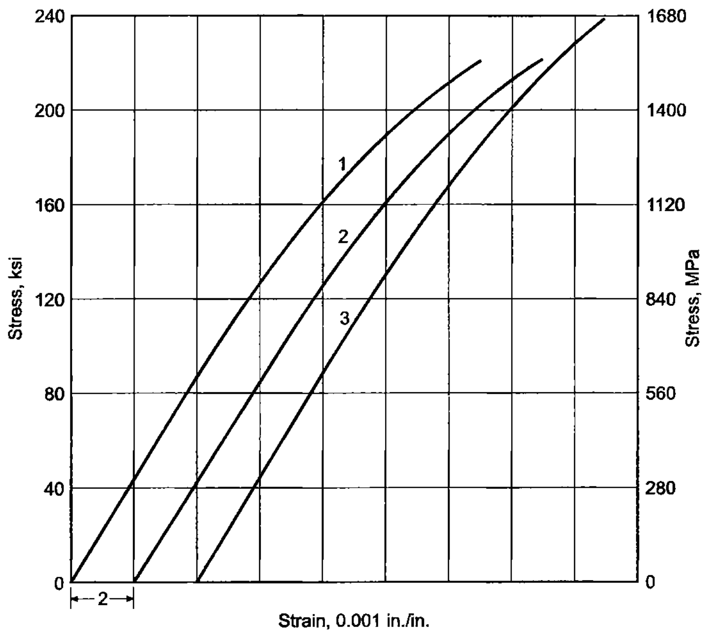
Source: "High Strength Cold Rolled Stainless Steels," Data Sheet, Allegheny Ludlum Steel Corp., 1958. As published in *Structural Alloys Handbook,* Vol 2, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1994, p 30



SS.018 301 stainless steel sheet, compressive stress-strain curves at room and elevated temperatures

(a) Extra hard sheet. Top: longitudinal; bottom: transverse. (b) Extra hard sheet, stress relief 399 °C (750 °F), 8 h. Top: longitudinal; bottom: transverse. Curve 1, room temperature; curve 2, 204 °C (400 °F); curve 3, 316 °C (600 °F); curve 4, 427 °C (800 °F); curve 5, 538 °C (1000 °F). Composition: Fe-18Cr-8Ni. UNS S30100

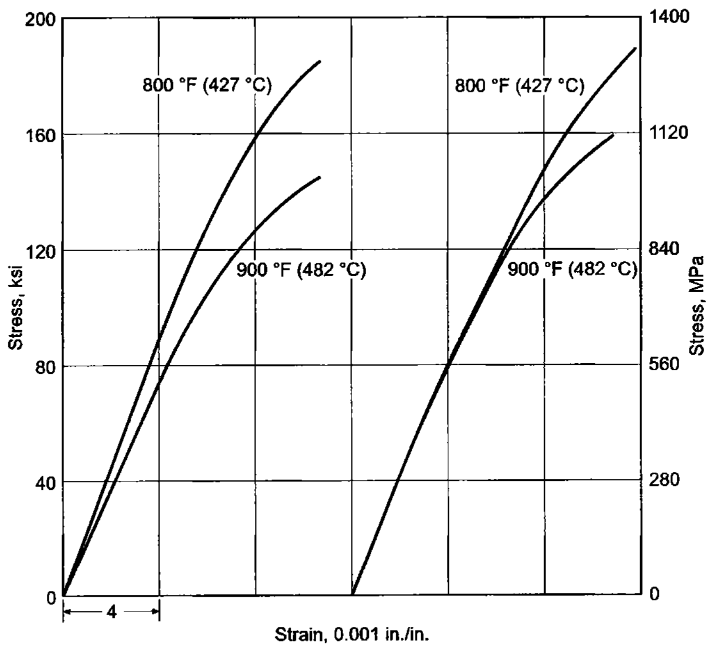
Source: "High Strength Cold Rolled Stainless Steels," Data Sheet, Allegheny Ludlum Steel Corp., 1958. As published in *Structural Alloys Handbook*, Vol 2, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1994, p 30



SS.019 301 stainless steel sheet, room-temperature tensile stress-strain curves with varying amounts of cold work prior to stress-relief annealing

Test direction: longitudinal. Curve 1: 50% cold reduction (CR), 399 °C (750 °F), 1 h, air cooled. Curve 2: 60% CR, 399 °C (750 °F), 1 h, AC. Curve 3: 70% CR, 399 °C (750 °F), 1 h, AC. Composition of heat: Fe-0.11C-17.9Cr-6.72Ni-0.56Mn-0.27Si. UNS S30100

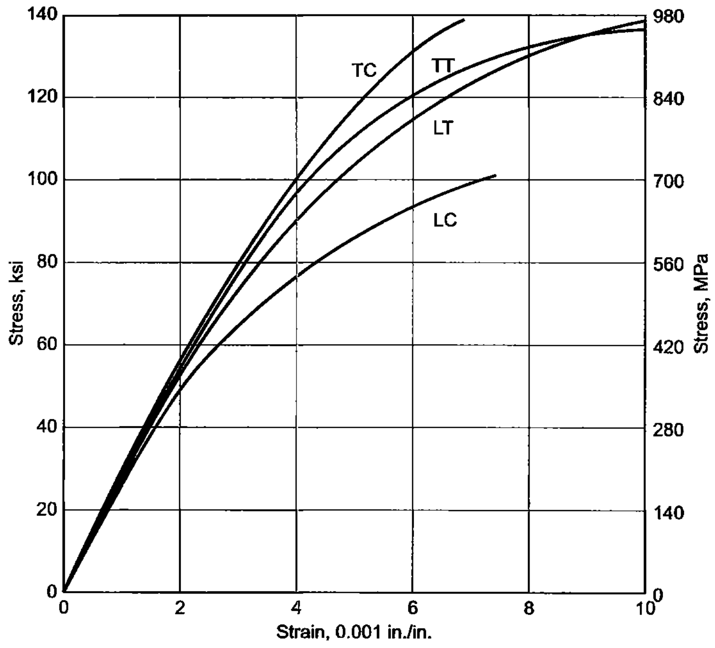
Source: "Data Sheet 14-10256-301," Allegheny Ludlum Steel Corp., Pittsburgh, PA. As published in *Structural Alloys Handbook,* Vol 2, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1994, p 28



SS.020 301 stainless steel sheet, elevated-temperature tensile stress-strain curves with different stress-relief annealing

Test direction: longitudinal. Curves on left, 65% cold reduction (CR), 482 °C (900 °F), 2 h, air cooled (AC). Curves on right, 65% CR, 399 °C (750 °F), 2 h, AC. Composition of heat: Fe-0.11C-17.25Cr-7.00Ni-0.57Mn-0.50Si. UNS S30100

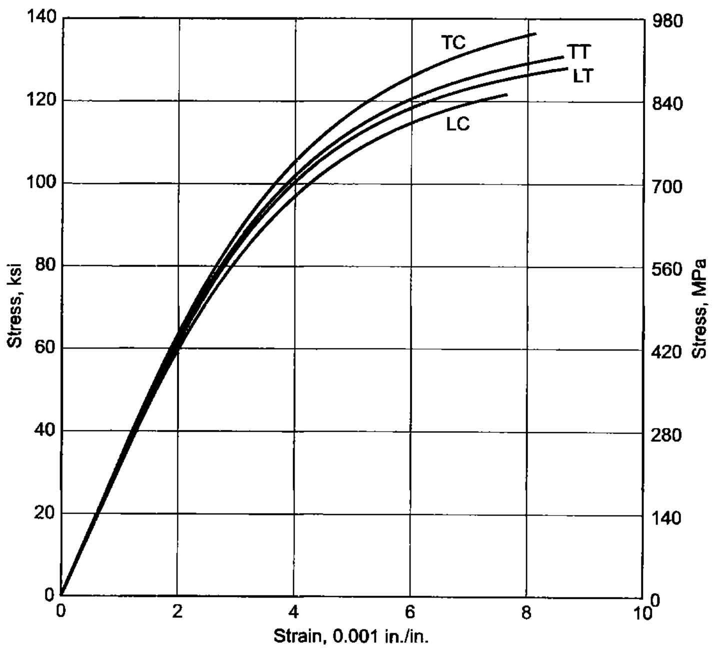
Source: "Data Sheet 19-101656-301," Allegheny Ludlum Steel Corp., Pittsburgh, PA. As published in *Structural Alloys Handbook,* Vol 2, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1994, p 29



SS.021 301 ½-hard stainless steel sheet, typical tensile and compressive stress-strain curves

Test direction: longitudinal and transverse. Half-hard sheet in as-rolled condition shows its anisotropic behavior. Curves: LT, longitudinal tensile; LC, longitudinal compressive; TT, transverse tensile; TC: transverse compressive. Composition: Fe-18Cr-8Ni. UNS S30100

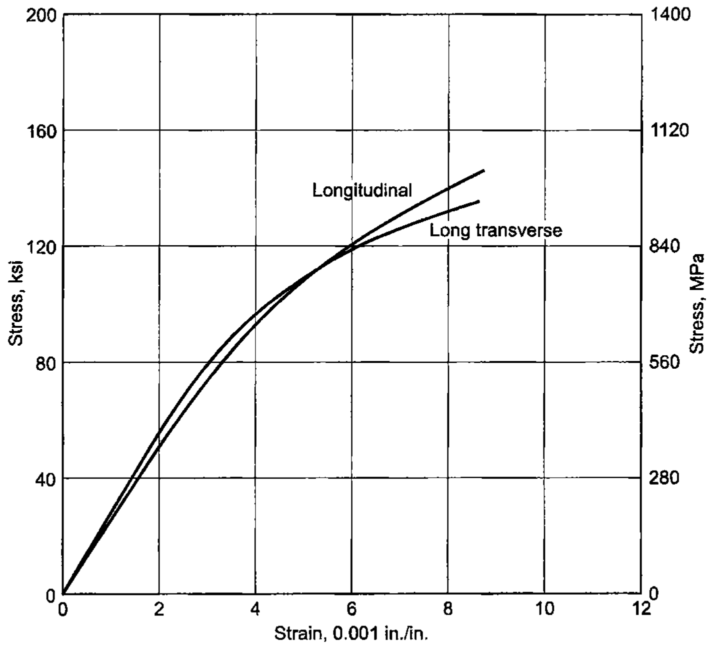
Source: Technical Blue Sheet, www.alleghenyludlum.com, Allegheny Ludlum Steel Corp., 2002, p 3



SS.022 301 ½-hard stainless steel sheet, typical tensile and compressive stress-strain curves

Test direction: longitudinal and transverse. Stress relief 538 °C (1000 °F), 2 h. A more isotropic nature and improved load-carrying ability is noted. This is especially true if longitudinal compression controls the design. Curves: LT, longitudinal tensile; LC, longitudinal compressive; TT, transverse tensile; TC: transverse compressive. Composition: Fe-18Cr-8Ni. UNS S30100

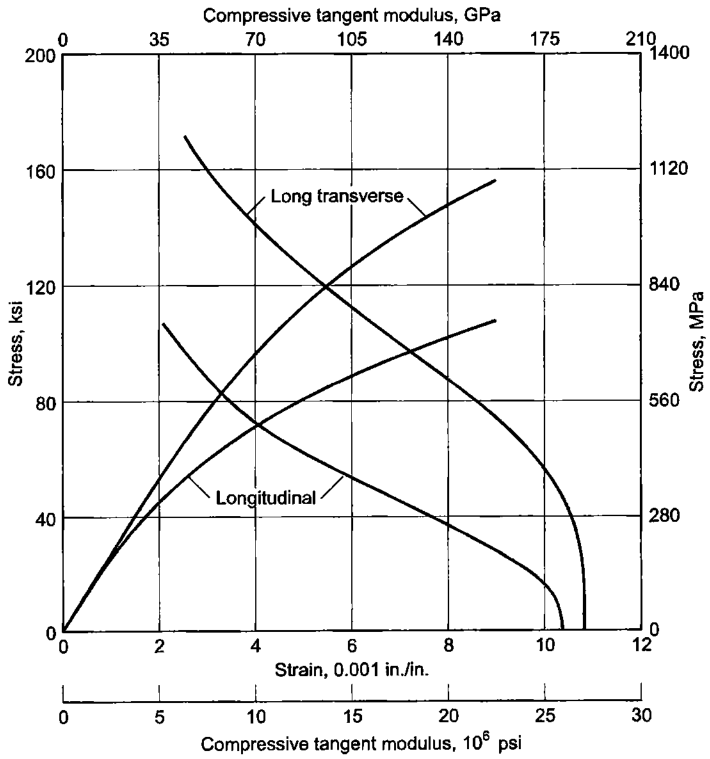
Source: Technical Blue Sheet, www.alleghenyludlum.com, Allegheny Ludlum Steel Corp., 2002, p 3



SS.023 301 ½-hard stainless steel sheet, typical tensile stress-strain curves

Test direction: longitudinal (L) and long transverse (LT). Ramberg-Osgood parameters: n(L) = 4.5; n(LT) = 5.9. Composition: Fe-18Cr-8Ni. UNS S30100

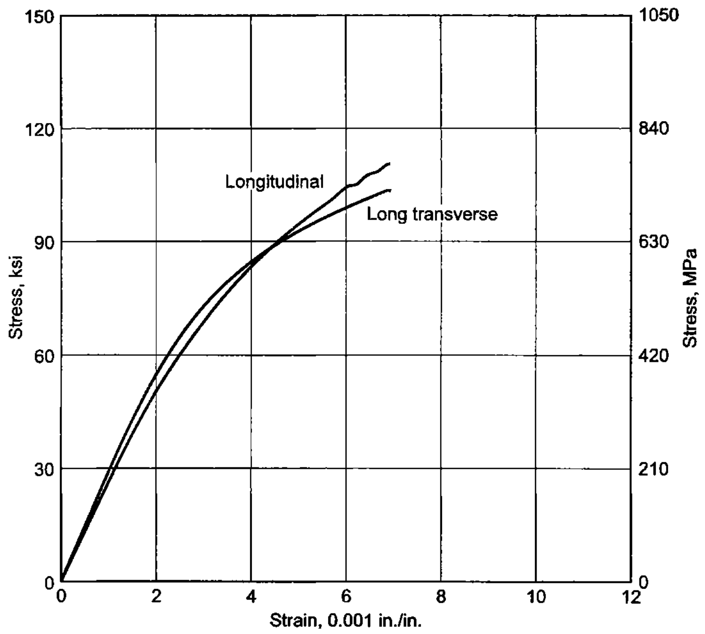
Source: *MIL-HDBK-5H,* Dec 1998, p 2-224



SS.024 301 ½-hard stainless steel sheet, typical compressive stress-strain and compressive tangent modulus curves

Test direction: longitudinal (L) and long transverse (LT). Ramberg-Osgood parameters: n(L) = 3.4; n(LT) = 4.3. Composition: Fe-18Cr-8Ni. UNS S30100

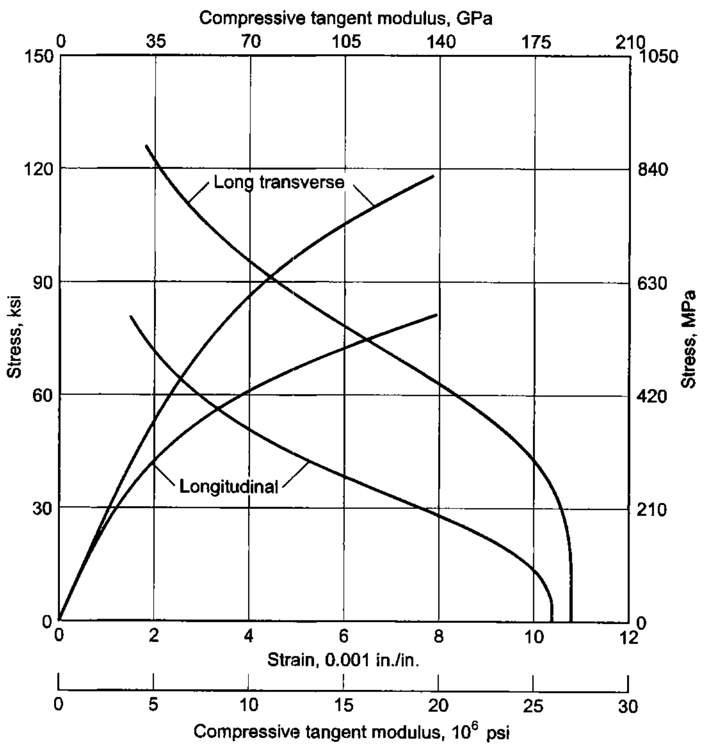
Source: *MIL-HDBK-5H,* Dec 1998, p 2-224



SS.025 301 ¼-hard stainless steel sheet, typical tensile stress-strain curves

Test direction: longitudinal (L) and long transverse (LT). Ramberg-Osgood parameters: n(L) = 3.9; n(LT) = 5.8. Composition: Fe-18Cr-8Ni. UNS S30100

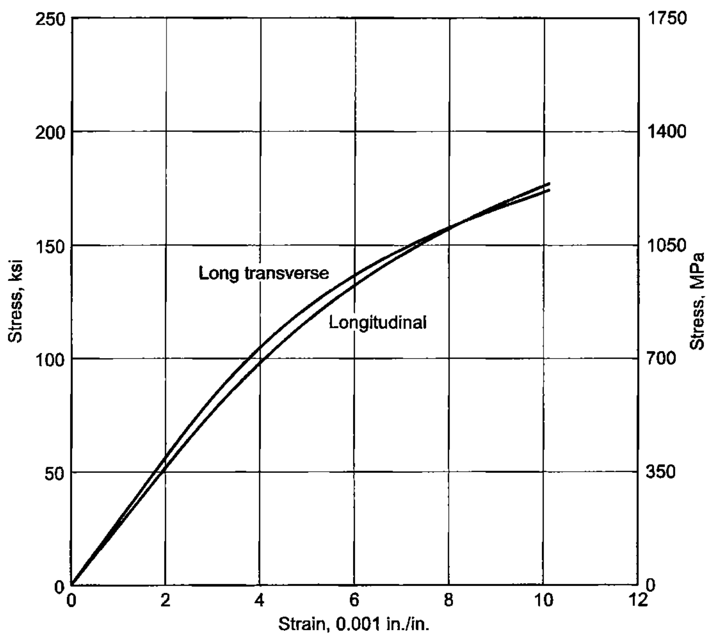
Source: *MIL-HDBK-5H,* Dec 1998, p 2-221



SS.026 301 ¼-hard stainless steel sheet, typical compressive stress-strain and compressive tangent modulus curves

Test direction: longitudinal (L) and long transverse (LT). Ramberg-Osgood parameters: n(L) = 3.8; n(LT) = 4.8. Composition: Fe-18Cr-8Ni. UNS S30100

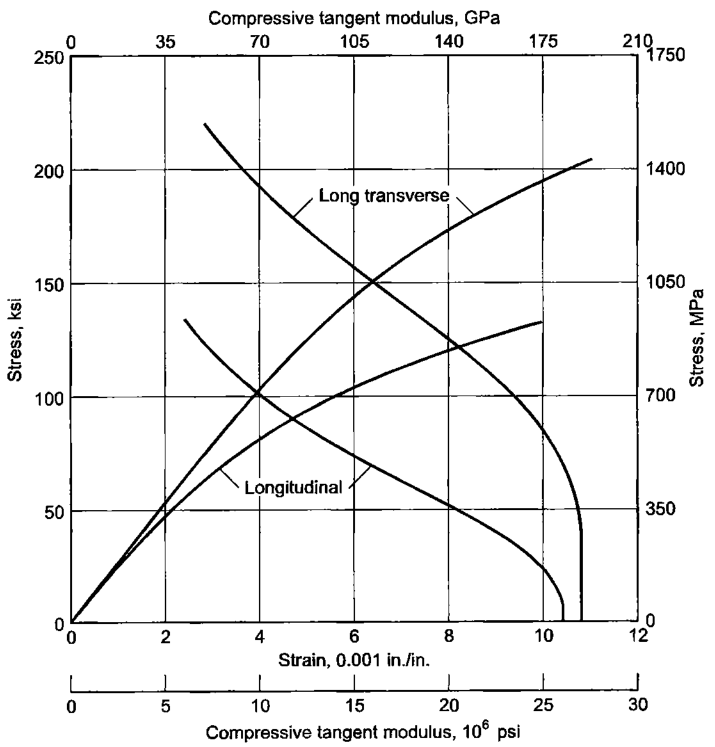
Source: *MIL-HDBK-5H,* Dec 1998, p 2-221



SS.027 301 ¾-hard stainless steel sheet, typical tensile stress-strain curves

Test direction: longitudinal (L) and long transverse (LT). Ramberg-Osgood parameters: n(L) = 4.7; n(LT) = 5.4. Composition: Fe-18Cr-8Ni. UNS S30100

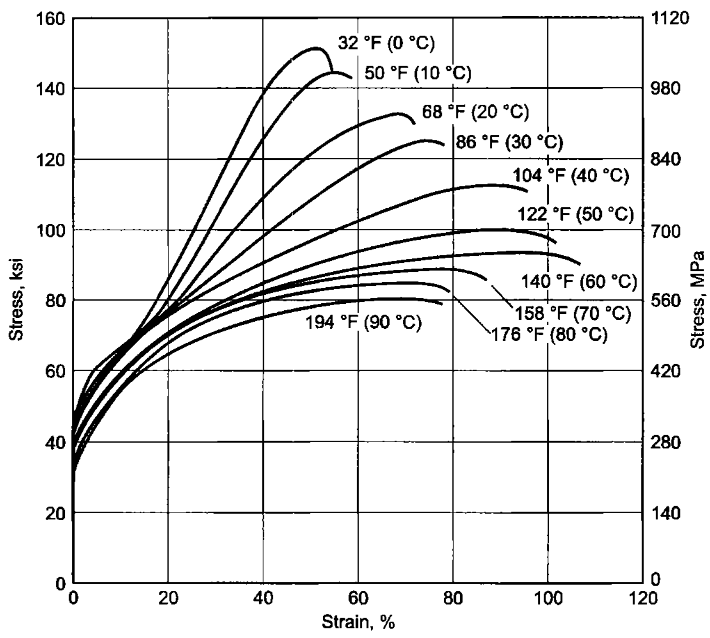
Source: *MIL-HDBK-5H,* Dec 1998, p 2-225



SS.028 301 ¾-hard stainless steel sheet, typical compressive stress-strain and compressive tangent modulus curves

Test direction: longitudinal (L) and long transverse (LT). Ramberg-Osgood parameters: n(L) = 3.5; n(LT) = 4.7. Composition: Fe-18Cr-8Ni. UNS S30100

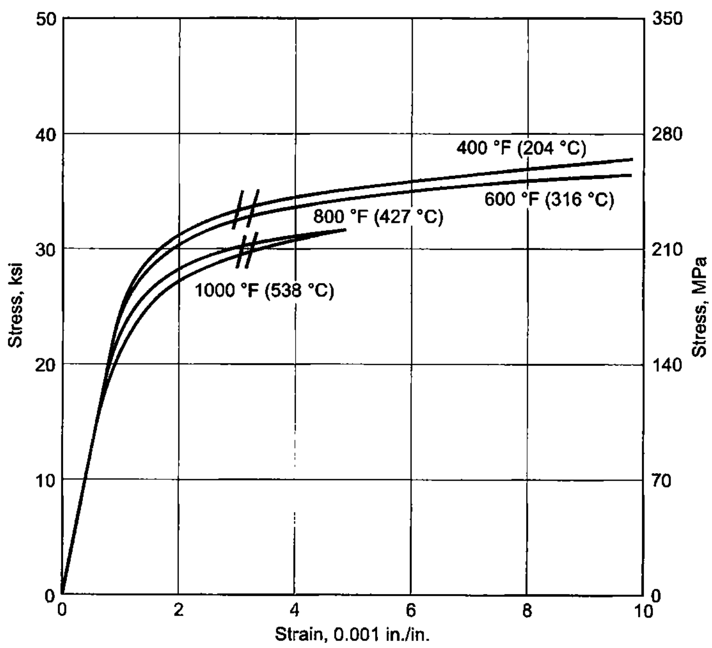
Source: *MIL-HDBK-5H,* Dec 1998, p 2-225



SS.029 301 annealed stainless steel sheet, stress-strain curves at various temperatures

Test direction: transverse. Sheet thickness = 0.508 mm (0.020 in.). Specimen size = 5.08 × 30.48 mm (0.20 × 1.20 in.). Strain rate = 0.062/min. Annealed 600 °C (1112 °F), 30 min, grain size = 34 μm. Composition: Fe-18Cr-8Ni. UNS S30100

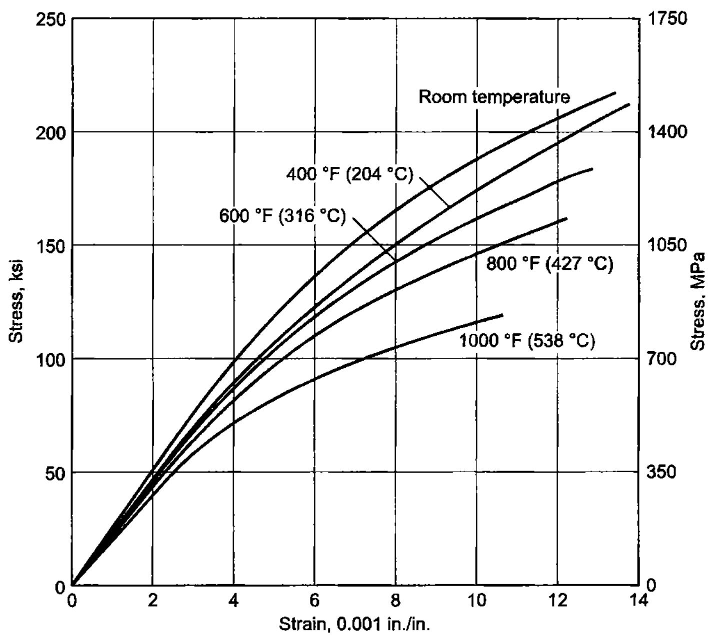
Source: A. Rosen, R. Jago, and T. Kjer, Tensile Properties of Metastable Stainless Steels, *J. Mater. Sci.*, Vol 7, 1972, p 870–876. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1301, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 29



SS.030 301 annealed stainless steel sheet, compressive stress-strain curves at elevated temperatures

Sheet thickness = 1.6 mm (0.063 in.). Composition: Fe-18Cr-8Ni. UNS S30100

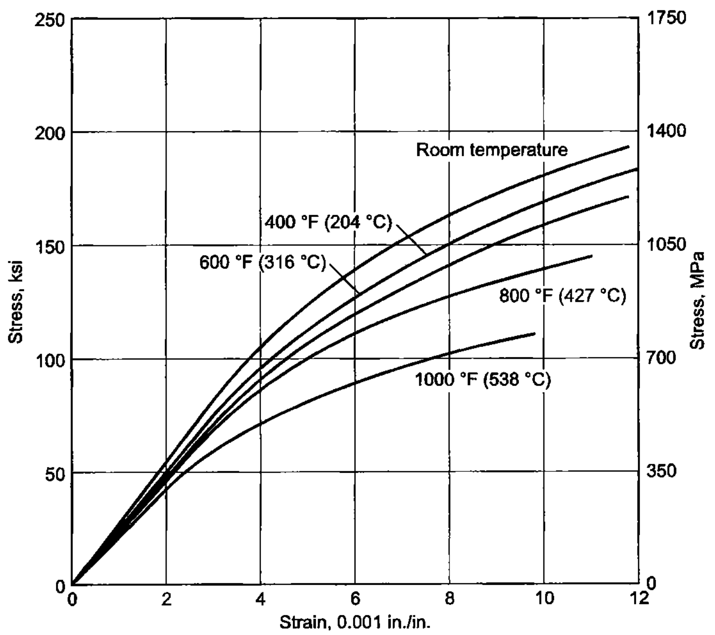
Source: D.E. Miller, "Determination of the Tensile, Compressive and Bearing Properties of Ferrous and Non-Ferrous Structural Sheet Materials at Elevated Temperatures," AF TR No. 6517, Pt V, Armour Research Foundation, Dec 1957. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1301, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 47



SS.031 301 full hard stainless steel sheet, typical tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal. 0.5 h exposure to elevated temperatures. Ramberg-Osgood parameters: n(room temperature) = 4.4; n(400 °F) = 3.4; n(600 °F) = 4.6; n(800 °F) = 4.2; n(1000 °F) = 4.3. Composition: Fe-18Cr-8Ni. UNS S30100

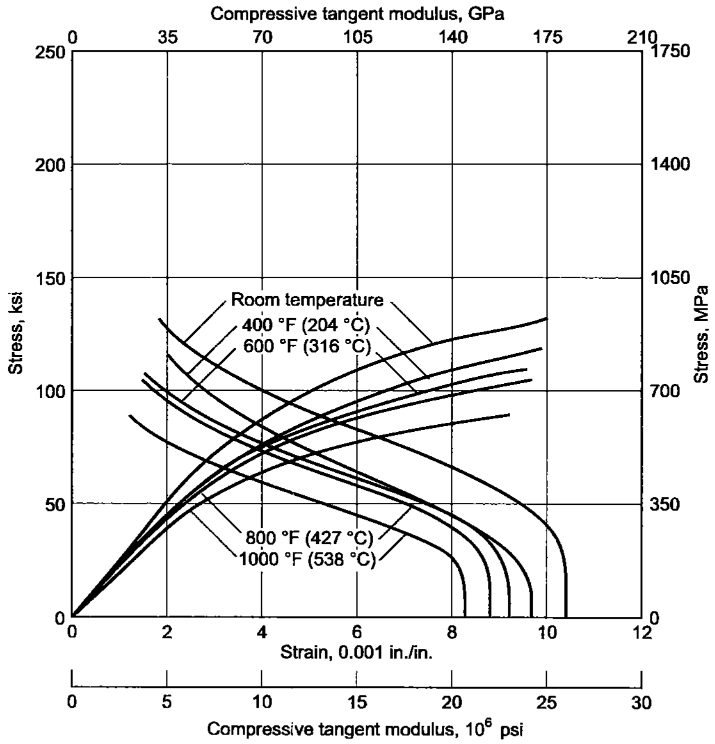
Source: *MIL-HDBK-5H,* Dec 1998, p 2-229



SS.032 301 full hard stainless steel sheet, typical tensile stress-strain curves at room and elevated temperatures

Test direction: long transverse. 0.5 h exposure to elevated temperatures. Ramberg-Osgood parameters: n(room temperature) = 5.4; n(400 °F) = 4.8; n(600 °F) = 4.3; n(800 °F) = 5.3; n(1000 °F) = 4.6. Composition: Fe-18Cr-8Ni. UNS S30100

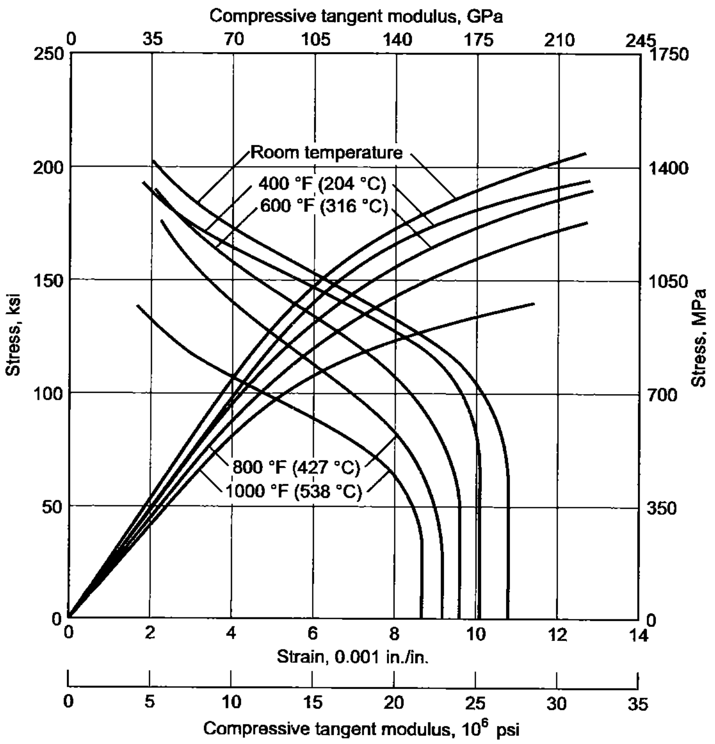
Source: *MIL-HDBK-5H,* Dec 1998, p 2-229



SS.033 301 full hard stainless steel sheet, typical compressive stress-strain and compressive tangent modulus curves at room and elevated temperatures

Test direction: longitudinal. 0.5 h exposure to elevated temperatures. Ramberg-Osgood parameters: n(room temperature) = 5.3; n(400 °F) = 4.8; n(600 °F) = 5.2; n(800 °F) = 5.4; n(1000 °F) = 5.7. Composition: Fe-18Cr-8Ni. UNS S30100

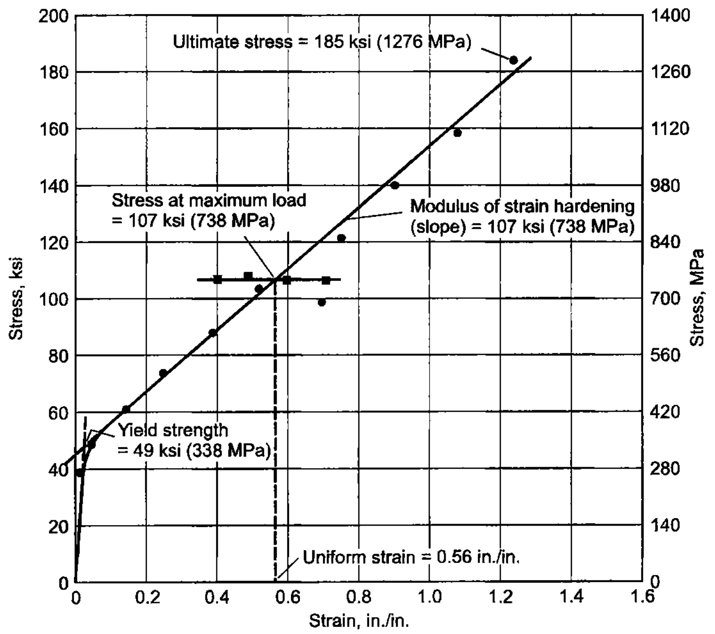
Source: *MIL-HDBK-5H,* Dec 1998, p 2-230



SS.034 301 full hard stainless steel sheet, typical compressive stress-strain and compressive tangent modulus curves at room and elevated temperatures

Test direction: long transverse. 0.5 h exposure to elevated temperatures. RT, room temperature. Ramberg-Osgood parameters: n(RT) = 7.7; n(400 °F) = 8.2; n(600 °F) = 6.7; n(800 °F) = 5.8; n(1000 °F) = 6.7. Composition: Fe-18Cr-8Ni. UNS S30100

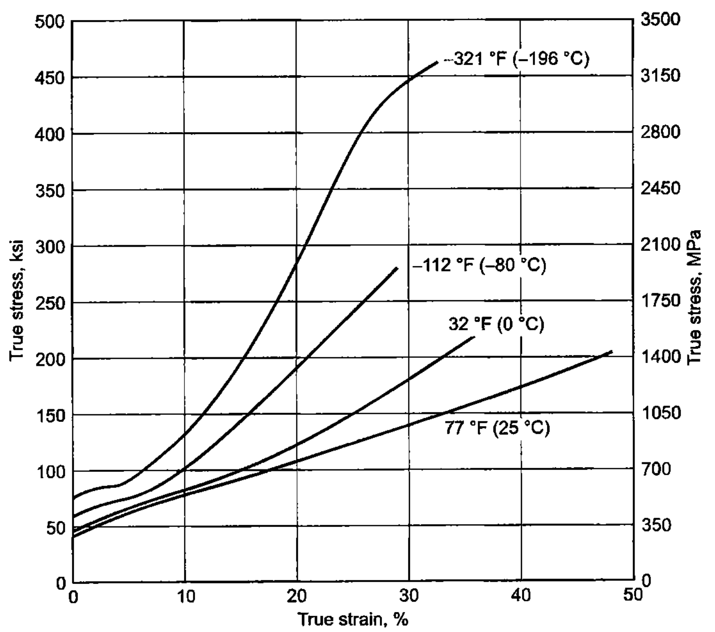
Source: *MIL-HDBK-5H,* Dec 1998, p 2-230



SS.035 301 stainless steel strip, true tensile stress-strain curves

Graph provides useful data for evaluating stretch-forming operations. Yield strength is the stress at which specimen shows deviation from linear proportionality of stress and strain. Stress at maximum load is the stress at the highest load sustained by the specimen. Maximum uniform strain is the maximum value before uniform deformation ceases and necking begins; this is the strain at point of maximum load. Modulus of strain hardening is the slope of plastic region of true stress-strain curve. Ultimate stress is the stress at rupture. Composition: Fe-18Cr-8Ni. UNS S30100

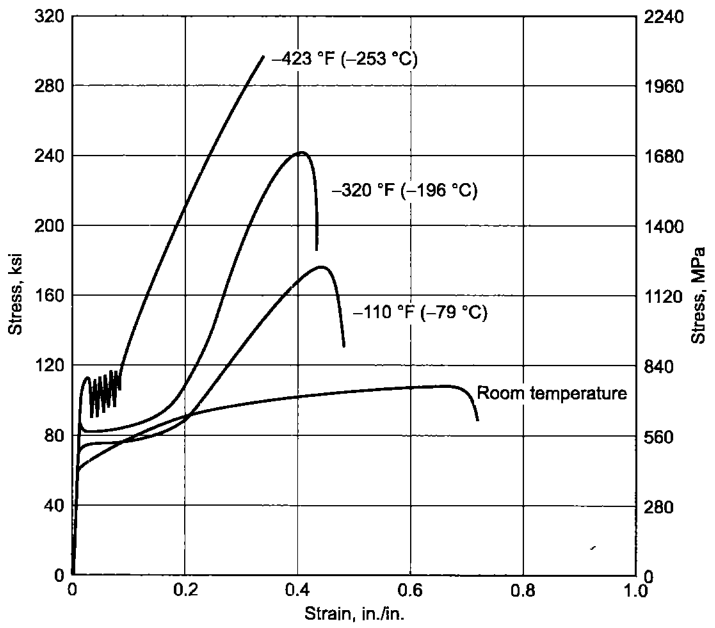
Source: E.R. Cunningham, Cold Forming Stainless Steels and Other Specialty Grades, *Sourcebook on Cold Forming,* American Society of Metals, 1975, p 124



SS.036 302 annealed stainless steel extruded bar, true stress-strain curves at room and low temperatures

Annealed 1093 °C (2000 °F), 1 h, grain size = 31 μm, strain rate = 0.025/min. Composition: Fe-18Cr-9Ni. UNS S30200

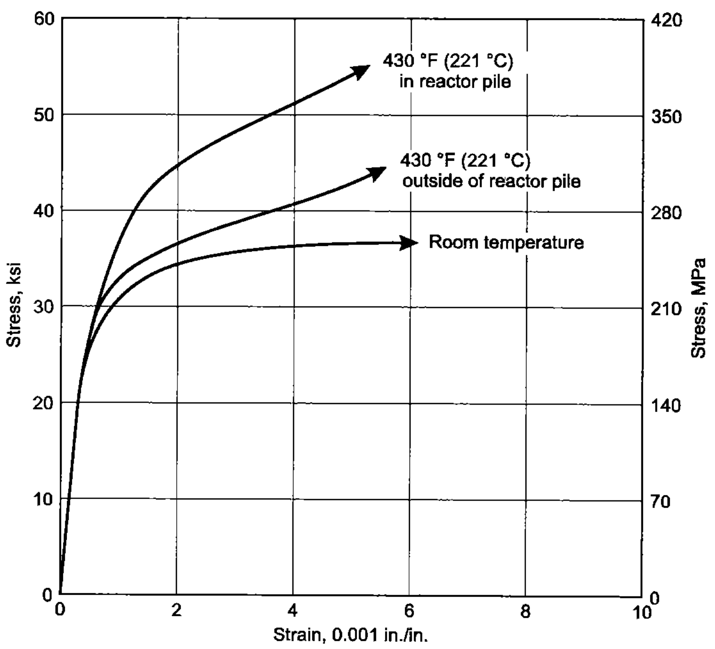
Source: S.N. Monteiro and H. Fonseca, The Effect of Phase Transformation on the Tensile Fracture of Austenitic Stainless Steel, *Proc. Fourth Int. Conf. Fracture,* University of Waterloo, Ontario, Canada, June 1977, p 135–140. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1301, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 29



SS.037 303 annealed stainless steel bar, stress-strain curves at room and low temperatures

Bar diameter = 19.05 mm (0.75 in.). Composition: Fe-18Cr-9Ni + S. UNS S30300

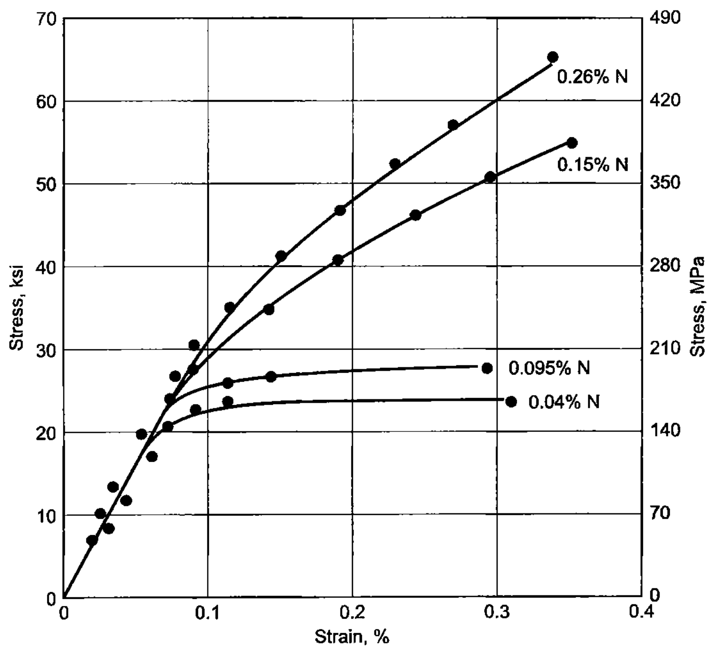
Source: K.A Warren and R.P. Reed, *Tensile and Impact Properties of Selected Materials from 20 to 300K,* Monograph 63, National Bureau of Standards, 28 June 1963. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1302, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 5



SS.038 304 annealed stainless steel bar, typical stress-strain curves at room temperature and 221 °C (430 °F) inside and outside of reactor pile

Bar diameter = 25.4 mm (1 in.). Ultimate strength = 612 MPa (88.8 ksi); yield strength = 295 MPa (42.8 ksi); elongation (in 4*D*) = 57.2%. Composition: Fe-19Cr-9.25Ni. UNS S30400

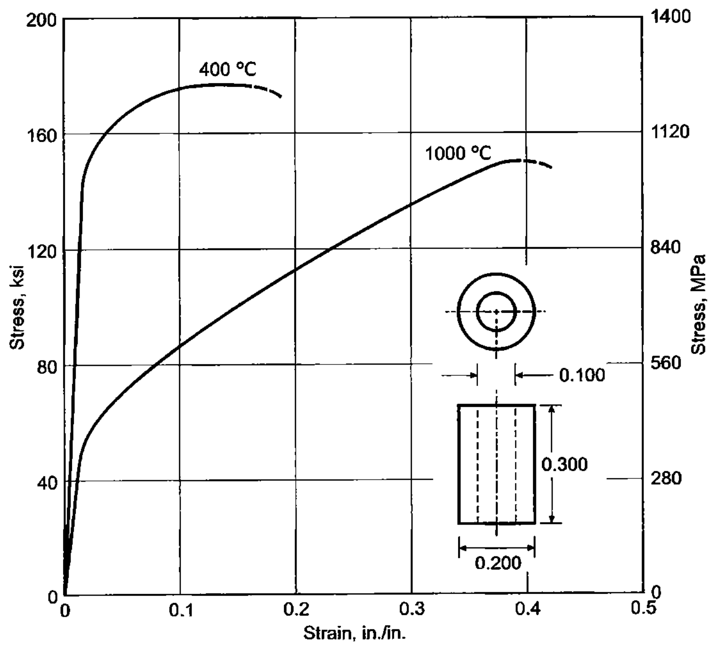
Source: C.A. Schwanbeck, "Effect of Nuclear Radiation on Materials at Cryogenic Temperatures," NASA CR-54881, Lockheed-Georgia Co., Jan 1965. As published in *Structural Alloys Handbook,* Vol 2, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1994, p 62



SS.039 304 stainless steel wire, stress-strain curves at 767 °C (302 °F) showing effect of nitrogen content

Wire diameter = 0.635 mm (0.025 in.). Heat treatment: annealed 1010 °C (1850 °F), 20 min, water quenched, nitrided at 538 °C (1000 °F) and homogenize annealed 1010 °C (1850 °F), 71 h, water quenched, carbide resolution annealed 1093 °C (2000 °F), 15 min, water quenched. Composition: 18.65Cr-10.5Ni-0.05C-1.44Mn-0.66Si-0.02P-0.008S-bal Fe-N as shown. UNS S30400

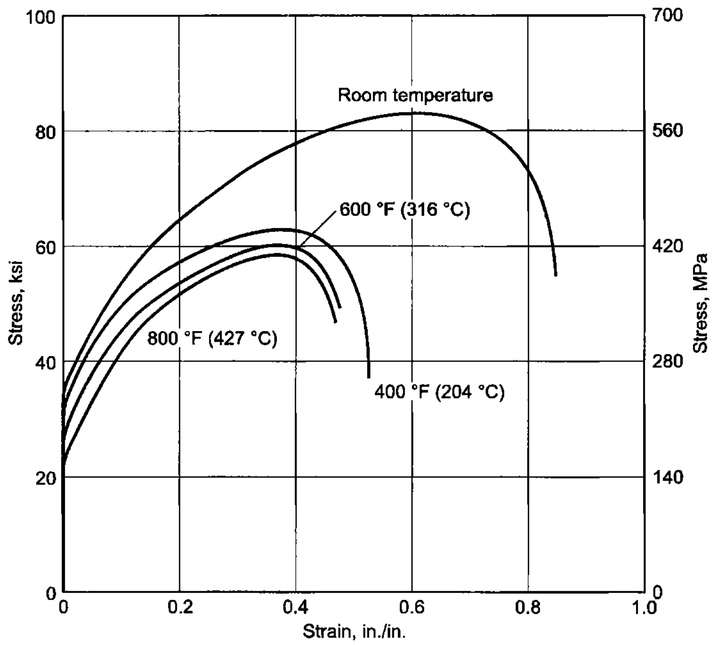
Source: B.N. Ferry and J.F. Eckel, The Effect of Nitrogen on AISI Type 304 Stainless Steel Proportional Limit and Work Hardening Rate at 302F, *J. Mater.*, Vol 5 (No. 1), March 1970. As published in *Structural Alloys Handbook*, Vol 2, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1994, p 63



SS.040 304 stainless steel tube, compressive stress-strain curves at elevated temperatures

Strain rate = 0.01/s. Composition: Fe-19Cr-9.25Ni. Dimensions in inset given in inches (1 in. = 25.4 mm). UNS S30400

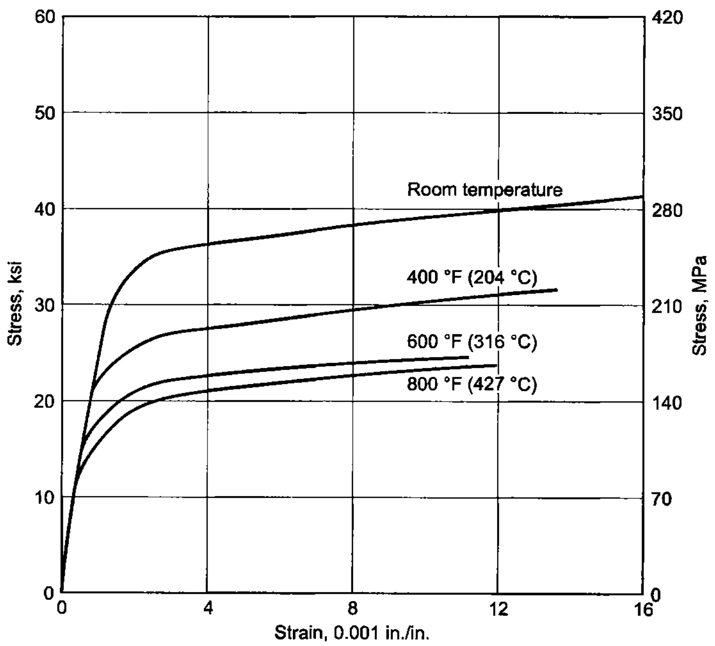
Source: M. Young et al., "Studies on the Warm Working Characteristics of Alloys," AMMRC CTR 72-27, Army Materials and Mechanics Research Center, Dec 1972, AD 758912. As published in *Structural Alloys Handbook*, Vol 2, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1994, p 72



SS.041 304 stainless steel, general, full-range stress-strain curves at room and elevated temperatures

Curves shown to failure. Composition: Fe-19Cr-9.25Ni. UNS S30400

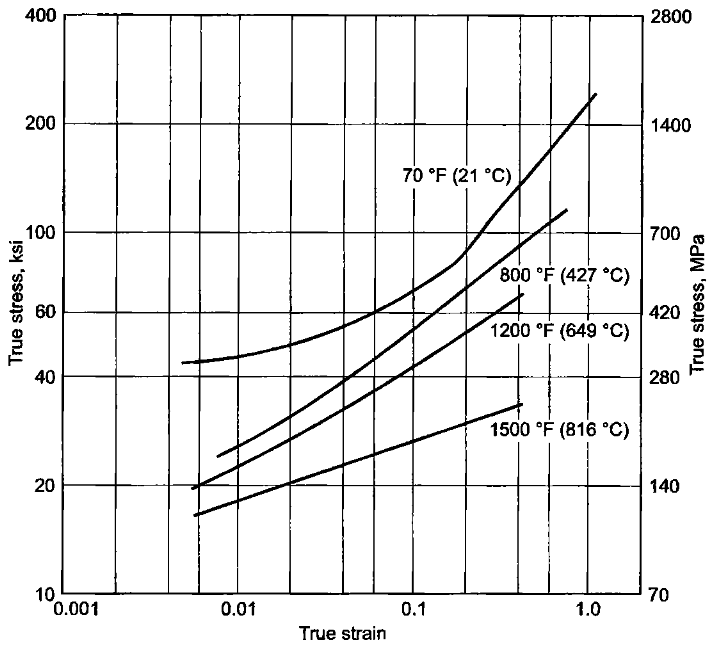
Source: *Bettis Plant Materials Manual,* Westinghouse Electric Corp., Standards Engineering Section, May 1957. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1303, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 13



SS.042 304 stainless steel, general, expanded-range stress-strain curves at room and elevated temperatures

Composition: Fe-19Cr-9.25Ni. UNS S30400

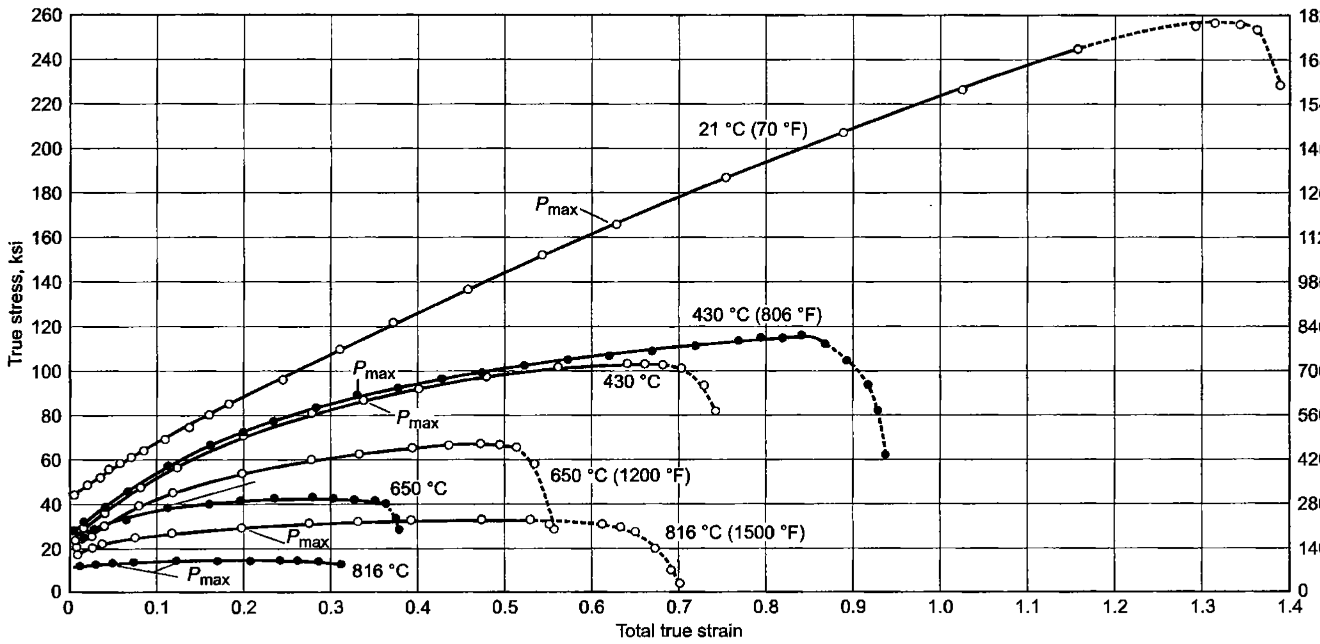
Source: *Bettis Plant Materials Manual,* Westinghouse Electric Corp., Standards Engineering Section, May 1957. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1303, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 13



SS.043 304 annealed stainless steel bar, true stress-strain curves at room and elevated temperatures

Bar diameter = 15.875 mm (0.625 in.). Composition: Fe-19Cr-9.25Ni. UNS S30400

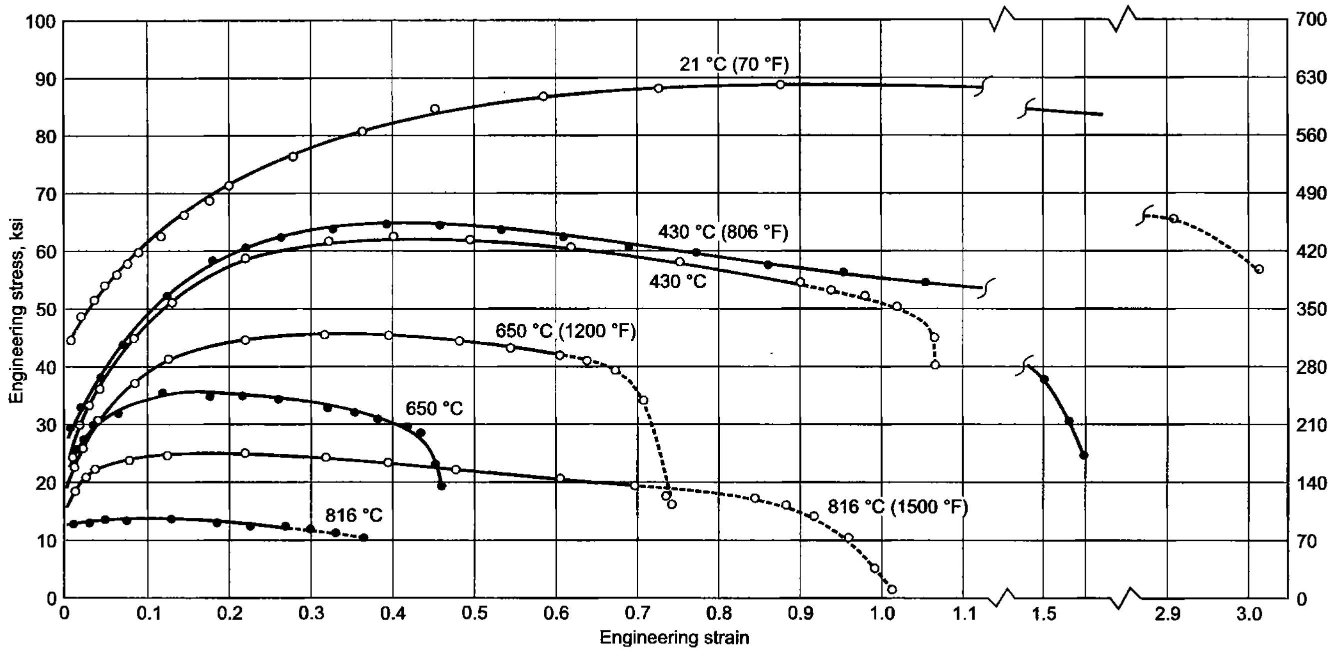
Source: J.B. Conway, "Evaluation of Plastic Fatigue Properties of Heat-Resistant Alloys," GEMP-740, General Electric Co., Dec 1969. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1303, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 13



SS.044 304 annealed stainless steel bar, true stress-strain curves at room and elevated temperatures

Bar diameter = 6.35 mm (0.25 in.). Data were collected at constant axial true strain rates of 0.004 (open data points) and 0.00004 (solid data points). The curves for the higher strain rates are above the other curve at 650 and 816 °C (1202 and 1580 °F), while the reverse is true for 430 °C (806 °F). Contrary to what is expected for true stress-strain curves, these have a maximum point. This is believed to be due to the formation of internal voids that reduce the actual area under stress. For this reason the lines are dashed as they approach the fracture point. P_{max} is the point of maximum load. Composition: Fe-19Cr-9.25Ni. UNS S30400

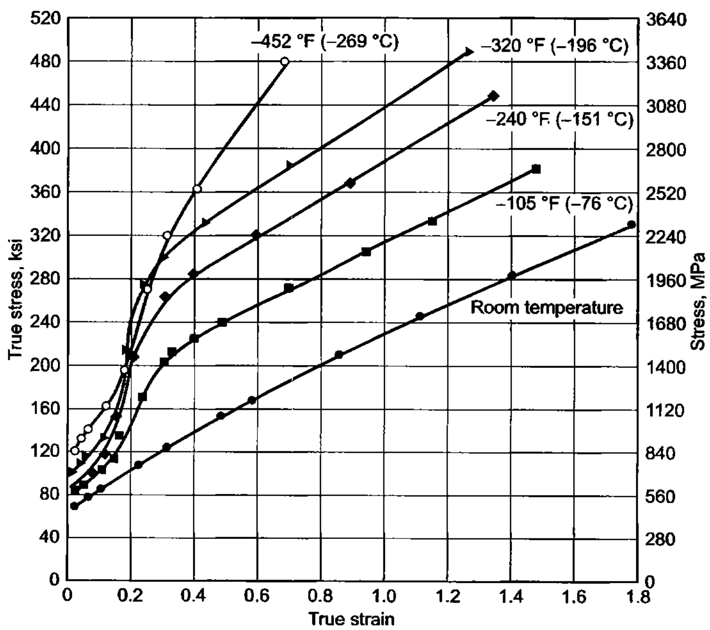
Source: J.B. Conway, R.H. Stentz, and J.T. Berling, "Fatigue, Tensile, and Relaxation Behavior of Stainless Steels," Technical Information Center, USAEC, 1975, p 213



SS.045 304 annealed stainless steel bar, engineering stress-strain curves at room and elevated temperatures

Bar diameter = 6.35 mm (0.25 in.). Data were collected at constant axial true strain rates of 0.004 (open data points) and 0.00004 (solid data points). Same data was used as for the true stress-strain curve. The curves for the higher strain rates are above the other curve at 650 and 816 °C (1202 and 1580 °F), while the reverse is true for 430 °C (806 °F). The strain rate effect is more pronounced for the higher temperatures. The lines are dashed as they approach the fracture point. Composition: Fe-19Cr-9.25Ni. UNS S30400

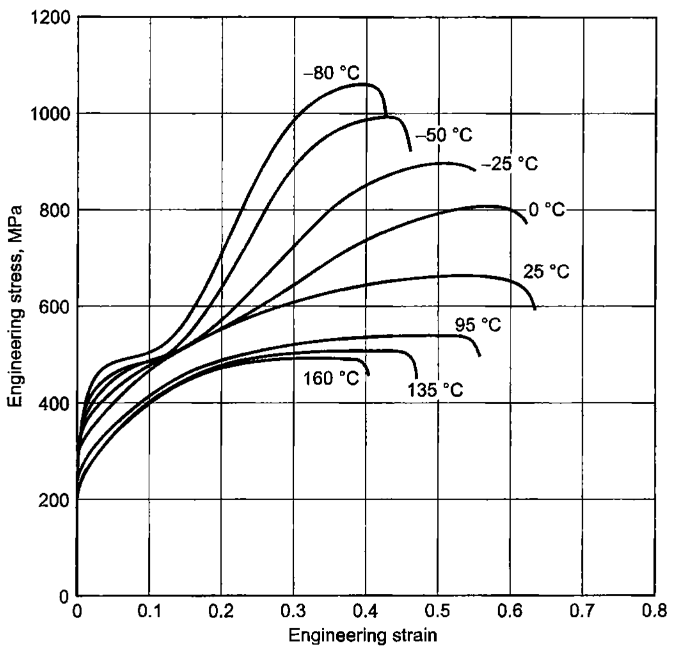
Source: J.B. Conway, R.H. Stentz, and J.T. Berling, "Fatigue, Tensile, and Relaxation Behavior of Stainless Steels," Technical Information Center, USAEC, 1975, p 216



SS.046 304 stainless steel bar, true stress-strain curves at room and low temperatures

Bar diameter = 12.7 mm (0.500 in.). Composition: Fe-19Cr-9.25Ni. UNS S30400

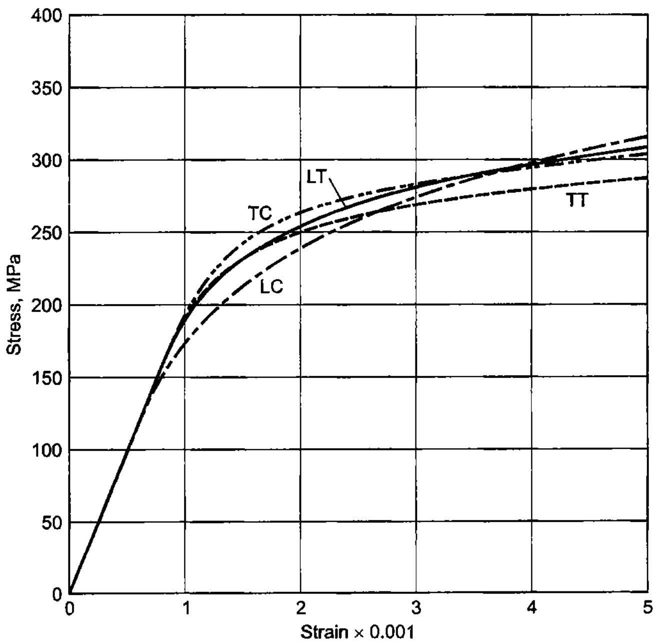
Source: T.S. DeSisto and F.L. Carr, "Low Temperature Mechanical Properties of 300 Series Stainless Steels and Titanium," WAL TR 323, 4/1, Dec 1961. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1303, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 14



SS.047 304 stainless steel sheet, true stress-strain curves at various temperatures

Strain rate = 0.015/s. Composition: Fe-19Cr-9.25Ni. UNS S30400

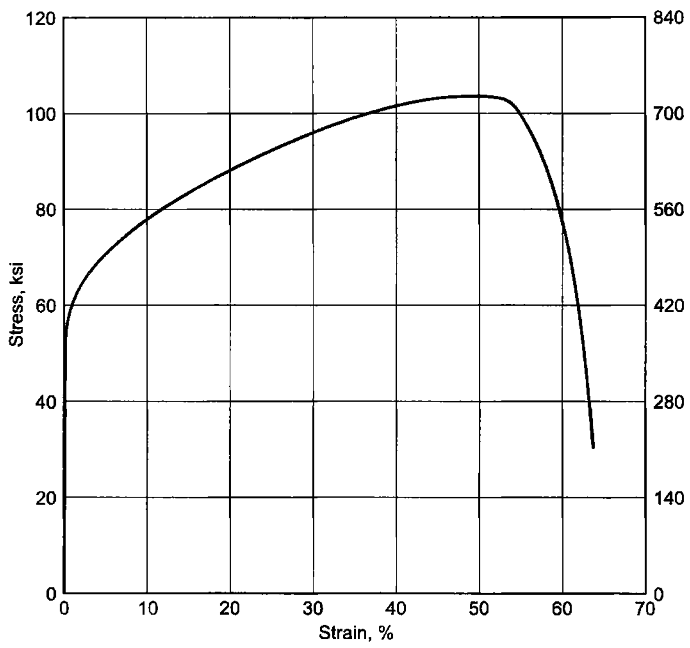
Source: G.L. Huang, D.K. Matlock, and G. Krauss, Martensite Formation, Strain Rate Sensitivity, and Deformation Behavior of Type 304 Stainless Steel Sheet, *Metall. Trans. A*, Vol 20A, 1989. As published in G. Krauss, *Steels: Heat Treatment Processing and Principles*, 1990, p 369



SS.048 304 stainless steel sheet, tensile and compressive stress-strain curves

24 to 35 tests were made in each orientation on cold-rolled specimens. Curves: LT, longitudinal tension; TT, transverse tension; LC, longitudinal compression; and TC, transverse compression. Elastic modulus: LT, 199.8 GPa; TT, 197.3 GPa; LC, 208.1 GPa; TC, 205.1 GPa. Yield strength (0.2%): LT, 290.3 MPa; TT, 290.0 MPa; LC, 295.7 MPa; TC, 308.0 MPa. Ultimate tensile strength: LT, 676 MPa; TT, 651 MPa. Composition: Fe-19Cr-9.25Ni. UNS S30400

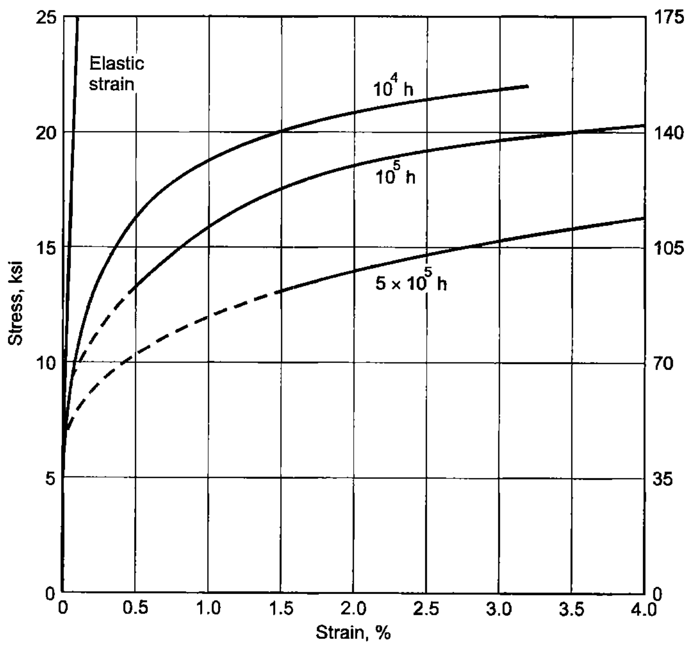
Source: P. Van Der Merwe and G.J Van Den Berg, The Advantages of Using Cr-Mn Steels Instead of Cr-Ni Steels in Cold-Formed Design, *High Manganese High Nitrogen Austenitic Steels*, R.A. Lula, Ed., Conf. Proc., 10–15 Oct 1987 (Cincinnati, OH) and 2–4 Nov 1992 (Chicago, IL), ASM International, 1992, p 129



SS.049 304 annealed stainless steel bar, stress-strain curves

Bar diameter = 12.7 mm (0.5 in.). Specimen: 9.525 mm (3/8 in.) diam threaded ends, 3.175 mm (0.125 in.) square cross section of 38.1 mm (1.5 in.) gage length tested at strain rate of 0.001/s. Composition: Fe-19Cr-9.25Ni. UNS S30400

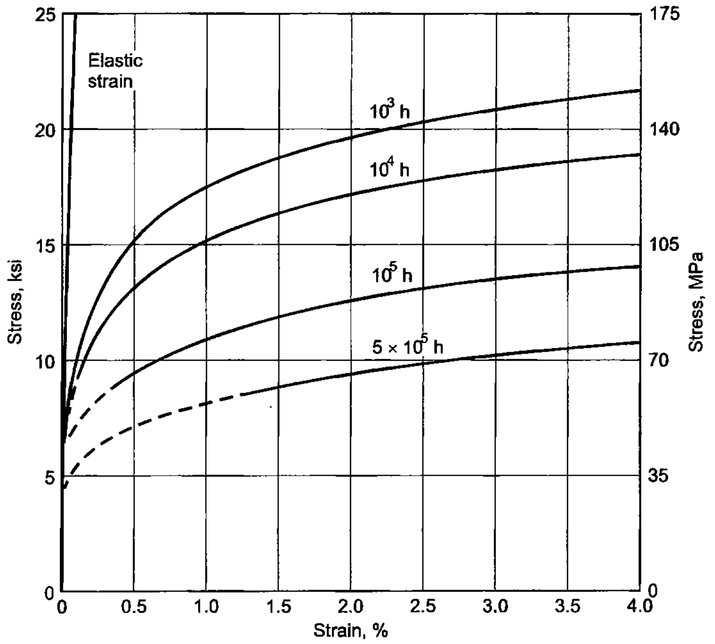
Source: P.C. Johnson, et al., "Basic Parameters of Metal Behavior under High Rate Forming," Report No. WAL TR 111.2/20-3, Arthur D. Little Inc., March 1962, AD 418727. As published in *Structural Alloys Handbook*, Vol 2, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1994, p 64



SS.050 304 annealed stainless steel, isochronous stress-strain curves at 538 °C (1000 °F)

Composition: Fe-19Cr-9.25Ni. UNS S30400

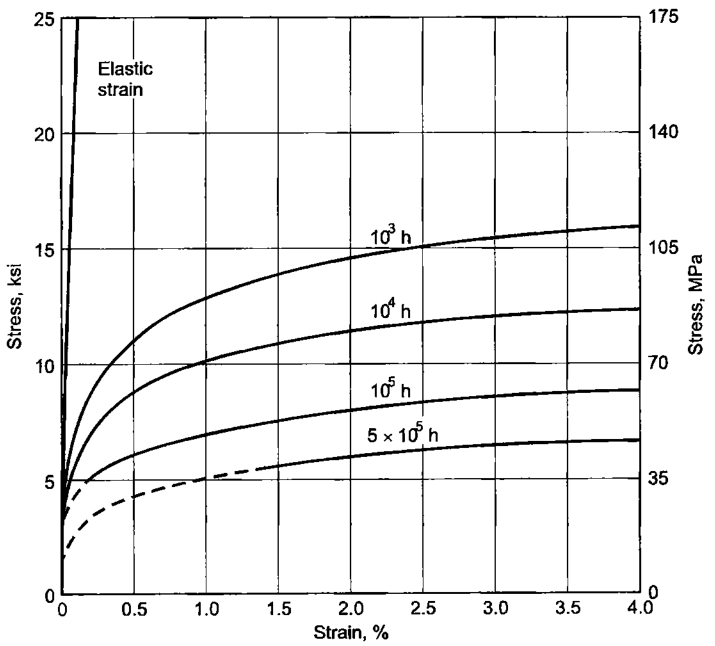
Source: "Isochronous Stress-Strain Curves for 2¼Cr-1Mo, Type 304-304H, and Type 316-316H Steels," TR 2012-Part 1, prepared for U.S. Atomic Energy Commission, Contract No. AT(04-3)-781, Braun Project 4122-W, United Nuclear Project 2351, 16 Oct 1970. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1303, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 25



SS.051 304 annealed stainless steel, isochronous stress-strain curves at 593 °C (1100 °F)

Composition: Fe-19Cr-9.25Ni. UNS S30400

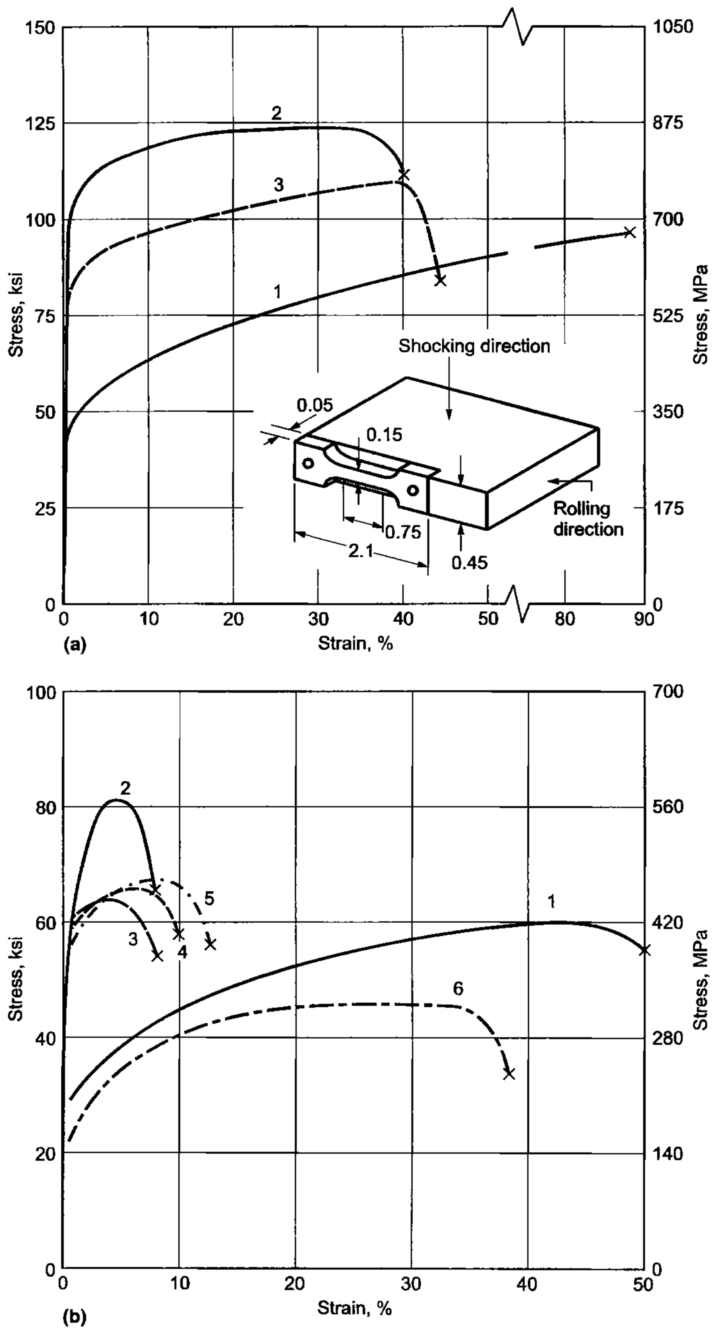
Source: "Isochronous Stress-Strain Curves for 2¼Cr-1Mo, Type 304-304H, and Type 316-316H Steels," TR 2012-Part 1, prepared for U.S. Atomic Energy Commission, Contract No. AT(04-3)-781, Braun Project 4122-W, United Nuclear Project 2351, 16 Oct 1970. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1303, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 25



SS.052 304 annealed stainless steel, isochronous stress-strain curves at 649 °C (1200 °F)

Composition: Fe-19Cr-9.25Ni. UNS S30400

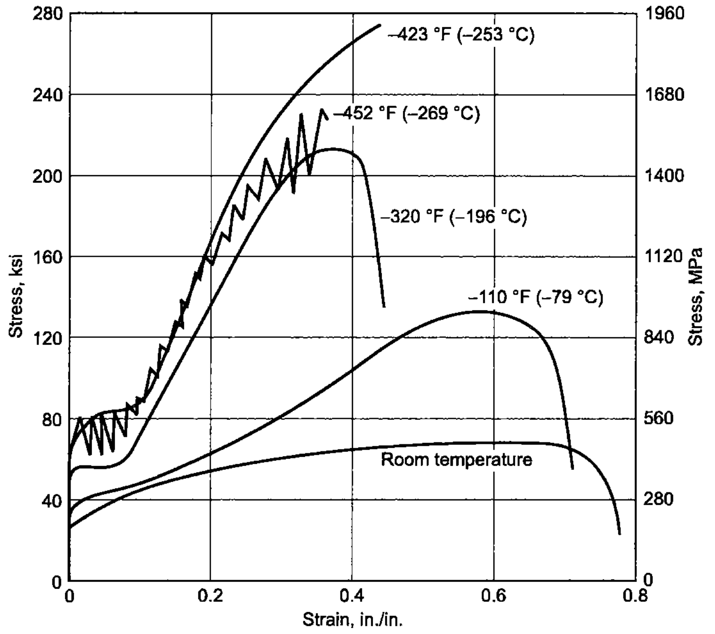
Source: "Isochronous Stress-Strain Curves for 2¼Cr-1Mo, Type 304-304H, and Type 316-316H Steels," TR 2012-Part 1, prepared for U.S. Atomic Energy Commission, Contract No. AT(04-3)-781, Braun Project 4122-W, United Nuclear Project 2351, 16 Oct 1970. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1303, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 25



SS.053 304 hot-rolled solution-annealed stainless steel plate, stress-strain curves at room temperature (a) and 500 °C (b) for shock-strengthened material

Plate thickness = 12.7 mm (0.5 in.). Curve 1: unshocked. Curve 2: as-shocked at 320 kbar. Curve 3: shocked at 320 kbar, annealed 100 h at 650 °C. Curve 4, shocked at 320 kbar, annealed 1 h at 750 °C. Curve 5: shocked at 320 kbar, annealed 1 h at 800 °C. Curve 6: shocked at 320 kbar, annealed 1 h at 900 °C. Composition: 18.20Cr-9.60Ni-0.06C-1.45Mn-0.60Si-0.024P-0.018S-0.18Mo-0.17Cu-bal Fe-N as shown. Dimensions in schematic are given in inches (1 in. = 25.4 mm). UNS S30400

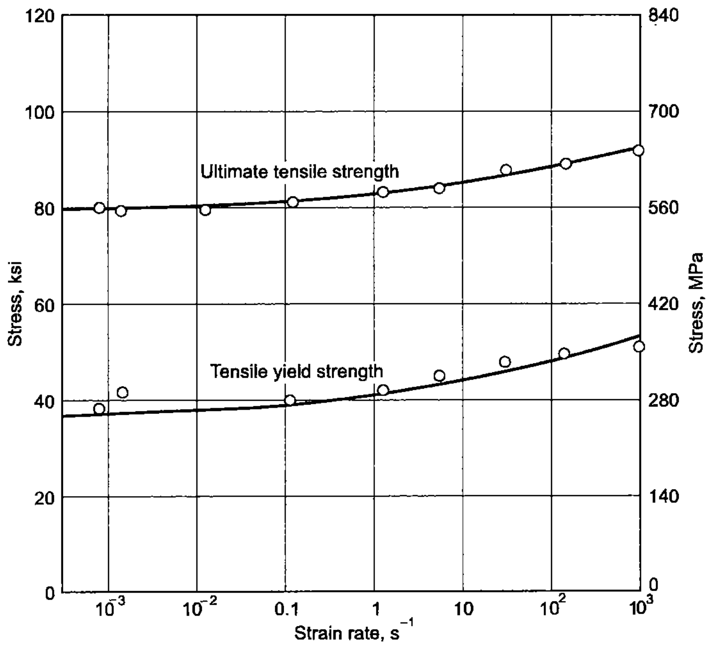
Source: M. Kangilaski and A.A. Bauer, "Mechanical Properties of Shock-Strengthened Austenitic Stainless Steel," BMI-1909, Battelle Columbus Laboratories, June 1971; M. Kangilaski et al., Elevated Temperature Mechanical Properties of Shock-Strengthened Austenitic Stainless Steel, *Metall. Trans.*, Vol 2, Sept 1971. As published in *Structural Alloys Handbook*, Vol 2, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1994, p 64



SS.054 304L annealed stainless steel bar, stress-strain curves for room and low temperatures

Bar diameter = 19.05 mm (0.750 in.). Composition: Fe-low C-19Cr-10Ni. UNS S30403

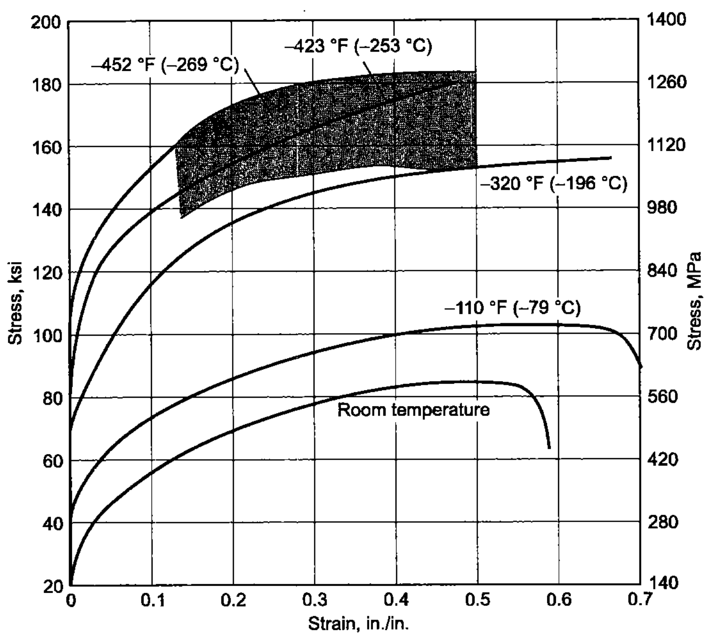
Source: "Cryogenic Materials Data Handbook," ML-TRD-64-280, Martin Co., Denver, CO, Aug 1964. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1303, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 13



SS.055 310 annealed stainless steel sheet, effect of strain rate on mechanical properties

Sheet thickness = 1.60 mm (0.063 in.). Composition: Fe-25Cr-20.5Ni. UNS S31000

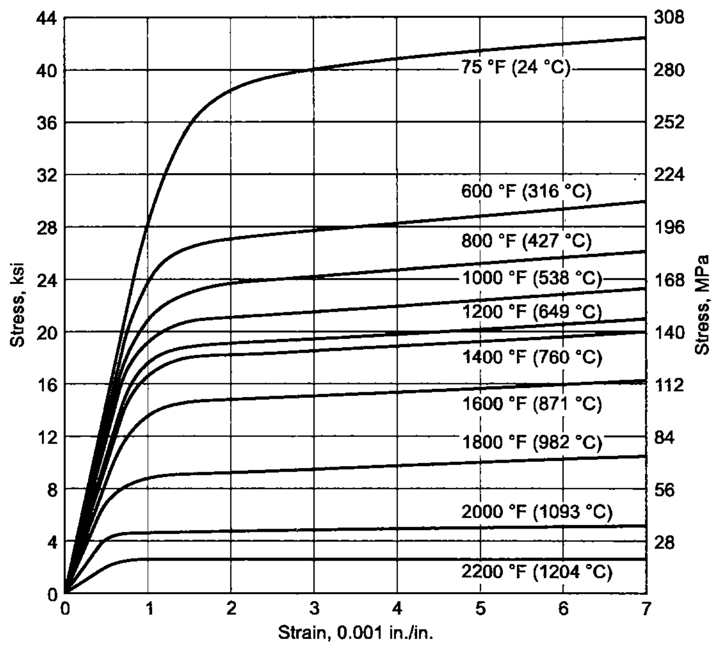
Source: R.G. Davies and C.L. Magee, The Effect of Strain-Rate upon the Tensile Deformation of Metals, *J. Eng. Mater. Technol.,* April 1975, p 151. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1305, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 22



SS.056 310 annealed stainless steel bar, stress-strain curves at room and low temperatures

Bar diameter = 19.05 mm (0.75 in.). Shaded area indicates serrated –452 °F (–269 °C) curve. Composition: Fe-25Cr-20.5Ni. UNS S31000

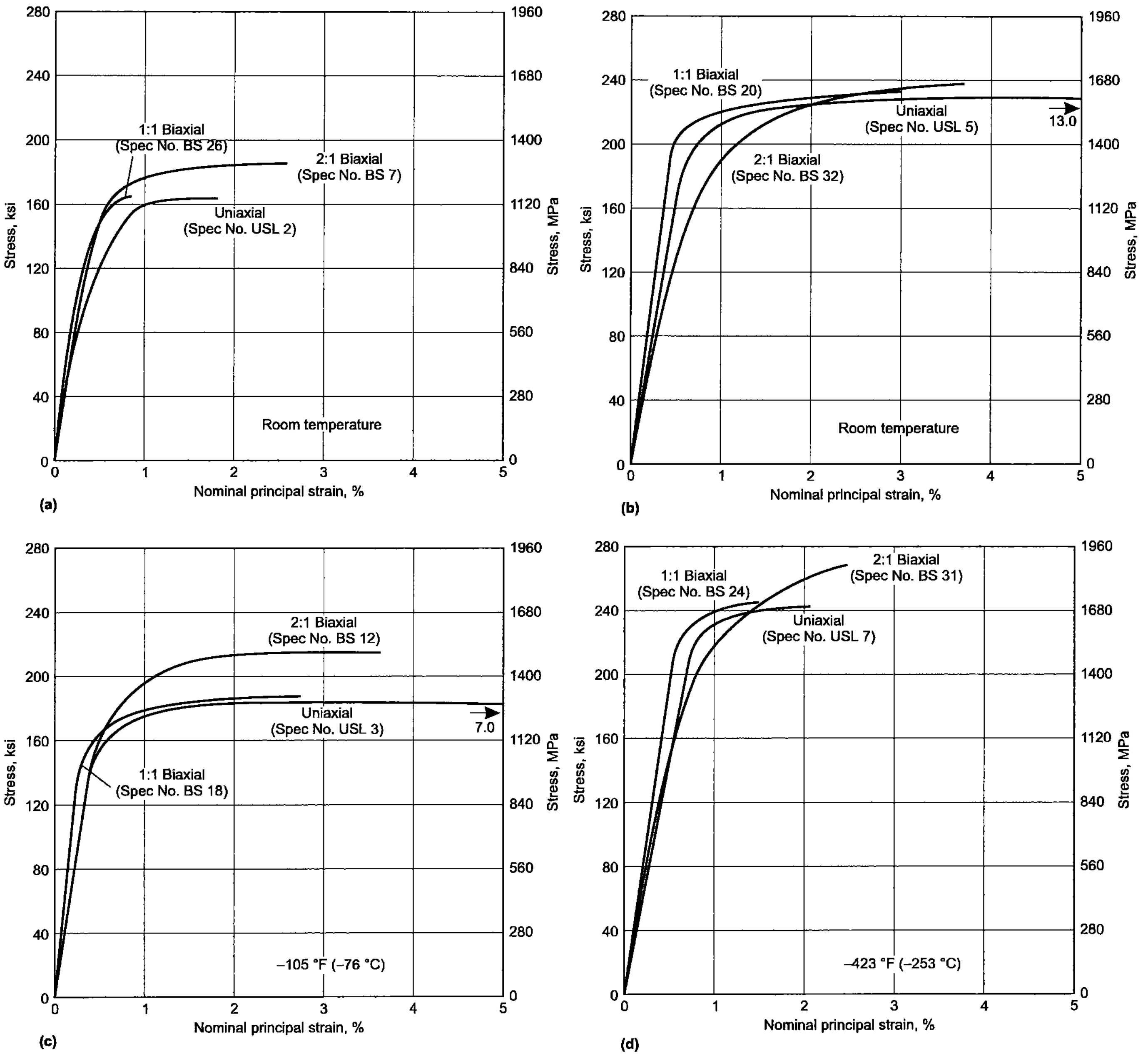
Source: C.J. Guntner and R.P. Reed, The Effect of Experimental Variables Including the Martensitic Transformation on the Low-Temperature Mechanical Properties of Austenitic Stainless Steels, *Trans. ASM,* Vol 55, 1962. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1305, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 22



SS.057 310 annealed stainless steel sheet, stress-strain curves at room and elevated temperatures

Sheet thickness = 1.575 mm (0.062 in.). Test conditions: resistance heated at 93 °C/s (200 °F/s). Strain rate = 0.001/s. Composition: Fe-25Cr-20.5Ni. UNS S31000

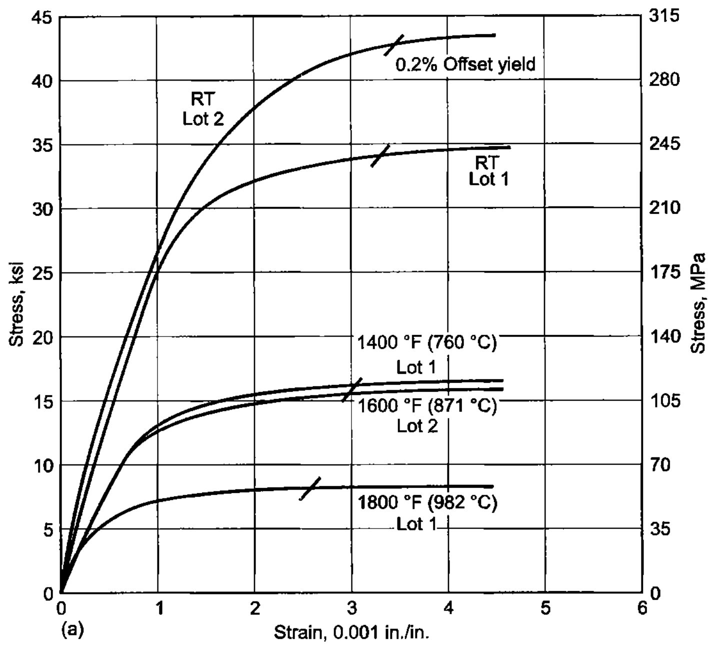
Source: A.S. Rabensteine, "Mechanical Properties of 310, 316 and 317L Stainless Steel Sheet Alloys at Elevated Temperatures," Contract Number AF33(657)-8706, Project 281, The Marquardt Corp., Van Nuys, CA, Dec 1962. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1305, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 23

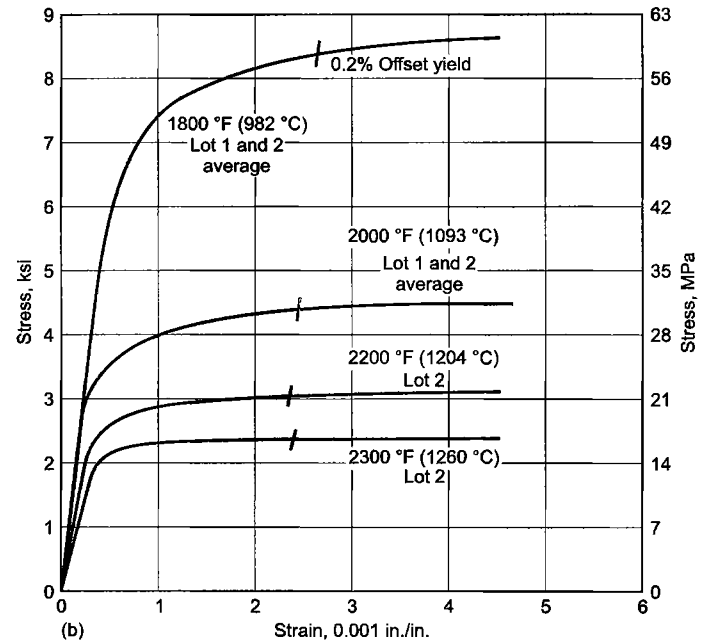


SS.058 310 stainless steel, typical stress-strain curves for uniaxial and biaxial stress at room and low temperatures

Test direction: longitudinal. Composition: Fe-25Cr-20.5Ni. UNS S31000

Source: S.W. McClaren and C.R. Foreman, "Cryogenic Design Data for Materials Subjected to Uniaxial and Multiaxial Stress Field," AFML-TR-65-140, May 1965. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1305, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 23

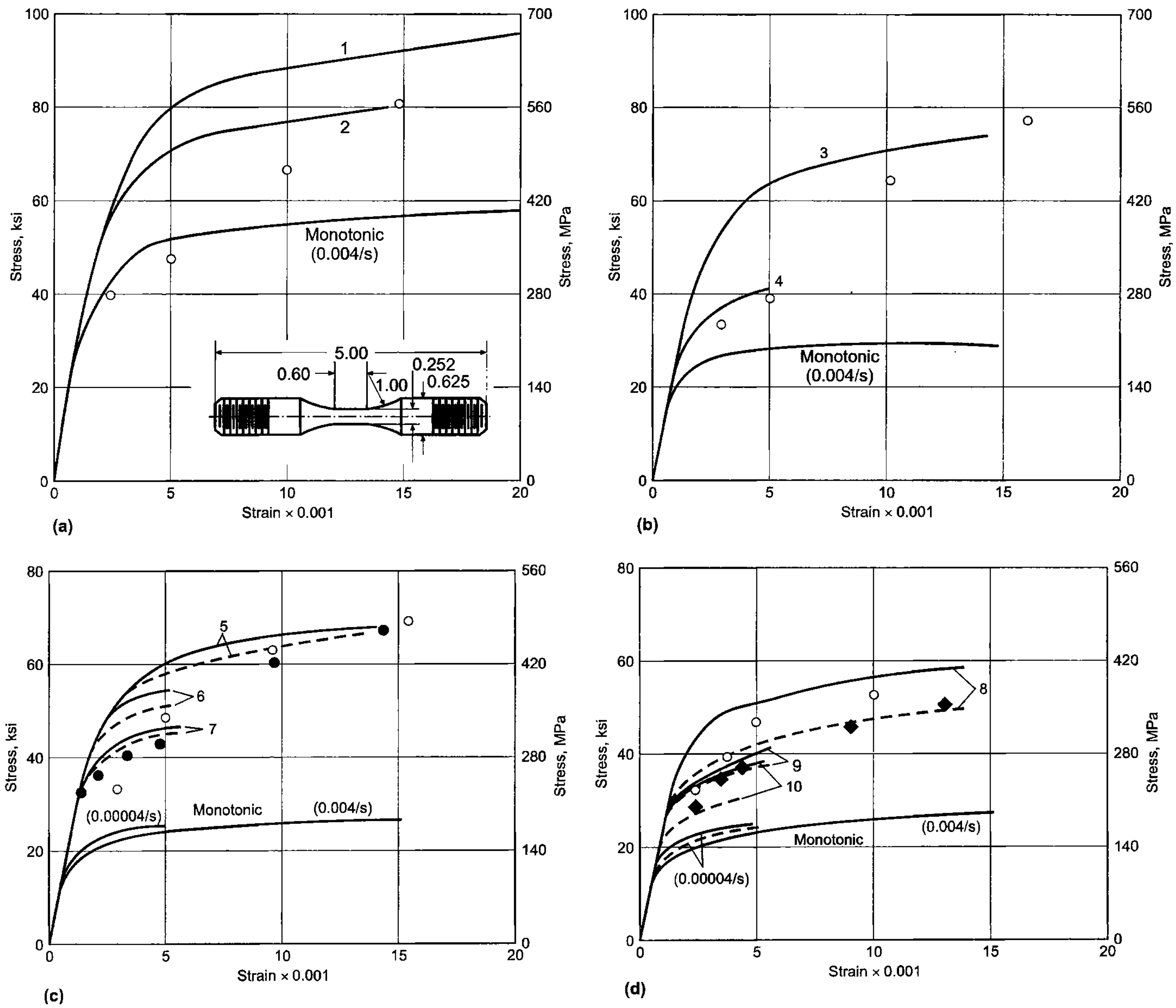




SS.059 316 stainless steel bar, stress-strain curves at room and elevated temperatures

Bar diameter = 19.05 mm (¾ in.). Test section diameter = 12.827 mm (0.505 in.). Difference between two lots is shown. RT, room temperature. Composition lot 1: 17.81Cr-13.17Ni-2.23Mo-1.54Mn-0.56Si-0.042C-0.027P-0.017S. Composition lot 2: 16.60Cr-12.15Ni-1.80Mo-1.58Mn-0.46Si-0.090C-0.028P-0.013S. UNS S31600

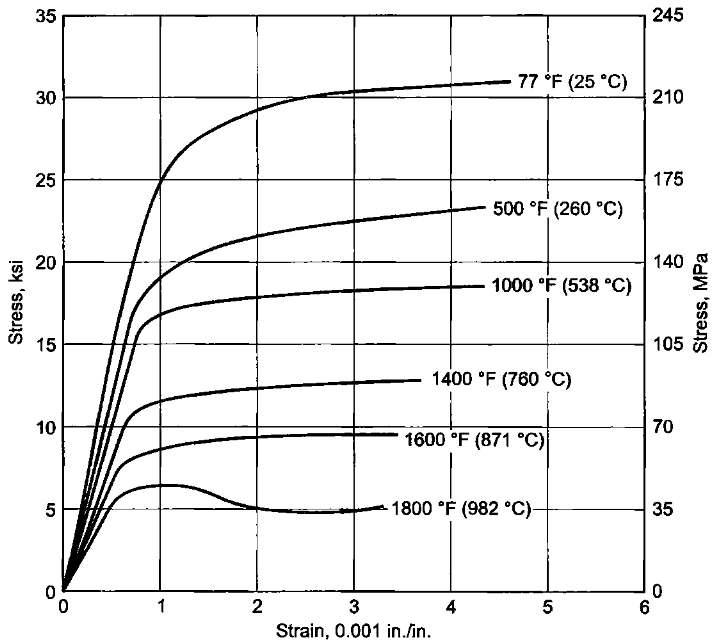
Source: T.W. Gibbs and H.W. Wyatt, Short Time Properties of Type 316 Stainless Steel at Very High Temperatures, Paper No. 60-WA-11, *Trans. ASME, J. Basic Eng.*, 1960. As published in *Structural Alloys Handbook*, Vol 2, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1994, p 31



SS.060 316 stainless steel bar, monotonic and cyclic stress-strain curves at room and elevated temperatures

Bar diameter = 15.875 mm (5/8 in.). Hot rolled, annealed 1066 °C (1950 °F), 1 h. Incremental steps: Solid line, annealed; dashed line, aged 1000 h at test temperature. Constant amplitude continuous cycling: open circle, annealed; solid circle, aged at 538 °C (1000 °F); solid diamond, aged at 649 °C (1200 °F). Strain rate for cyclic curves 1–5, 7–9 = 0.004/s; for curves 6 and 10, strain rate = 0.00004/s. (a) 21 °C (70 °F). (b) 427 °C (800 °F). (c) 566 °C (1050 °F). (d) 649 °C (1200 °F). Composition:17.30Cr-13.30Ni-2.33Mo-1.72Mn-0.40Si-0.06C-0.012P-0.007S-0.065Cu-0.003Ti. Dimensions in schematic given in inches (1 in. = 25.4 mm). UNS S31600

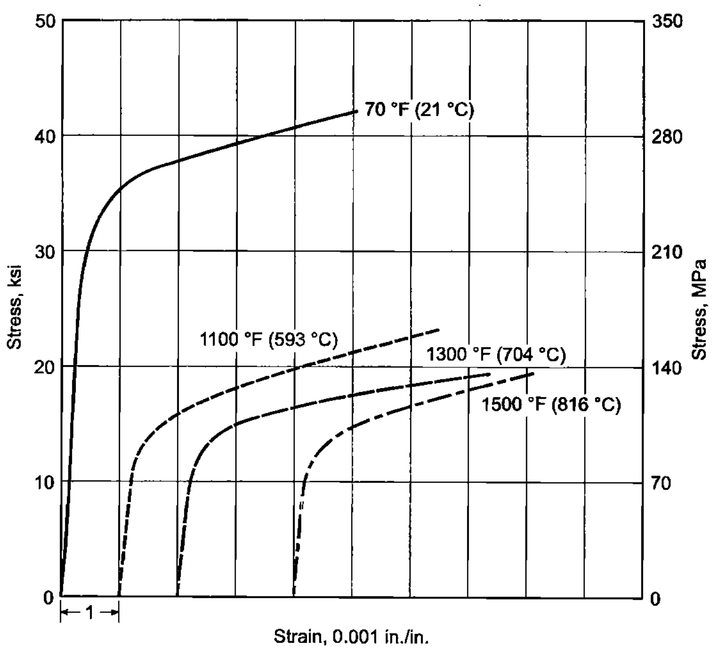
Source: D.A. Keller, "Progress on LMFBR Cladding, Structural and Component Material Studies During July 1971 through June 1972," BMI-1928, Final Report, Task 32, Battelle Columbus, July 1972. As published in *Structural Alloys Handbook*, Vol 2, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1994, p 32



SS.061 316 stainless steel sheet, typical stress-strain curves at room and elevated temperatures

Sheet thickness = 3.175 mm (0.125 in.). Composition: 17.17Cr-12.96Ni-2.15Mo-1.7Mn-0.2Si-0.03C. UNS S31600

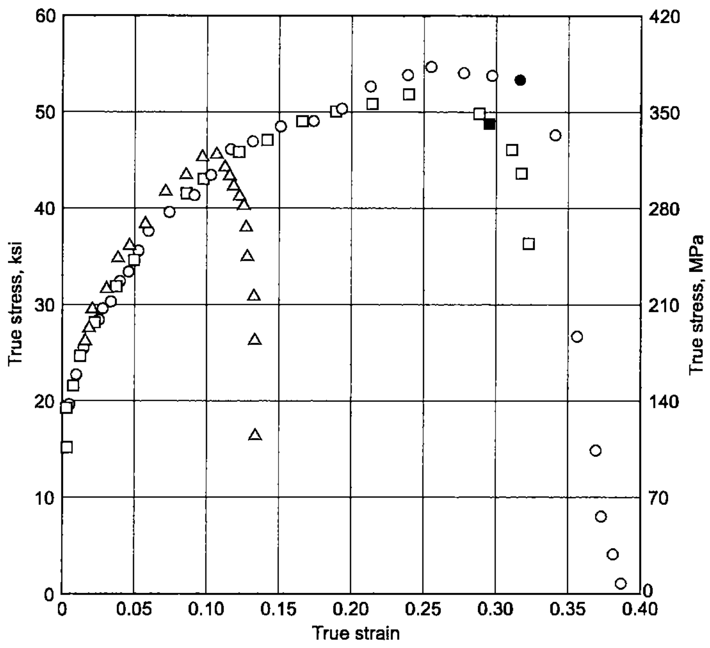
Source: T.W. Gibbs, W. Kyros, and C.L. Theberge, "Development of a Resistance Heating Facility for the Determination of Tensile Properties of Aircraft and Missile Alloys," RaD. TM-63-8, Avco Corp., Feb 1963. As published in *Structural Alloys Handbook,* Vol 2, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1994, p 33



SS.062 316 wrought stainless steel bar, typical stress-strain curves at room and elevated temperatures

Composition: Fe-18Cr-13Ni-Mo. UNS S31600

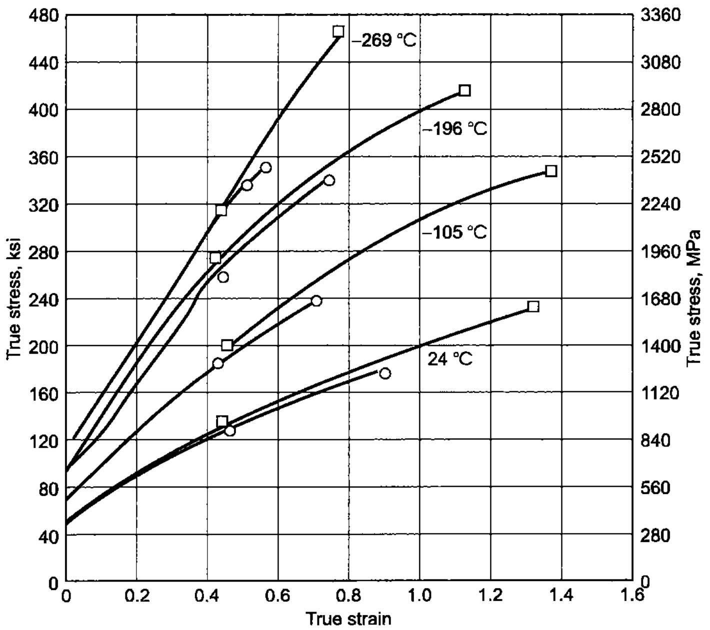
Source: L.J. Fritz and W.P. Koster, "Tensile and Creep Rupture Properties of (16) Uncoated and (2) Coated Engineering Alloys at Elevated Temperatures," NASA Cr-135138, Metcut Research Associates, Inc., Jan 1977. As published in *Structural Alloys Handbook,* Vol 2, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1994, p 33



SS.063 316 annealed stainless steel bar, true stress-strain curves for irradiated and unirradiated samples

True axial strain rate = 4×10^{-5}/s. Test temperature = 649 °C (1200 °F). Closed data points: unirradiated specimens in duplicate tests. Open circles and squares: unirradiated specimens. Open diamond: irradiated specimen 4×10^{18} n/cm^2, $E > 1$ MeV at 70 °C in the ORR core facility. Composition: Fe-17.3Cr-13.1Ni-2.33Mo-1.72Mn-0.4Sc-0.065Cu-0.06C-0.012Al. UNS S31600

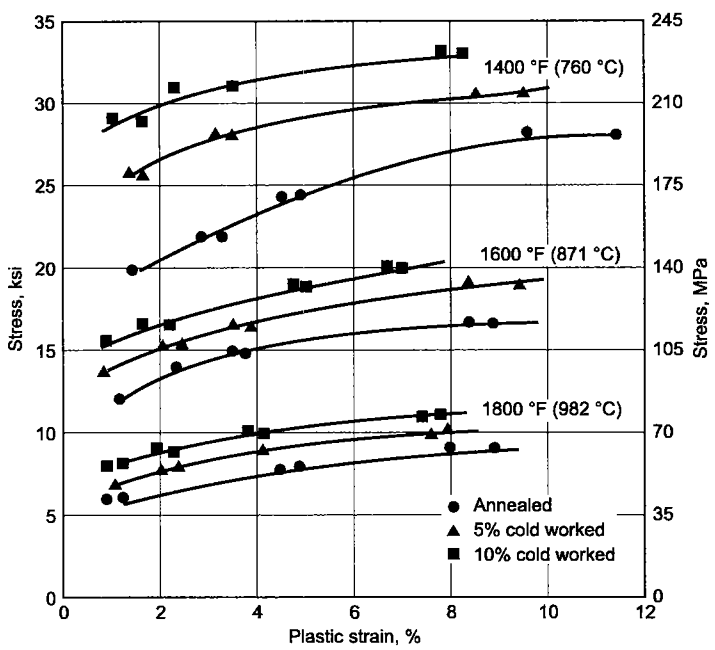
Source: J.B. Conway, J.T. Berling, and R.H. Stentz, "New Correlations Involving the Low-Cycle Fatigue and Short-Term Tensile Behavior of Irradiated and Unirradiated 304 and 316 Stainless Steel," GEMP 726, General Electric Co., Dec 1969. N70-25351. As published in *Structural Alloys Handbook*, Vol 2, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1994, p 34



SS.064 316 stainless steel plate, true stress-strain curves at room and low temperatures for base and weld metal

Plate thickness = 15.9 mm (5/8 in.). Squares: base metal data. Circles: weld metal data. Specimen diameter = 6.401 mm (0.252 in.). Composition: 16.64Cr-12.84Ni-2.69Mo-1.91Mn-0.45Si-0.068C-0.026P-0.012S. UNS S31600

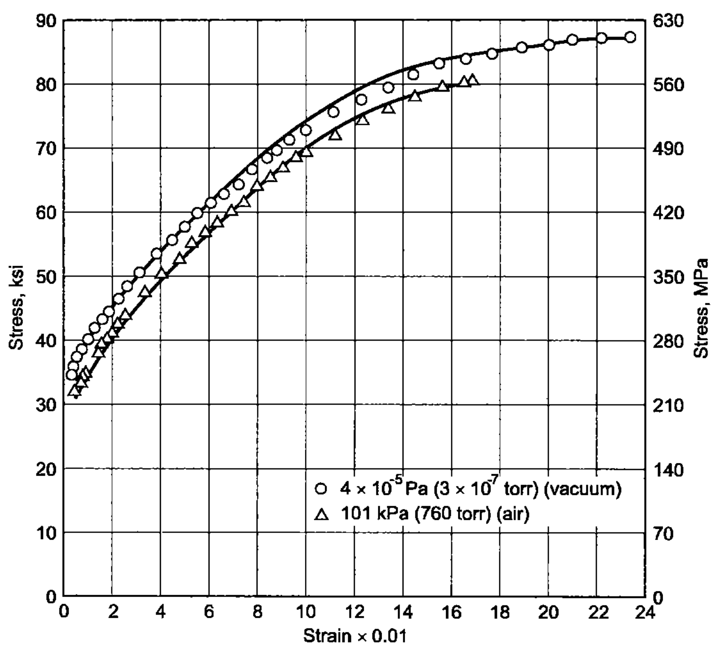
Source: T.S. DeSisto, "Low Temperature Mechanical Properties of Base and Weld Deposits of Selected Austenitic Stainless Steels," AMRA TR 63-08, Metals and Ceramics Research Agency, U.S. Army Materials Research Agency, July 1963, AD 416 119. As published in *Structural Alloys Handbook*, Vol 2, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1994, p 34



SS.065 316 stainless steel sheet, stress versus plastic strain curves for elevated temperatures with effect of annealing and cold working

Sheet thickness = 1.47 mm (0.058 in.). Plastic strain resulting from constant stress for 2 min at elevated temperature. Composition: Fe-18Cr-13Ni-Mo. UNS S31600

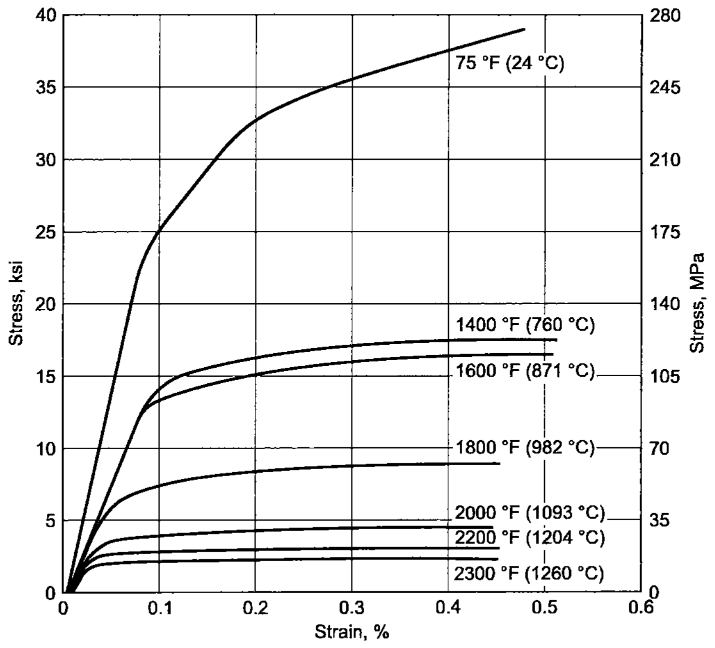
Source: T.W. Gibbs and Wyatt, H.W., "Short-Time Tensile Properties of Type 316 Stainless Steel at Very High Temperatures," ASME Paper No. 60-WA-11. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1307, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 40



SS.066 316 annealed stainless steel wire, effect of vacuum on stress-strain curves at room temperature

Wire diameter = 0.457 mm (0.018 in.). Strain rate = 0.0001/s. Composition: Fe-18Cr-13Ni-Mo. UNS S31600

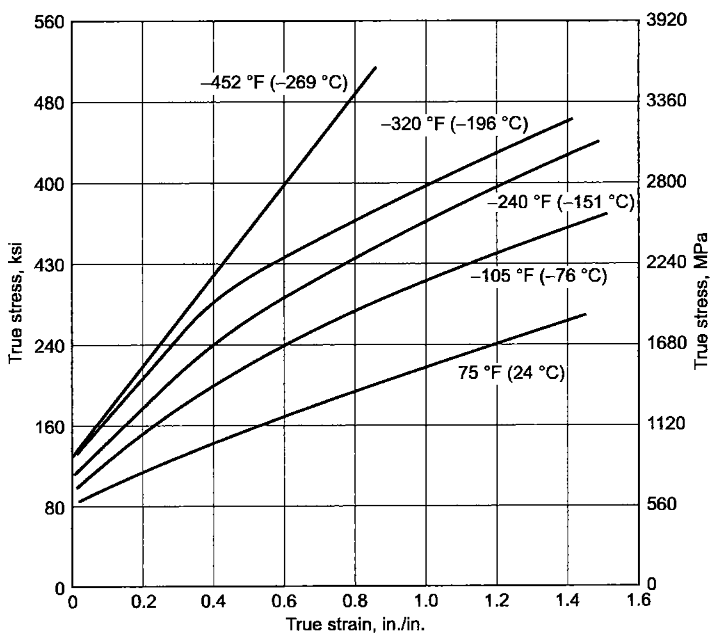
Source: I.R. Kramer and S.D. Podlaseck, "Effect of Low Pressures on the Mechanical Behavior of Metals," Martin Marietta Corp., Oct 1963, AD 424 292. As published in *Structural Alloys Handbook*, Vol 2, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1994, p 33



SS.067 316 annealed stainless steel bar, stress-strain curves at room and elevated temperatures

Composition: Fe-18Cr-13Ni-Mo. UNS S31600

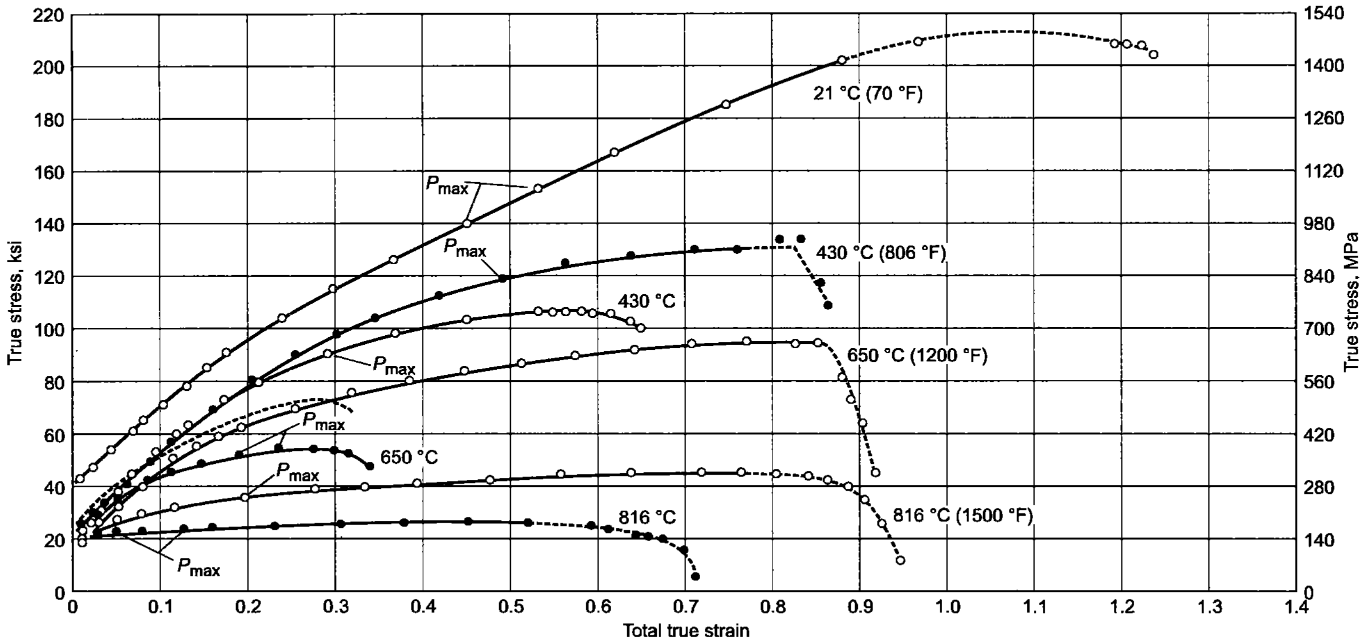
Source: T.W. Gibbs and H.W. Wyatt, "Short-Time Tensile Properties of Type 316 Stainless Steel at Very High Temperatures," ASME Paper No. 60-WA-11. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1307, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 29



SS.068 316 mill annealed stainless steel bar, complete true stress-strain curves for room and low temperatures

Bar diameter = 12.7 mm (0.5 in.). Composition: Fe-18Cr-13Ni-Mo. UNS S31600

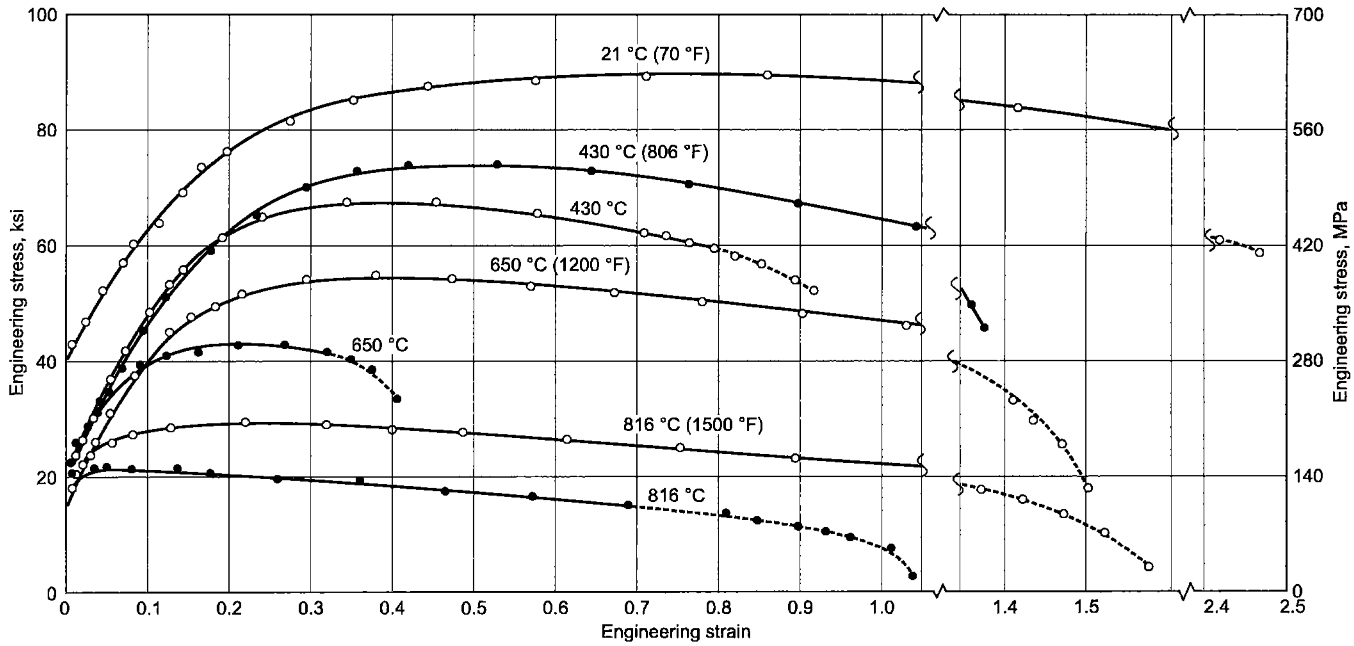
Source: T.S. DeSisto and F.L. Carr, "Low Temperature Mechanical Properties of 300 Series Stainless Steels and Titanium," WAL TR 323, 4/1, Watertown Arsenal Laboratories, Dec 1961. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1307, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 29



SS.069 316 annealed stainless steel bar, true stress-strain curves at room and elevated temperatures

Bar diameter = 6.35 mm (0.25 in.). Data were collected at constant axial true strain rates of 0.004 (open data points) and 0.00004 (solid data points). The curves for the higher strain rates are above the other curve at 650 and 816 °C (1202 and 1580 °F), while the reverse is true for 430 °C (806 °F). Contrary to what is expected for true stress-strain curves, these have a maximum point. This is believed to be due to the formation of internal voids that reduce the actual area under stress. For this reason the lines are dashed as they approach the fracture point. P_{max} is the point of maximum load. Composition: Fe-18Cr-13Ni-Mo. UNS S31600

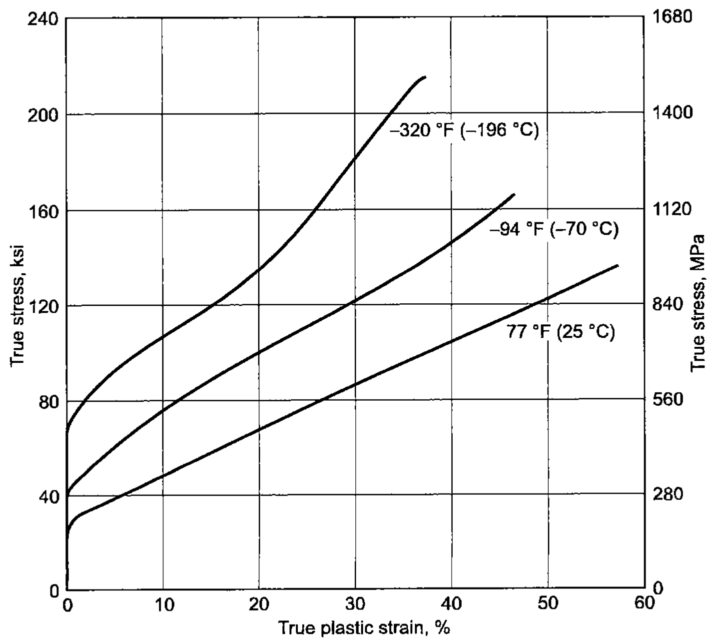
Source: J.B. Conway, R.H. Stentz, and J.T. Berling, "Fatigue, Tensile, and Relaxation Behavior of Stainless Steels," Technical Information Center, USAEC, 1975, p 214



SS.070 316 annealed stainless steel bar, engineering stress-strain curves at room and elevated temperatures

Bar diameter = 6.35 mm (0.25 in.). Data were collected at constant axial true strain rates of 0.004 (open data points) and 0.00004 (solid data points). Same data was used as for the true stress-strain curve. The curves for the higher strain rates are above the other curve at 650 and 816 °C (1202 and 1580 °F), while the reverse is true for 430 °C (806 °F). The strain rate effect is more pronounced for the higher temperatures. The lines are dashed as they approach the fracture point. Composition: Fe-18Cr-13Ni-Mo. UNS S31600

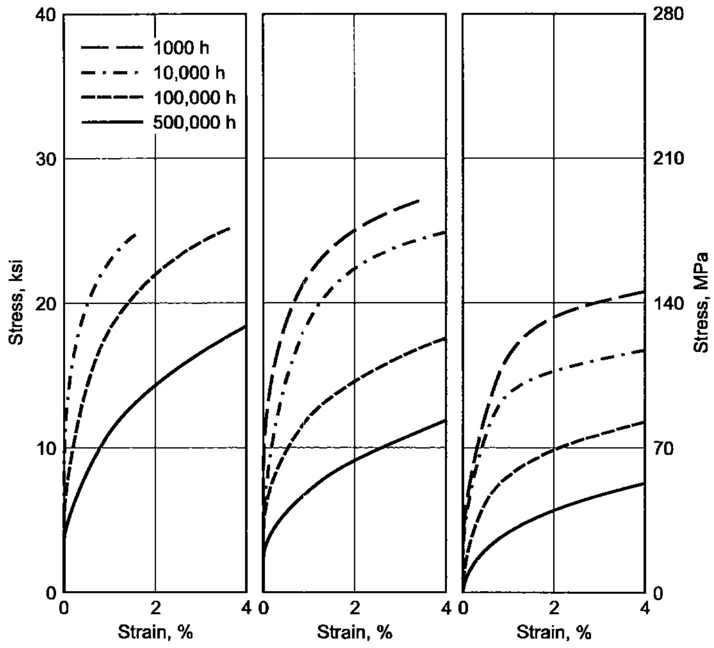
Source: J.B. Conway, R.H. Stentz, and J.T. Berling, "Fatigue, Tensile, and Relaxation Behavior of Stainless Steels," Technical Information Center, USAEC, 1975, p 216



SS.071 316 annealed stainless steel sheet, true stress-strain curves at room and low temperatures

Sheet thickness = 0.762 mm (0.03 in.). Annealed 1049 °C (1920 °F), 0.25 h, water quenched, grain size = 100 μm, gage section = 6.35 × 0.762 × 25.4 mm (0.25 × 0.03 × 1.0 in.), strain rate = 0.004/min. Composition: Fe-18Cr-13Ni-Mo. UNS S31600

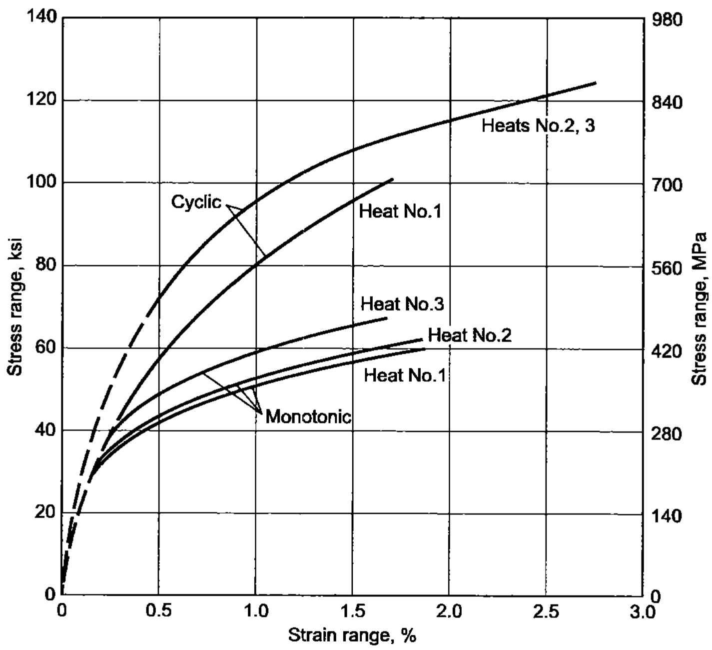
Source: V. Seetharaman and R. Krishnan, Influence of the Martensitic Transformation on the Deformation Behavior of an AISI 316 Stainless Steel at Low Temperatures, *J. Mater. Sci.*, Vol 16 (No. 2), Feb 1981, p 523–530. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1307, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 30



SS.072 316 annealed stainless steel wrought, isochronous stress-strain curves at elevated temperatures

Left: 538 °C (1000 °F). Middle: 593 °C (1100 °F). Right: 649 °C (1200 °F). Composition: Fe-18Cr-13Ni-Mo. UNS S31600

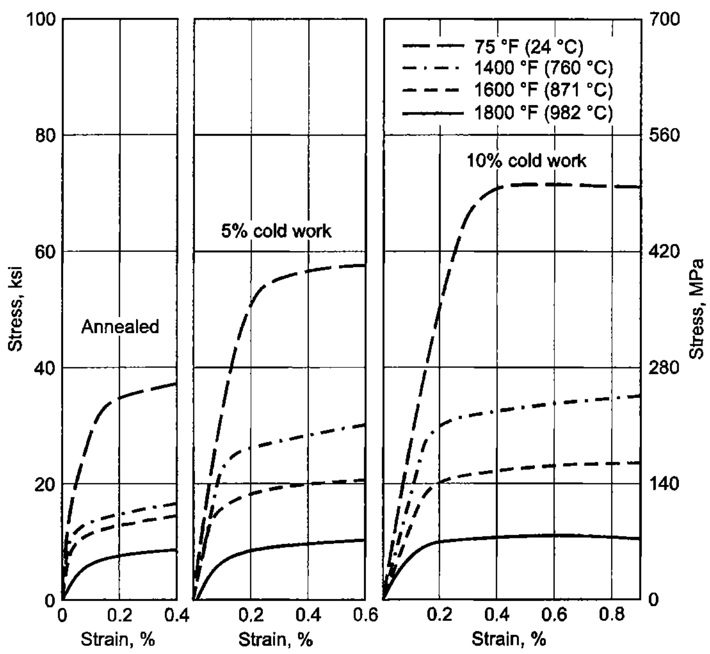
Source: "Isochronous Stress-Strain Curves for 2¼Cr-1Mo, Type 304-304H, and Type 316-316H Steels," Technical Report 2012-Part 1, United Nuclear Corp., Sept 1970. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1307, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 40



SS.073 316 annealed stainless steel bar, cyclic and monotonic stress-strain curves in air at 627 °C (1160 °F)

Specimen reduced section 7.4 mm (0.29 in.) diam × 12.7 mm (0.50 in.) long. Solution annealed 699 °C (1920 °F). Cyclic test: triangular strain wave form, $R = -1$, strain rate = 4%/min. Composition: Fe-18Cr-13Ni-Mo. UNS S31600

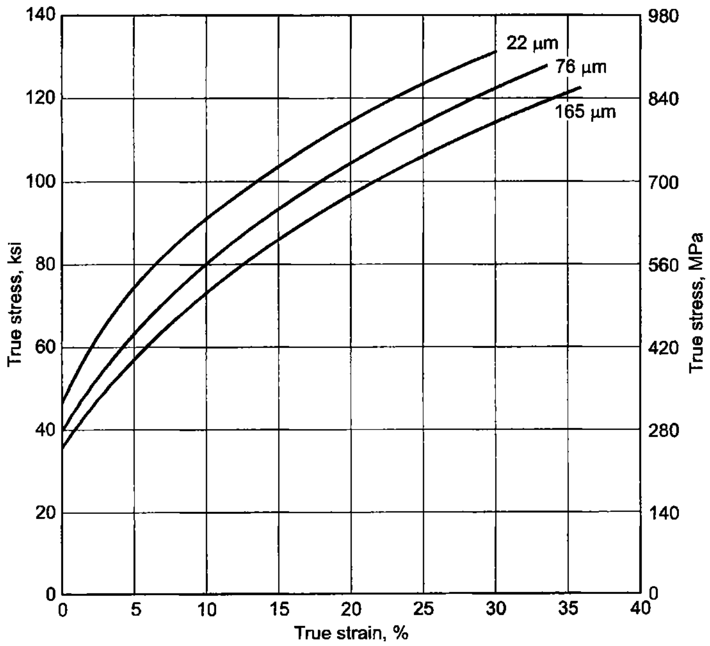
Source: D.S. Wood, J. Wynn, A.B. Baldwin, and P. O'Riordan, Some Creep Fatigue Properties of Type 316 Steel at 625 C, *Fatigue Eng. Mater. Struct.,* Vol 3, No. 1, 1980, p 39–57. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1307, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 43



SS.074 316 annealed and cold-worked stainless steel sheet, stress-strain curves for room and elevated temperatures

Test direction: longitudinal. Sheet thickness = 1.473 mm (0.058 in.). Specimens vacuum annealed, 1093 °C (2000 °F), 15 min, plus 5% and 10% cold worked. Composition: Fe-18Cr-13Ni-Mo. UNS S31600

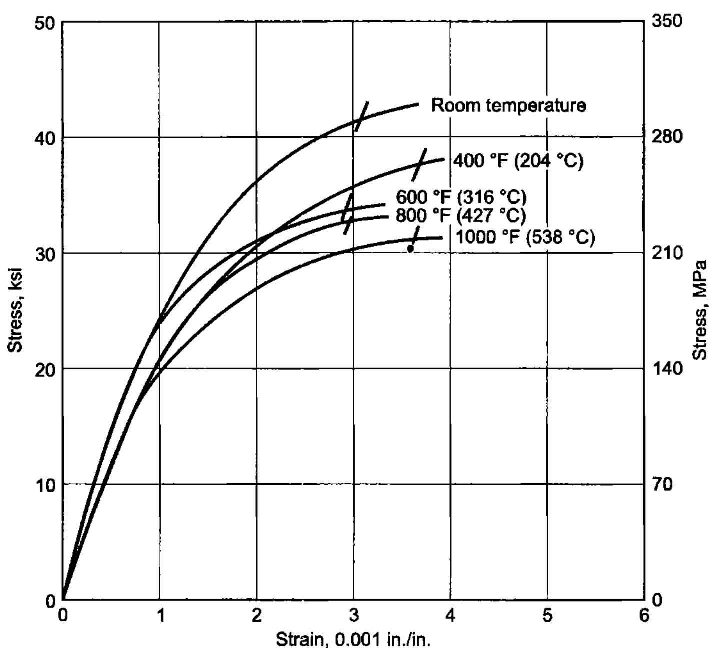
Source: T.W. Gibbs and H.W. Wyatt, "Short-Time Tensile Properties of Type 316 Stainless Steel at Very High Temperatures," ASME Paper No. 60-WA-11. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1307, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 28



SS.075 316L stainless steel plate, true room-temperature stress-strain curves showing effects of grain size

60 kg (110 lb) laboratory heat containing 0.11% N, annealed 999–1199 °C (1830–2190 °F), water quenched. Strain rate = 0.06/min. Composition: Fe-18Cr-13Ni-Mo-low C. UNS S31603

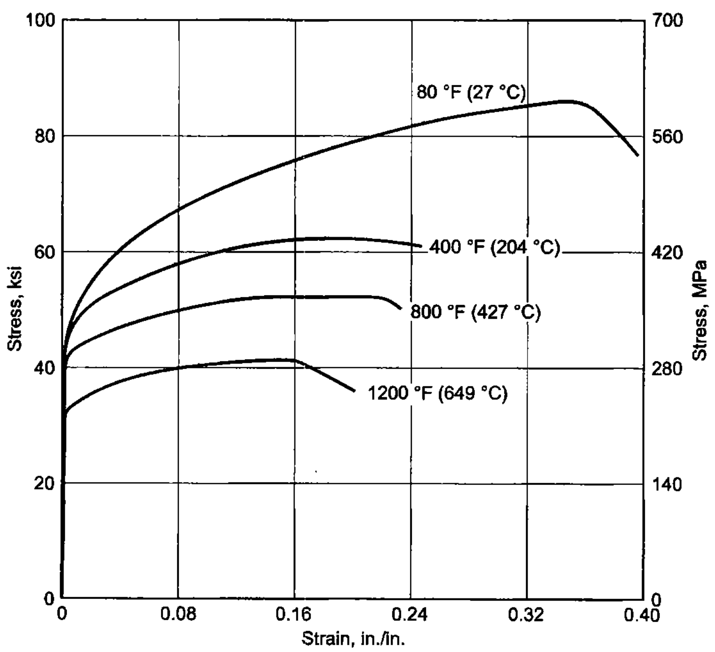
Source: L.-A. Norstrom, Influence of Grain Size on Flow Stress in an Austenitic Stainless Steel, *Scand. J. Metall.,* Vol 6 (No. 4), 1977, p 145–150. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1307, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 25



SS.076 321 annealed stainless steel sheet, tensile stress-strain curves at room and elevated temperatures

Sheet thickness = 1.60 mm (0.063 in.). 0.5–100 h exposure. Composition: Fe-18Cr-10Ni-Ti. UNS S32100

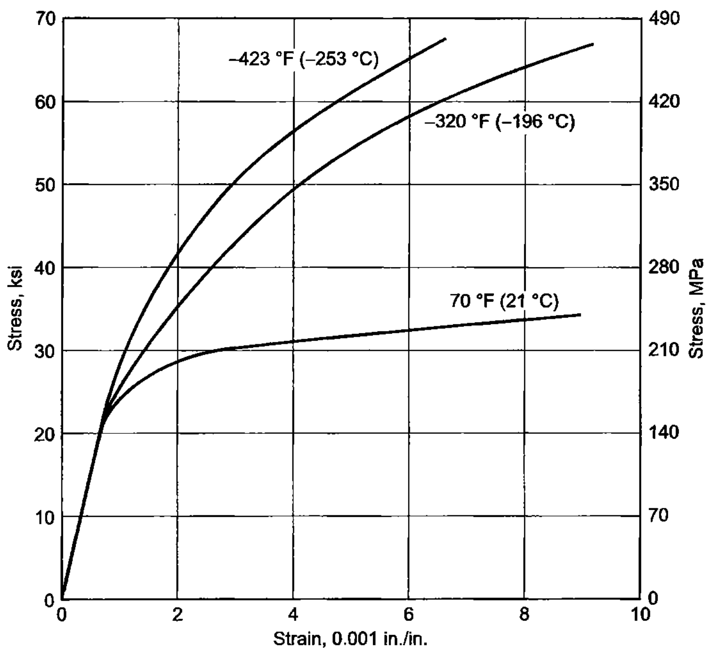
Source: D.E. Miller, "Determination of the Physical Properties of Ferrous and Non-Ferrous Structural Sheet Materials at Elevated Temperatures," AFTR 6517, Pt 4, Dec 1954. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1308, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 21



SS.077 321 annealed stainless steel sheet, complete tensile stress-strain curves at room and elevated temperatures

Sheet thickness = 1.016 mm (0.040 in.). 0.5 h exposure. Strain rate = 0.003/s. Composition: Fe-18Cr-10Ni-Ti. UNS S32100

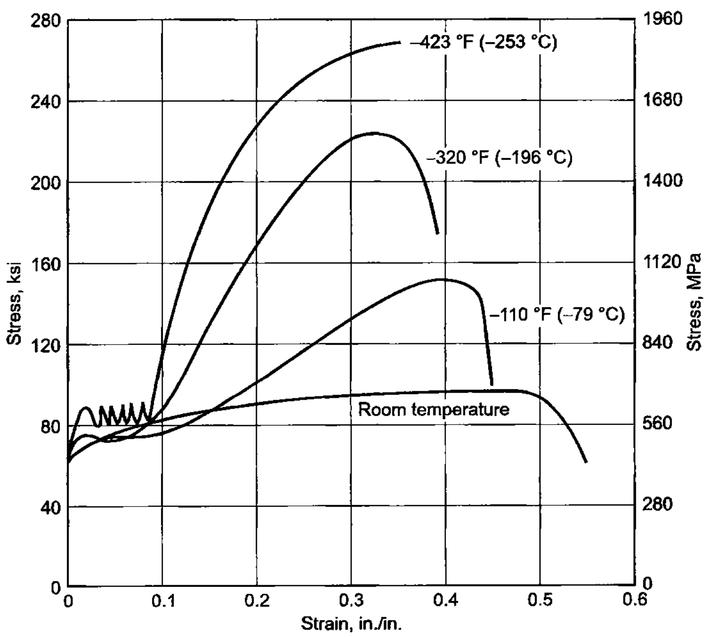
Source: H.E. Dedman, E.J. Wheelahan, and J.R. Kattus, "Tensile Properties of Aircraft-Structural Metals at Various Rates of Loading after Rapid Heating," WADC TR58-440, Part 1, Nov 1958. As published in *Aerospace Structural Metals Handbook,* Vol 2,
Code 1308, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 21



SS.078 321 annealed stainless steel sheet, tensile stress-strain curves at room and low temperatures

Sheet thickness = 1.27 mm (0.050 in.). Annealed 1066 °C (1950 °F), air cooled. Composition: Fe-18Cr-10Ni-Ti. UNS S32100

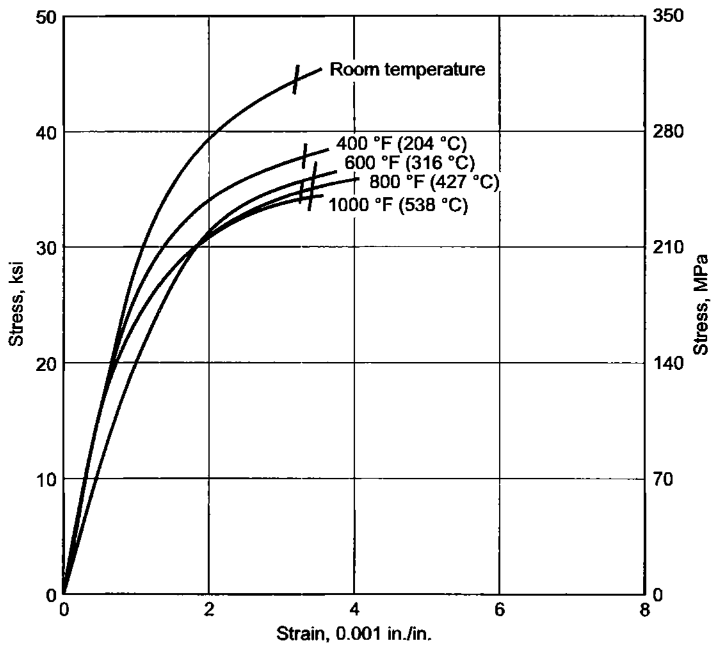
Source: E.H. Schmidt and E.F. Green, "Fatigue Properties of Sheet, Bar and Cast Metallic Materials for Cryogenic Applications," Rocketdyne R-7564, Aug 1968. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1308, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 22



SS.079 321 annealed stainless steel bar, complete tensile stress-strain curves at room and low temperatures

Bar diameter = 19.05 mm (0.75 in.). Composition: Fe-18Cr-10Ni-Ti. UNS S32100

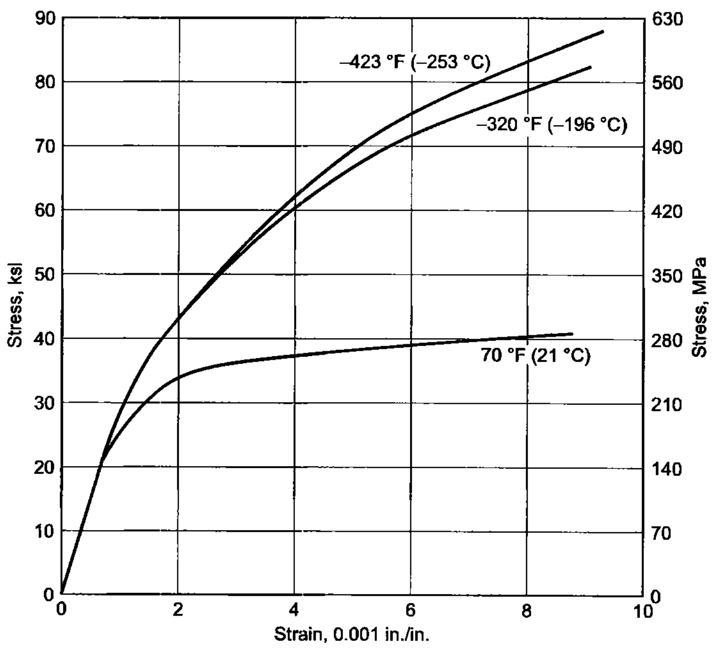
Source: T.F. Durham, R.M. McClintock, and R.P. Reed, "Cryogenic Materials Data Handbook," U.S. Dept. of Commerce, 1960. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1308, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 22



SS.080 321 annealed stainless steel sheet, compressive stress-strain curves at room and elevated temperatures

Sheet thickness = 1.60 mm (0.063 in.). 0.5–100 h exposure. Composition: Fe-18Cr-10Ni-Ti. UNS S32100

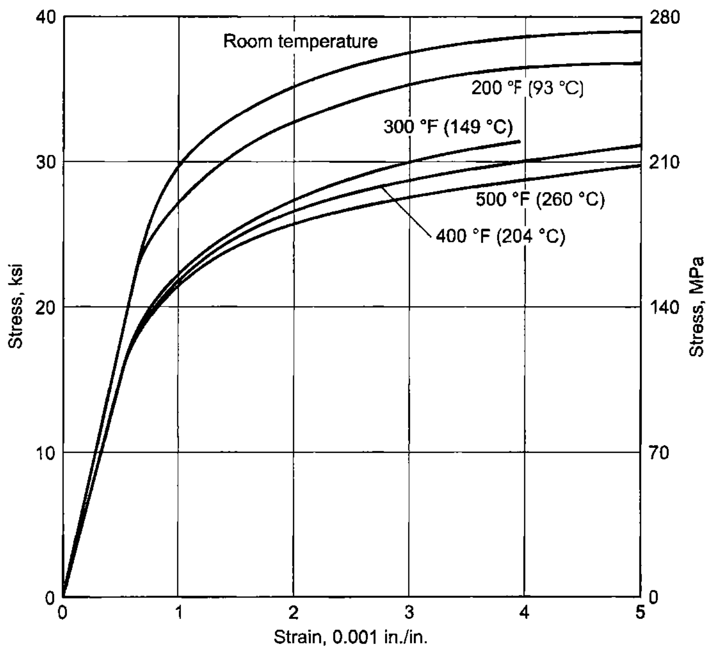
Source: D.E. Miller, "Determination of the Physical Properties of Ferrous and Non-Ferrous Structural Sheet Materials at Elevated Temperatures," AFTR 6517, Pt 4, Dec 1954. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1308, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 26



SS.081 347 annealed stainless steel sheet, tensile stress-strain curves at room and low temperatures

Sheet thickness = 1.27 mm (0.050 in.). Composition: Fe-18Cr-12Ni-Nb (Nb stabilized). UNS S34700

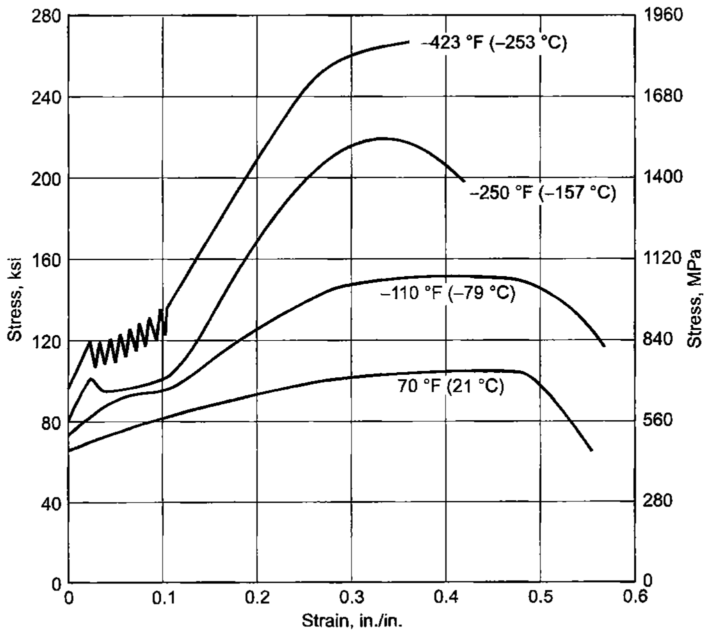
Source: E.F. Green and E.H. Schmidt, "Fatigue Properties of Metallic Materials for Cryogenic Applications," R-7564, Rocketdyne, Aug 1968. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1309, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 11



SS.082 347 stainless steel sheet, tensile stress-strain curves at room and elevated temperatures

Sheet thickness = 1.60 mm (0.063 in.). Composition: Fe-18Cr-12Ni-Nb (Nb stabilized). UNS S34700

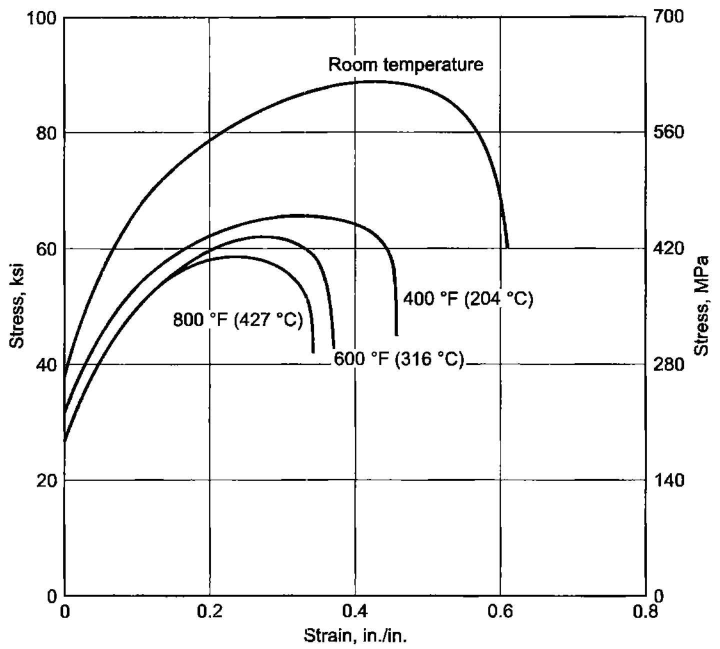
Source: "Short-Time High Temperature Data," No. BLR 53-195, Bell Aircraft Corp., 16 July 1954. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1309, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 11



SS.083 347 annealed stainless steel bar, complete engineering tensile stress-strain curves at room and low temperatures

Composition: Fe-18Cr-12Ni-Nb (Nb stabilized). UNS S34700

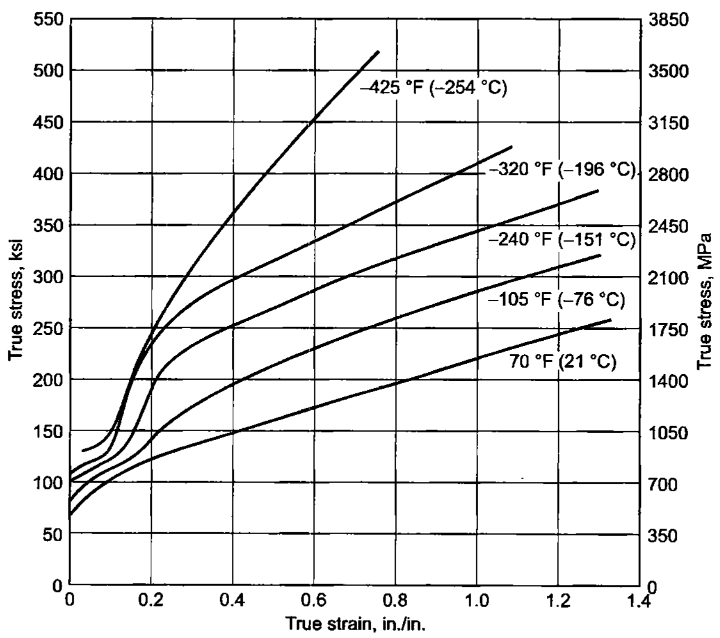
Source: K.A Warren and R.P. Reed, *Tensile and Impact Properties of Selected Materials from 20 to 300K*, Monograph 63, National Bureau of Standards, 28 June 1963. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1309, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



SS.084 347 stainless steel, general, complete engineering tensile stress-strain curves at room and elevated temperatures

Composition: Fe-18Cr-12Ni-Nb (Nb stabilized). UNS S34700

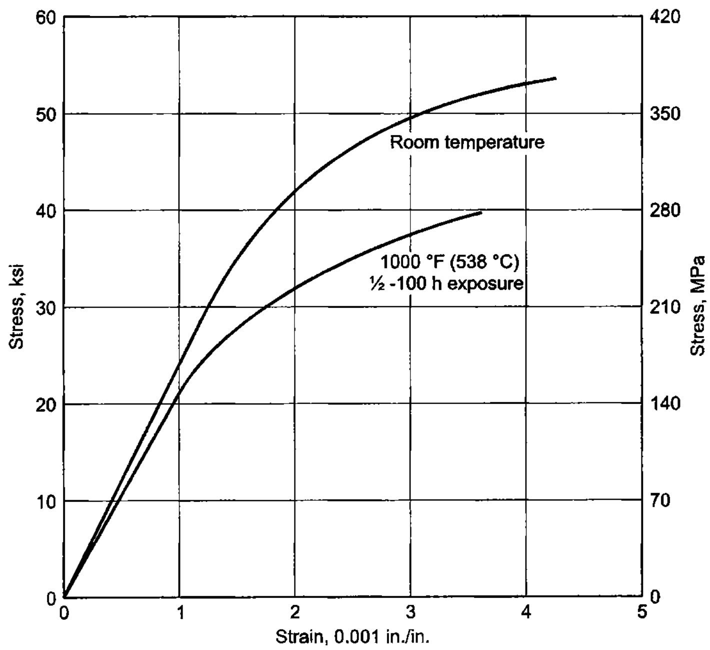
Source: Properties of AISI Type 347 and 348 Stainless Steel, *Bettis Plant Materials Manual,* Westinghouse, May 1957. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1309, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



SS.085 347 mill annealed stainless steel bar, complete true tensile stress-strain curves at room and low temperatures

Bar diameter = 12.7 mm (0.5 in.). Composition: Fe-18Cr-12Ni-Nb (Nb stabilized). UNS S34700

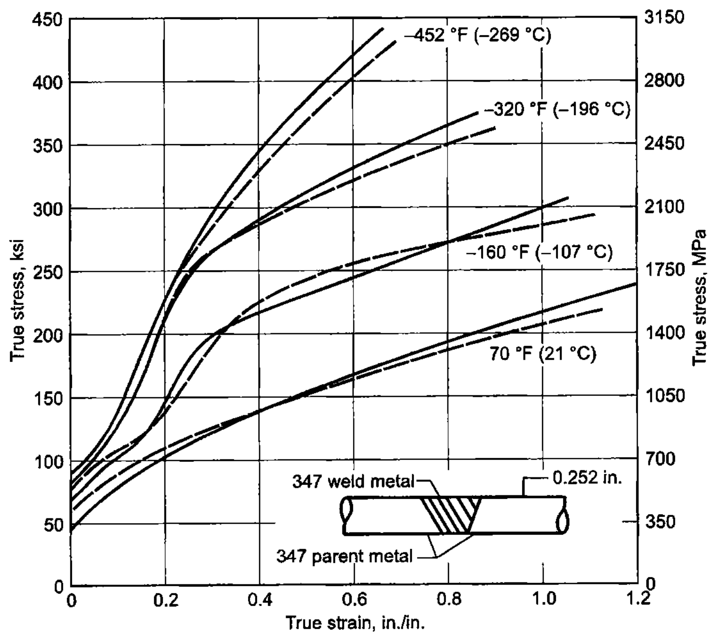
Source: T.S. DeSisto and F.L. Carr, "Low Temperature Mechanical Properties of 300 Series Stainless Steels and Titanium," WAL TR 323, 4/1, Watertown Arsenal Laboratories, Dec 1961. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1309, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



SS.086 347 annealed stainless steel sheet, compressive stress-strain curves at room and elevated temperature

Sheet thickness = 1.60 mm (0.063 in.). Composition: Fe-18Cr-12Ni-Nb (Nb stabilized). UNS S34700

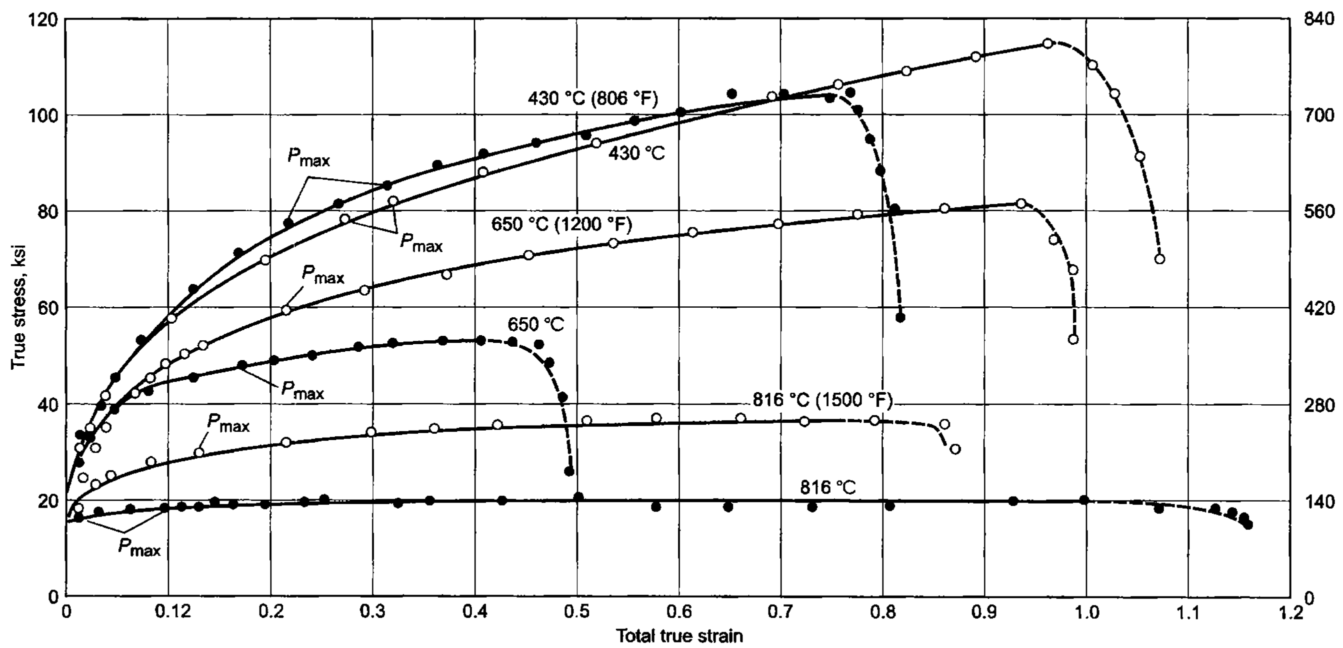
Source: D.E. Miller, "Determination of the Physical Properties of Ferrous and Non-Ferrous Structural Sheet Materials at Elevated Temperatures," AFTR 6517, Pt 4, Dec 1954. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1309, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 16



SS.087 347 stainless steel plate, complete true tensile stress-strain curves at room and low temperatures

Plate thickness = 15.875 mm (5/8 in.). Comparison of parent metal (solid line) and weld metal (dashed line). Butt welded with type 347 coated stick electrodes and annealed after welding. Composition: Fe-18Cr-12Ni-Nb (Nb stabilized). UNS S34700

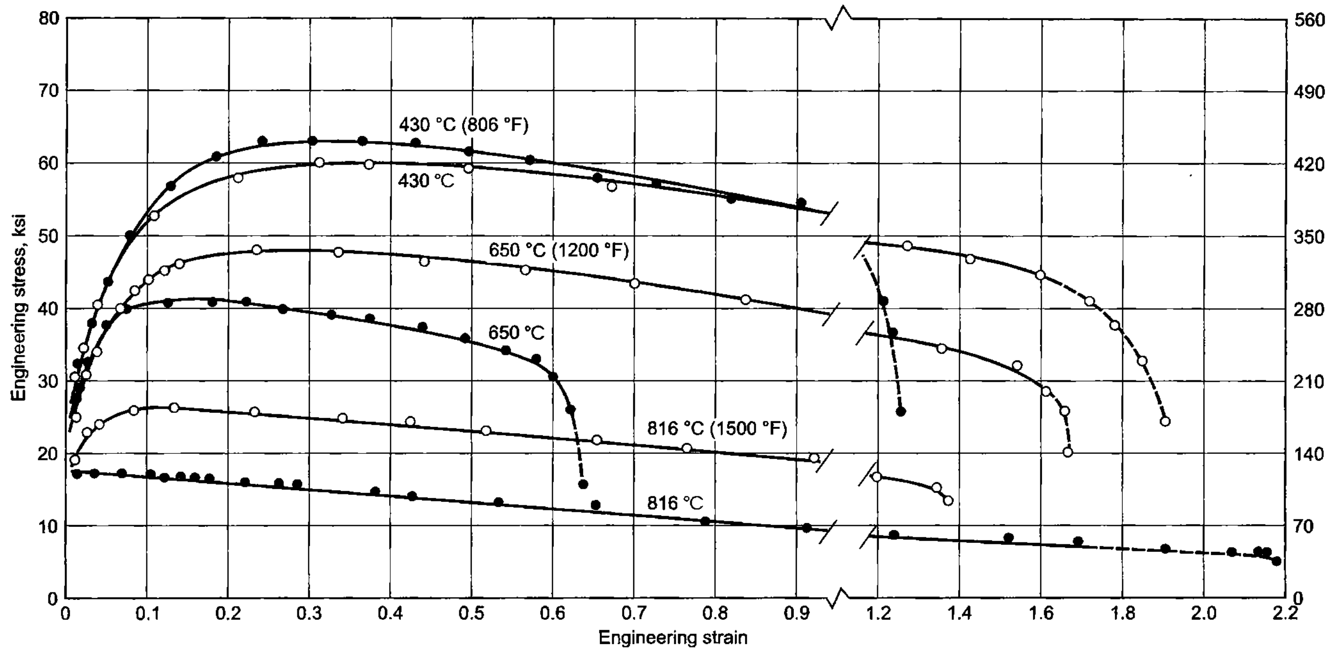
Source: T.S. DeSisto, "Low Temperature Mechanical Properties of Base and Weld Deposits of Selected Austenitic Stainless Steels," AMRA TR 63-08, United States Army Materials Research Agency, July 1963. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1309, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 21



SS.088 348 annealed stainless steel bar, true stress-strain curves at room and elevated temperatures

Bar diameter = 6.35 mm (0.25 in.). Data were collected at constant axial true strain rates of 0.004 (open data points) and 0.00004 (solid data points). The curves for the higher strain rates are above the other curve at 650 and 816 °C (1202 and 1580 °F), while the reverse is true for 430 °C (806 °F). Contrary to what is expected for true stress-strain curves, these have a maximum point. This is believed to be due to the formation of internal voids that reduce the actual area under stress. For this reason the lines are dashed as they approach the fracture point. P_{max} is the point of maximum load. Composition: Fe-18Cr-12Ni-Nb(Nb stabilized, Ta and Co restricted). UNS S34800

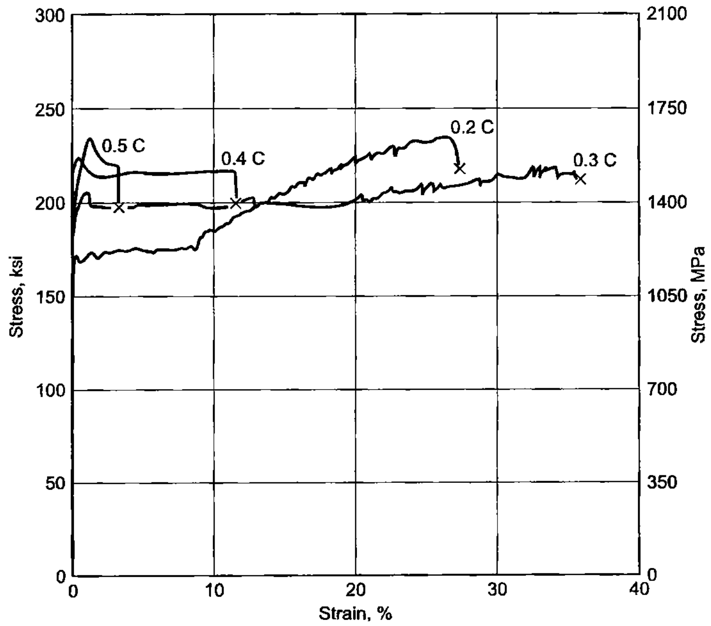
Source: J.B. Conway, R.H. Stentz, and J.T. Berling, "Fatigue, Tensile, and Relaxation Behavior of Stainless Steels," Technical Information Center, USAEC, 1975, p 215



SS.089 348 annealed stainless steel bar, engineering stress-strain curves at room and elevated temperatures

Bar diameter = 6.35 mm (0.25 in.). Data were collected at constant axial true strain rates of 0.004 (open data points) and 0.00004 (solid data points). Same data was used as for the true stress-strain curve. The curves for the higher strain rates are above the other curve at 650 and 816 °C (1202 and 1580 °F), while the reverse is true for 430 °C (806 °F). The strain rate effect is more pronounced for the higher temperatures. The lines are dashed as they approach the fracture point. Composition: Fe-18Cr-12Ni-Nb(Nb stabilized, Ta and Co restricted). UNS S34800

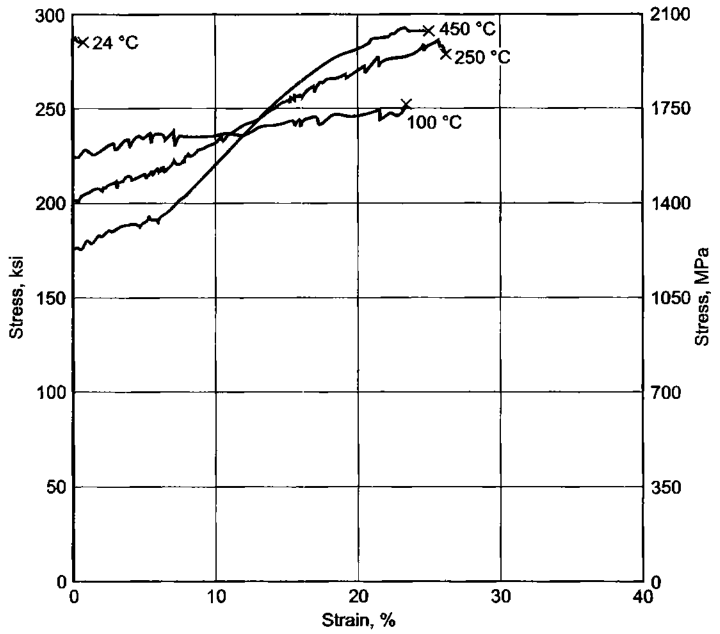
Source: J.B. Conway, R.H. Stentz, and J.T. Berling, "Fatigue, Tensile, and Relaxation Behavior of Stainless Steels," Technical Information Center, USAEC, 1975, p 217



SS.090 Metastable austenitic stainless steel sheet, engineering stress-strain curves showing effect of varying carbon content at room temperature

Sheet thickness = 1.27 mm (0.050 in.). After 80% reduction in thickness at 450 °C. Crosshead speed 0.04 in./min. Composition: Fe-9Cr-8Ni-3Mn with 0.2–0.5C

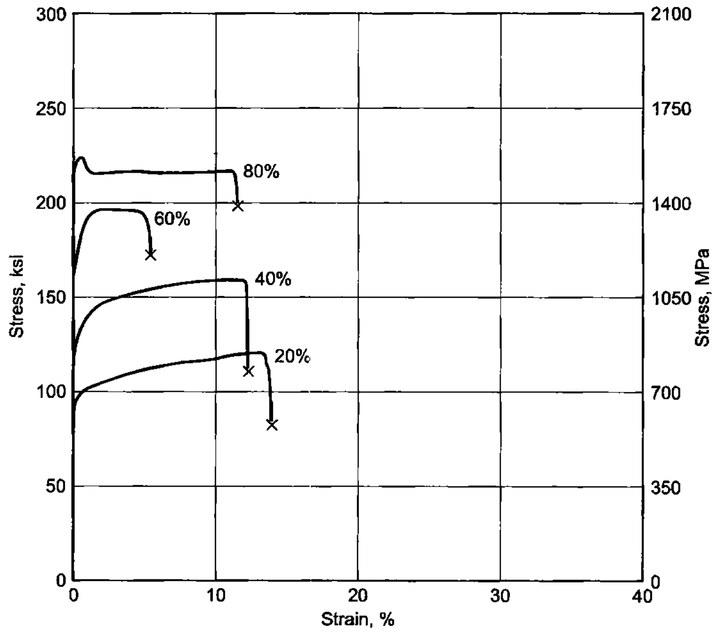
Source: D. Fahr, Stress and Strain-Induced Formation of Martensite and Its Effects on Strength and Ductility of Metastable Austenitic Stainless Steels, *Metall. Trans. A*, July 1971, p 1887



SS.091 Metastable austenitic stainless steel, room-temperature engineering stress-strain curves

Effect of different rolling temperatures is shown. Reduction in thickness = 80%. Composition: 9Cr-8Ni-1Mn-0.4C-bal Fe

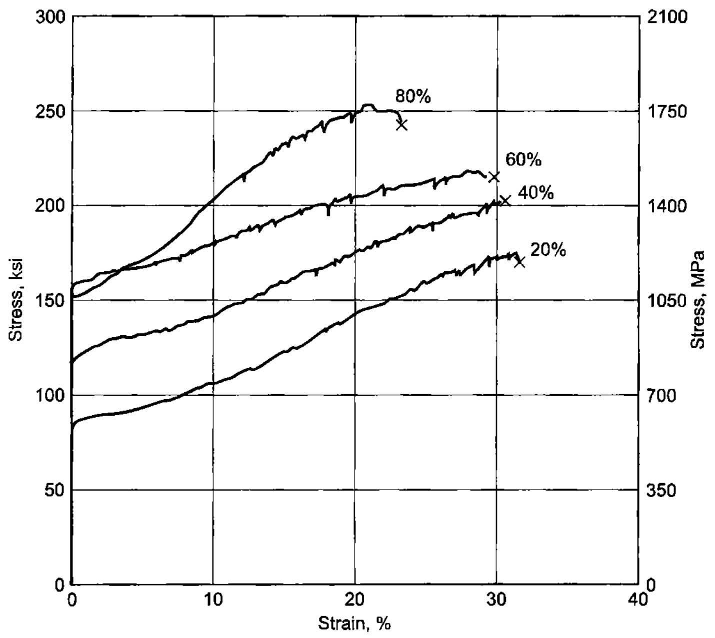
Source: D. Fahr, Stress and Strain-Induced Formation of Martensite and Its Effects on Strength and Ductility of Metastable Austenitic Stainless Steels, *Metall. Trans. A*, July 1971, p 1889–1890



SS.092 Metastable austenitic stainless steel, room-temperature engineering stress-strain curves

Effect of varying reductions in thickness (and rolling times) at 450 °C rolling temperature is shown for a relatively unstable alloy. Crosshead speed = 0.04 in./min. Composition: 9Cr-8Ni-2Mn-0.2C-bal Fe

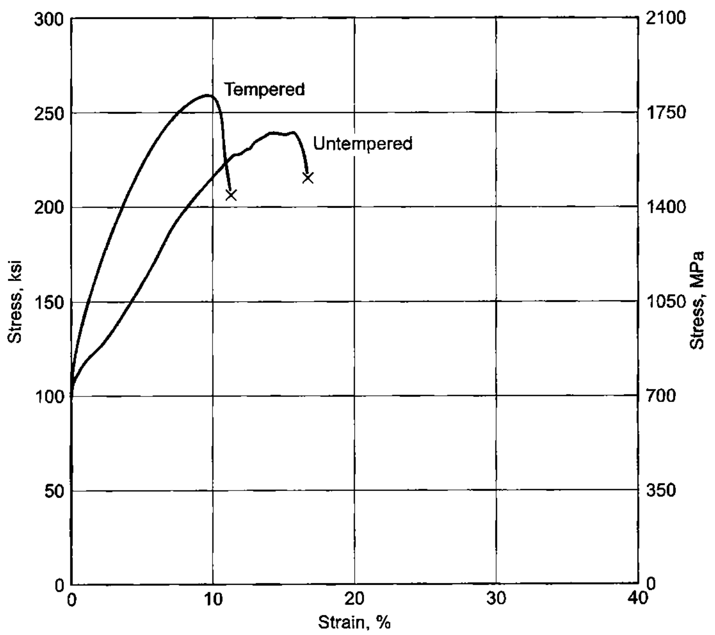
Source: D. Fahr, Stress and Strain-Induced Formation of Martensite and Its Effects on Strength and Ductility of Metastable Austenitic Stainless Steels, *Metall. Trans. A*, July 1971, p 1889–1890



SS.093 Metastable austenitic stainless steel, room-temperature engineering stress-strain curves

Effect of varying reductions in thickness (and rolling times) at 450 °C rolling temperature is shown for a relatively unstable alloy. Crosshead speed = 0.04 in./min. Composition: 9Cr-8Ni-2Mn-0.2C-bal Fe

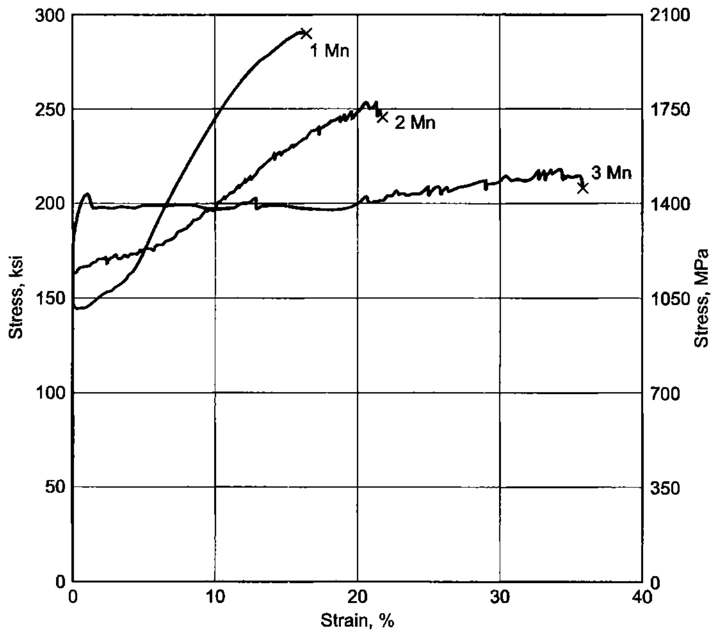
Source: D. Fahr, Stress and Strain-Induced Formation of Martensite and Its Effects on Strength and Ductility of Metastable Austenitic Stainless Steels, *Metall. Trans. A*, July 1971, p 1889–1890



SS.094 Metastable austenitic stainless steel, room-temperature engineering stress-strain curves

Effect of annealing 450 °C, 80 min, on partially transformed (M_s > room temperature) alloy (alloy 6811-13). 60% reduction in thickness at 450 °C. Crosshead speed = 0.04 in./min. Composition: 9Cr-8Ni-2Mn-0.1C-bal Fe

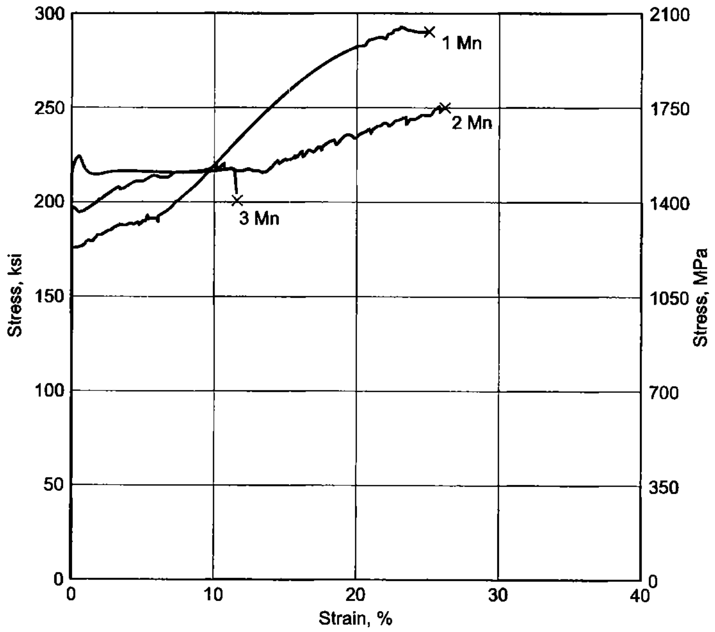
Source: D. Fahr, Stress and Strain-Induced Formation of Martensite and Its Effects on Strength and Ductility of Metastable Austenitic Stainless Steels, *Metall. Trans. A*, July 1971, p 1889–1890



SS.095 Metastable austenitic stainless steel, room-temperature engineering stress-strain curves

Effect of varying manganese content after 80% reduction in thickness, 450 °C. Crosshead speed 0.04 in./min. Composition: 9Cr-8Ni-1Mn-0.3C-bal Fe

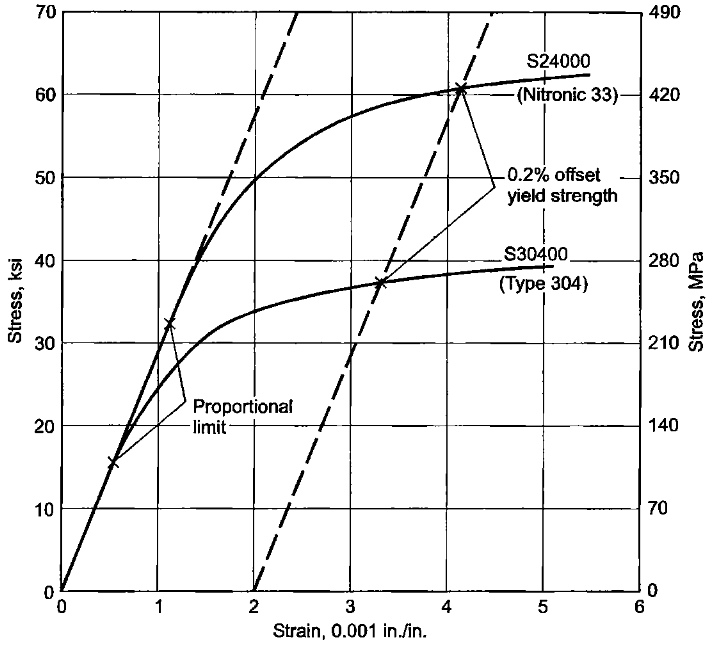
Source: D. Fahr, Stress and Strain-Induced Formation of Martensite and Its Effects on Strength and Ductility of Metastable Austenitic Stainless Steels, *Metall. Trans. A*, July 1971, p 1885–1886



SS.096 Metastable austenitic stainless steel, room-temperature engineering stress-strain curves

Effect of varying manganese content after 80% reduction in thickness, 450 °C. Crosshead speed 0.04 in./min Composition: 9Cr-8Ni-1Mn-0.4C-bal Fe

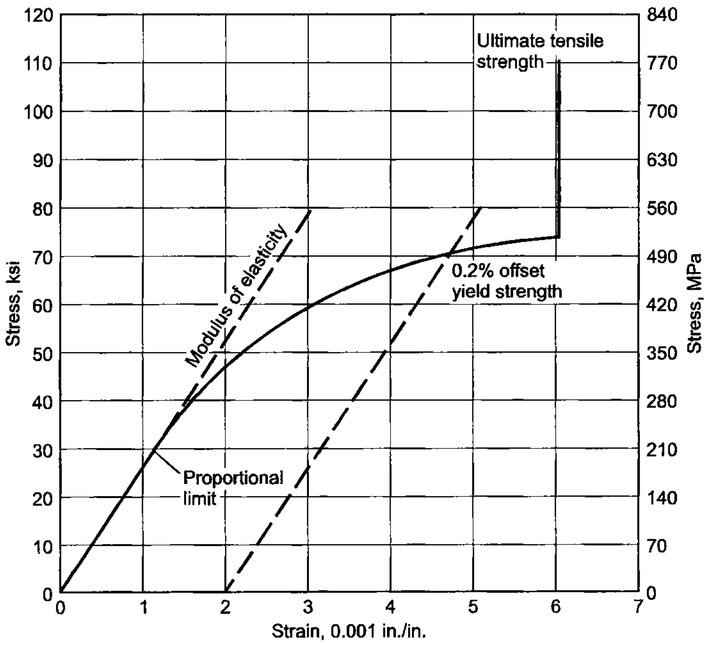
Source: D. Fahr, Stress and Strain-Induced Formation of Martensite and Its Effects on Strength and Ductility of Metastable Austenitic Stainless Steels, *Metall. Trans. A*, July 1971, p 1885–1886



SS.097 S24000 (Nitronic 33) and S30400 (304) stainless steel bar, typical engineering tensile stress-strain curves. UNS S24000, S30400

Test direction: longitudinal. Modulus of elasticity for Nitronic 33 = 199 GPa (28.8 × 10^6 psi) at room temperature. USN S24000, S30400

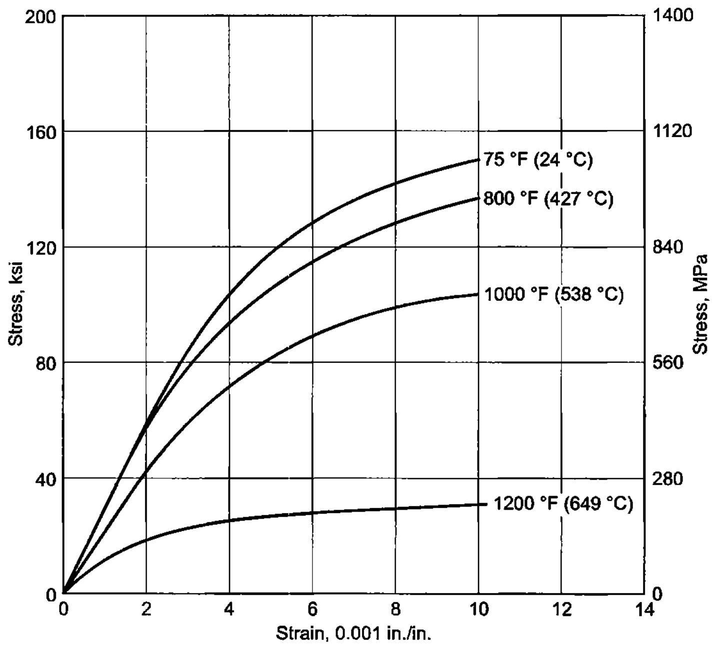
Source: Product Data, S-53b, Armco Steel Corp., 1977



SS.098 UNS S21800 (Nitronic 60) stainless steel rod, room-temperature engineering stress-strain curves

In steel tension. Rod diameter = 9.525 mm (3/8 in.). Ultimate tensile strength = 765 MPa (111 ksi). 0.2% yield strength = 483 MPa (70 ksi). Modulus of elasticity = 181 GPa (26.2 × 10^6 psi). Elongation = 69%. Reduction of area = 71%. Developed with class B extensometer. Composition: Fe-17Cr-8.5Ni-8Mn-4Si. UNS S21800

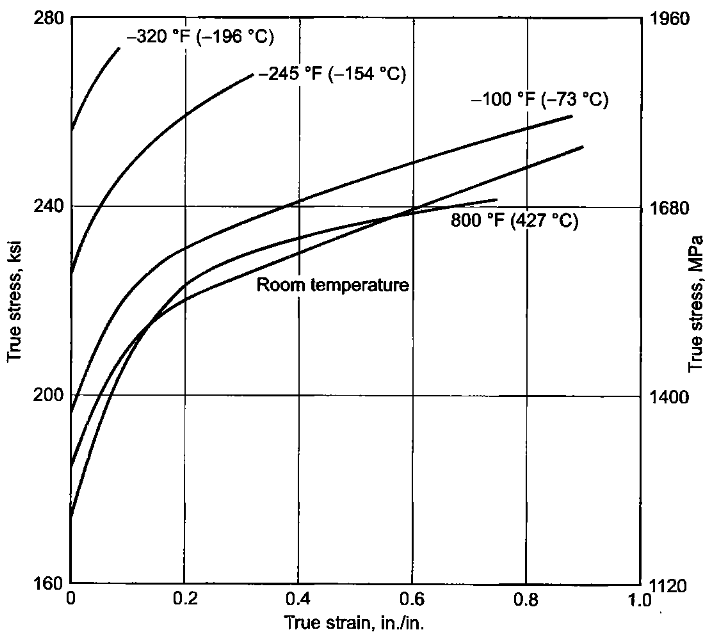
Source: Steel Company Technical Literature, Armco. As published in *Structural Alloys Handbook*, Vol 2, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1994, p 49



SS.099 410 stainless steel sheet, tensile stress-strain curves at room and elevated temperatures

Sheet thickness = 1.6 mm (0.063 in.). Treatment: 982 °C (1800 °F), 30 min, oil quenched, 371 °C (700 °F), 1 h, air cooled. Composition: Fe-12Cr-lowC. UNS S41000

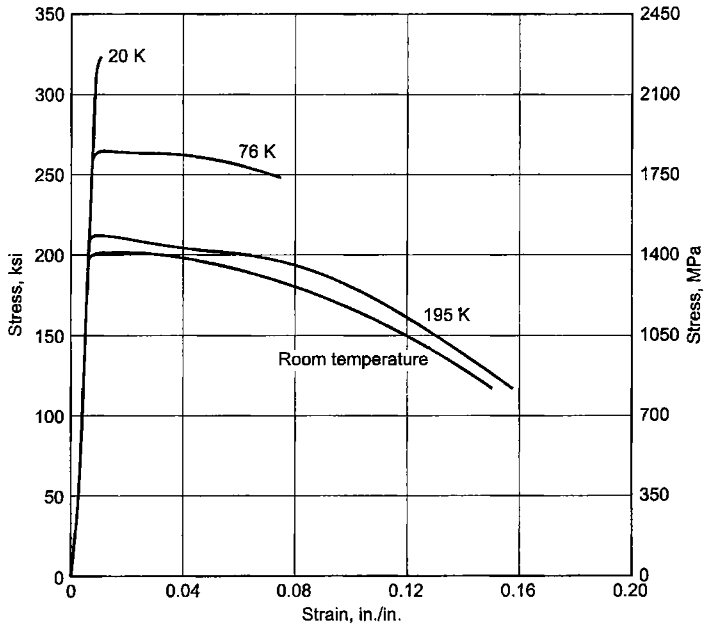
Source: W.W. Gerberich, H.E. Martens, and R.A. Boundy, "Tensile Properties of Five Low-Alloy and Stainless Steels under High-Heating-Rate and Constant-Temperature Conditions," Technical Report No. 32-222, Jet Propulsion Laboratory, June 1962. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1401, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 24



SS.100 410 stainless steel bar, true stress-strain curves at various temperatures

Bar diameter = 19.05 mm (0.750 in.). Treatment: 982 °C (1800 °F), 1 h, oil quenched, 427 °C (800 °F), 4 h, air cooled. Composition: Fe-12Cr-lowC. UNS S41000

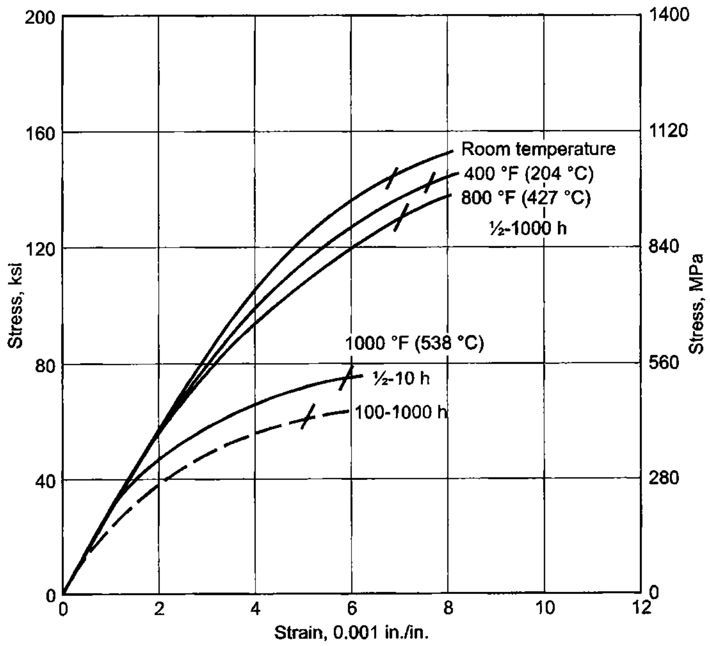
Source: R. Chait and V. Weiss, "Isothermal True Stress-Strain Curves of Body Centered Metals," Report No. MET. E. 1081-0666, Syracuse University Research Institute, June 1966; see also R. Chait, "Deformation and Fracture of High Strength BCC Polycrystalline Alloys," Ph.D. thesis, Syracuse University, 1967, available from University of Michigan, Order No. 68-5451. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1401, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 24



SS.101 410 stainless steel bar, stress-strain curves at room and low temperatures

Bar diameter = 19.05 mm (0.750 in.). Treatment: 982 °C (1800 °F), 1 h, oil quenched + tempered 371 °C (700 °F), 4 h, air cooled, to 42 HRC hardness. Composition: Fe-12.2Cr-0.12C-0.5Mn-0.2Si-0.02P-0.01S. UNS S41000

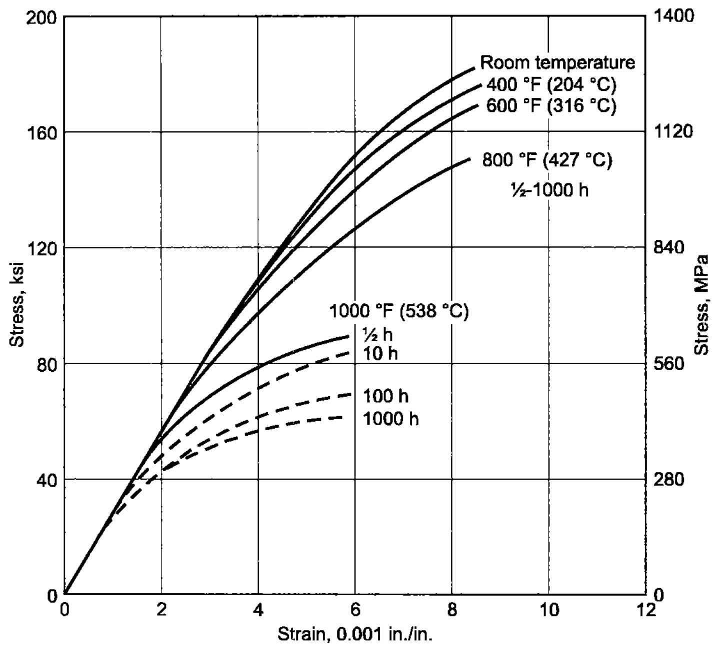
Source: K.A. Warren and R.P. Reed, *Tensile and Impact Properties of Selected Materials from 20 to 300K*, Monograph 63, National Bureau of Standards, June 1963. As published in *Structural Alloys Handbook*, Vol 2, CINDAS/Purdue University, 1995, p 22



SS.102 420 stainless steel sheet, tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Sheet thickness = 1.575 mm (0.062 in.). Treatment: 982 °C (1800 °F), 15 min, oil quenched, 482 °C (900 °F), 3 h. Composition: Fe-13Cr-0.35C. UNS S42000

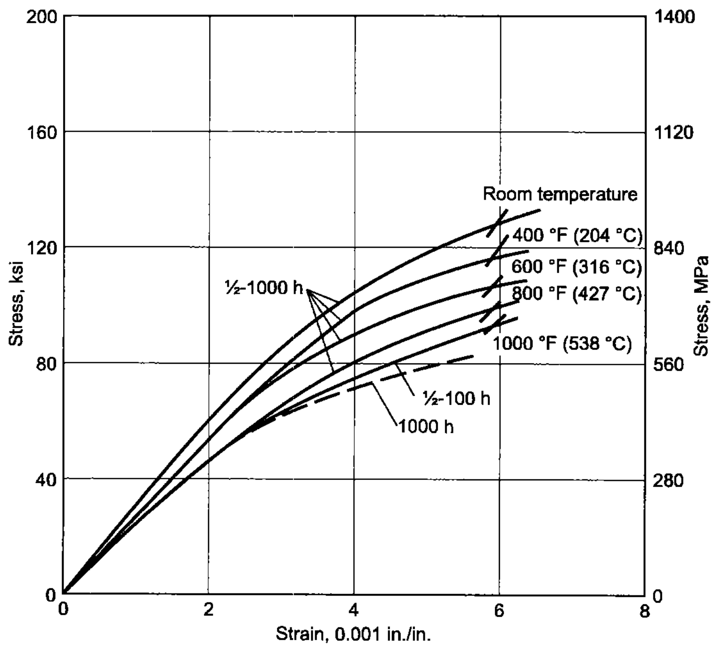
Source: J.R. Kattus, J.B. Preston, and H.L. Lessley, "Determination of Tensile, Compressive, Bearing, and Shear Properties of Sheet Steels at Elevated Temperatures," WADC TR 58-365, ASTIA Document No. 206075, Southern Research Institute, Nov 1958. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1402, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 8



SS.103 420 stainless steel sheet, compressive stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Sheet thickness = 1.575 mm (0.062 in.). Treatment: 982 °C (1800 °F), 15 min, oil quenched, 482 °C (900 °F), 3 h. Composition: Fe-13Cr-0.35C. UNS S42000

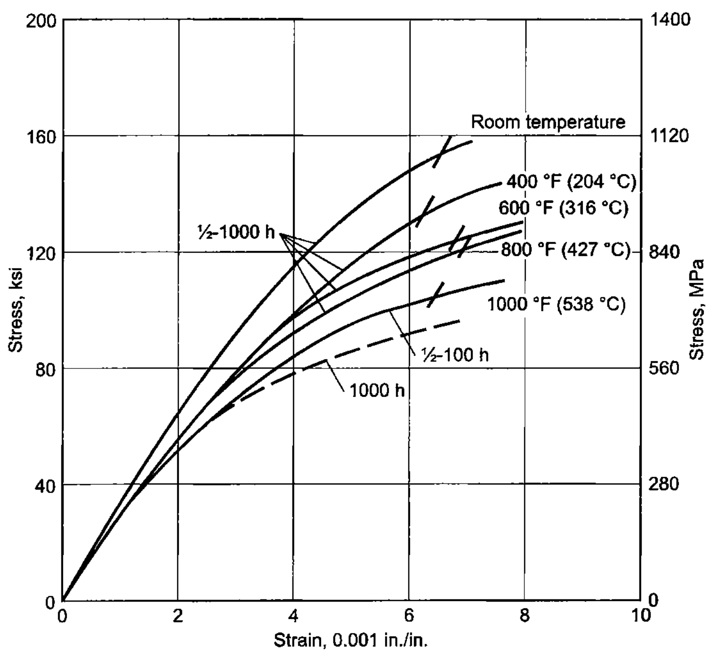
Source: J.R. Kattus, J.B. Preston, and H.L. Lessley, "Determination of Tensile, Compressive, Bearing, and Shear Properties of Sheet Steels at Elevated Temperatures," WADC TR 58-365, ASTIA Document No. 206075, Southern Research Institute, Nov 1958. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1402, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 9



SS.104 422 stainless steel sheet, tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Sheet thickness = 1.575 mm (0.062 in.). Treatment: 1038 °C (1900 °F), 15 min, oil quenched, 538 °C (1000 °F), 2 h. Composition: Fe-12Cr-0.23C-1Mo-1W-0.8Ni-0.25V. UNS S42200

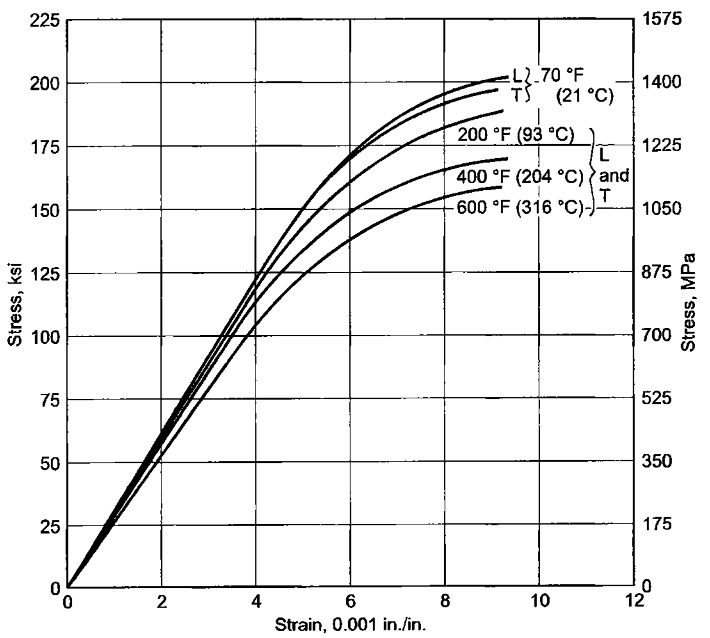
Source: J.R. Kattus, J.B. Preston, and H.L. Lessley, "Determination of Tensile, Compressive, Bearing and Shear Properties of Sheet Steels at Elevated Temperatures," WADC TR 58-365, ASTIA Document No. 206075, Southern Research Institute, Nov 1958. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1403, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 10



SS.105 422 stainless steel sheet, compressive stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Sheet thickness = 1.575 mm (0.062 in.). Treatment: 1038 °C (1900 °F), 15 min, oil quenched, 538 °C (1000 °F), 2 h. Composition: Fe-12Cr-0.23C-1Mo-1W-0.8Ni-0.25V. UNS S42200

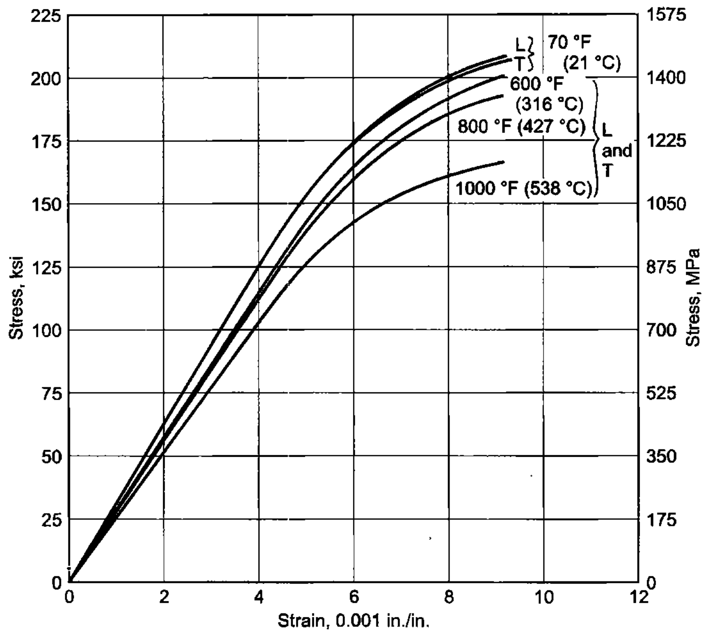
Source: J.R. Kattus, J.B. Preston, and H.L. Lessley, "Determination of Tensile, Compressive, Bearing and Shear Properties of Sheet Steels at Elevated Temperatures," WADC TR 58-365, ASTIA Document No. 206075, Southern Research Institute, Nov 1958. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1403, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



SS.106 AFC-77 stainless steel sheet, tensile stress-strain curves at room and elevated temperatures

Test direction: L, longitudinal; T, transverse. Sheet thickness = 2.54 mm (0.10 in.). Tempered at 371 °C (700 °F). Treatment: 1038 °C (1900 °F), 15 min in protective atmosphere, oil quenched, –73 °C (–100 °F), 30 min, 371 °C (700 °F), 2 + 2 h. Composition: Fe-14.5Cr-13.5Co-5Mo-0.5V-0.15C. UNS S65770

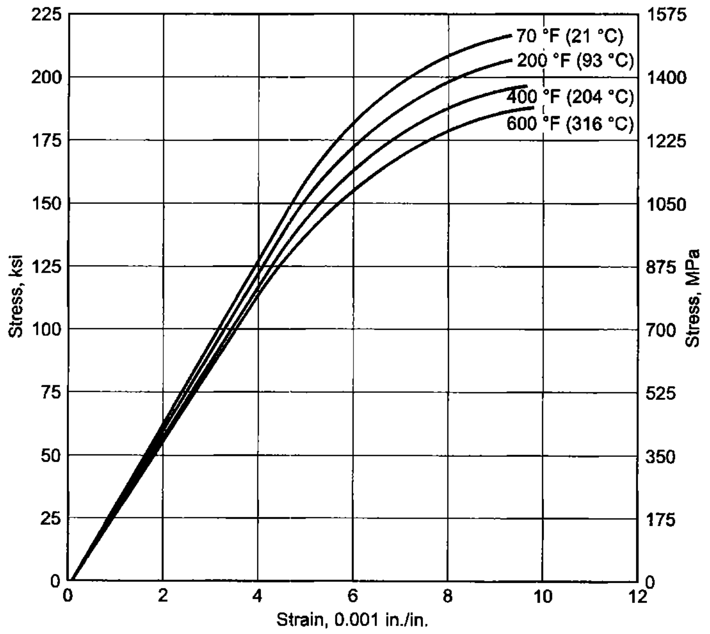
Source: O.L. Deel and W.S. Hyler, "Engineering Data on Newly Developed Structural Materials," Technical Report AFML-TR-67-418, April 1968, p 145. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1509, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 10



SS.107 AFC-77 stainless steel sheet, tensile stress-strain curves at room and elevated temperatures

Test direction: L, longitudinal; T, transverse. Sheet thickness = 2.54 mm (0.10 in.). Tempered at 593 °C (1100 °F). Treatment: 1038 °C (1900 °F), 15 min in protective atmosphere, oil quenched, –73 °C (–100 °F), 30 min, 593 °C (1100 °F), 2 + 2 h. Composition: Fe-14.5Cr-13.5Co-5Mo-0.5V-0.15C. UNS S65770

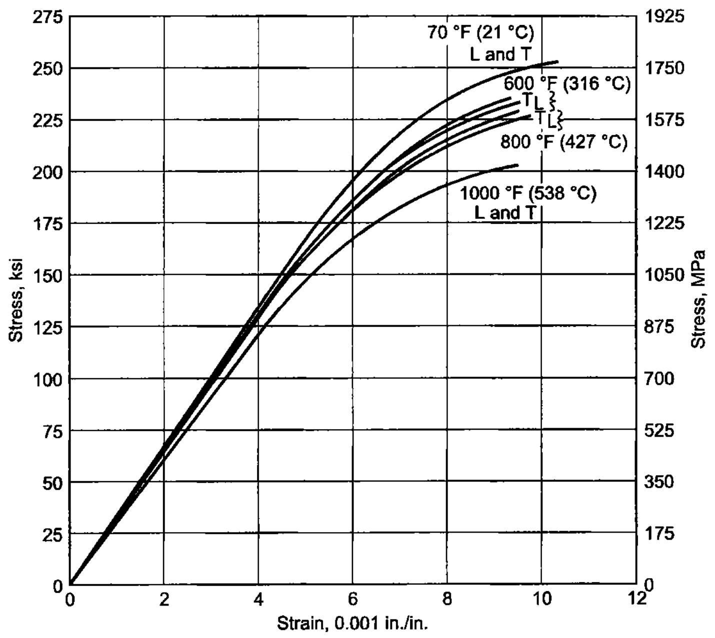
Source: O.L. Deel and W.S. Hyler, "Engineering Data on Newly Developed Structural Materials," Technical Report AFML-TR-67-418, April 1968, p 160. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1509, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 11



SS.108 AFC-77 stainless steel sheet, compressive stress-strain curves at room and elevated temperatures

Test direction: longitudinal and long transverse. Sheet thickness = 2.54 mm (0.10 in.). Tempered at 371 °C (700 °F). Treatment: 1038 °C (1900 °F), 15 min in protective atmosphere, oil quenched, –73 °C (–100 °F), 30 min, 371 °C (700 °F), 2 + 2 h. Composition: Fe-14.5Cr-13.5Co-5Mo-0.5V-0.15C. UNS S65770

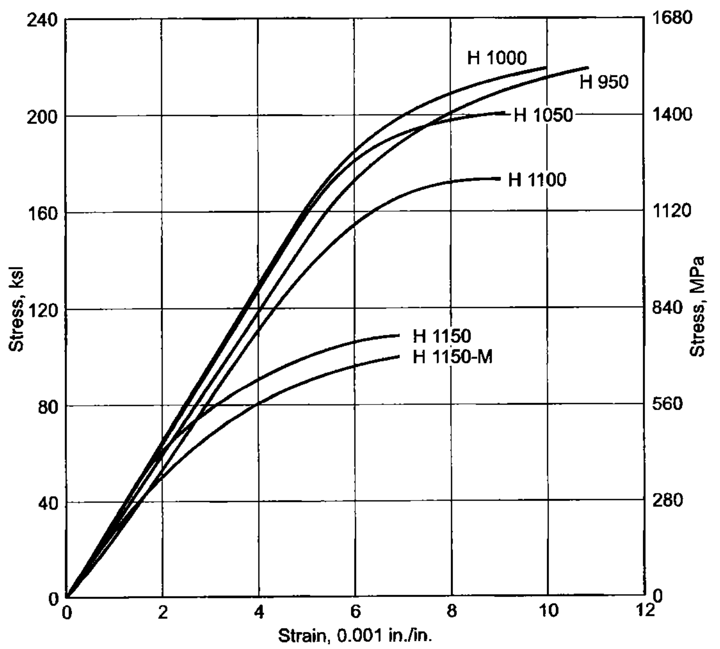
Source: O.L. Deel and W.S. Hyler, "Engineering Data on Newly Developed Structural Materials," Technical Report AFML-TR-67-418, April 1968, p 147. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1509, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 14



SS.109 AFC-77 stainless steel sheet, compressive stress-strain curves at room and elevated temperatures

Test direction: L, longitudinal; LT, long transverse. Sheet thickness = 2.54 mm (0.10 in.). Tempered at 593 °C (1100 °F). Treatment: 1038 °C (1900 °F), 15 min in protective atmosphere, oil quenched, –73 °C (–100 °F), 30 min, 593 °C (1100 °F), 2 + 2 h. Composition: Fe-14.5Cr-13.5Co-5Mo-0.5V-0.15C. UNS S65770

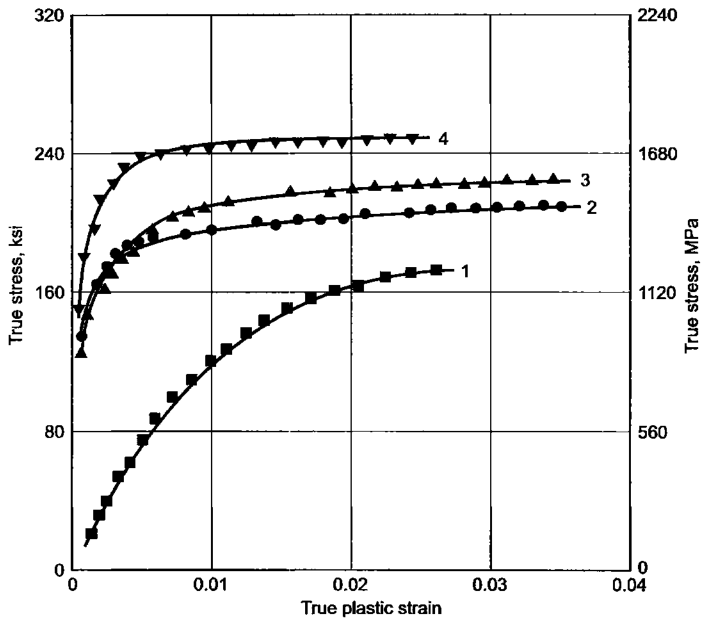
Source: O.L. Deel and W.S. Hyler, "Engineering Data on Newly Developed Structural Materials," Technical Report AFML-TR-67-418, April 1968, p 162. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1509, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 14



SS.110 13-8 PH Mo stainless steel bar, stress-strain curves with effect of aged condition

Bar diameter = 19.05 mm (0.75 in.). Composition: Fe-13Cr-8Ni-2Mo. UNS S13800

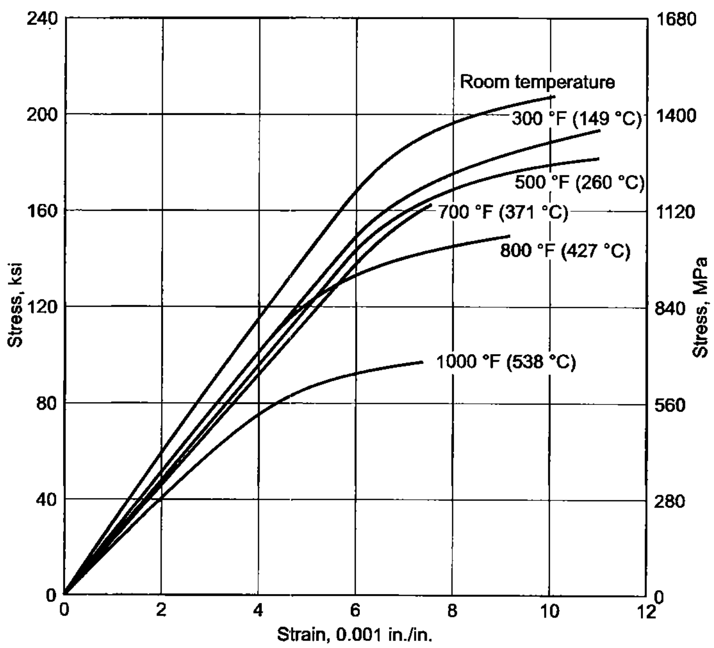
Source: P.W. Johnson, Jr., Armco Steel Corp., Baltimore, MD, personal communication with C.I. Hickey, Jr., Feb 1973. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1510, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 15



SS.111 13-8 PH Mo stainless steel bar, true stress-strain curves with effect of heat treatment

Test direction: transverse. Strain rate = 0.004/min. Heat treatment: curve 1, 899 °C (1650 °F), 0.5 h; curve 2, 899 °C (1650 °F), 0.5 h, 599 °C (1110 °F), 4 h; curve 3, 899 °C (1650 °F), 0.5 h, 449 °C (840 °F), 4 h; curve 4, 899 °C (1650 °F), 0.5 h, 527 °C (980 °F), 4 h. Composition: Fe-13Cr-8Ni-2Mo. UNS S13800

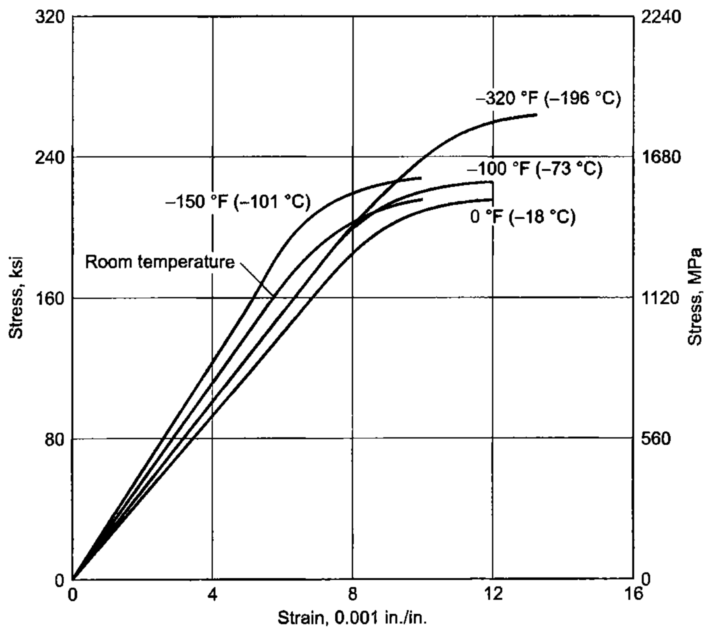
Source: V. Seetharaman, M. Sundararaman, and R. Krisknan, Precipitation Hardening in a PH 13-8Mo Stainless Steel, *Mater. Sci. Eng.*, Vol 47 (No. 1), Jan 1981, p 1–11. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1510, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 15



SS.112 13-8 PH Mo H1000 stainless steel bar, stress-strain curves at room and elevated temperatures

Bar diameter = 19.05 mm (0.75 in.). Aging treatment: 538 °C (1000 °F), 4 h, air cooled. Composition: Fe-13Cr-8Ni-2Mo. UNS S13800

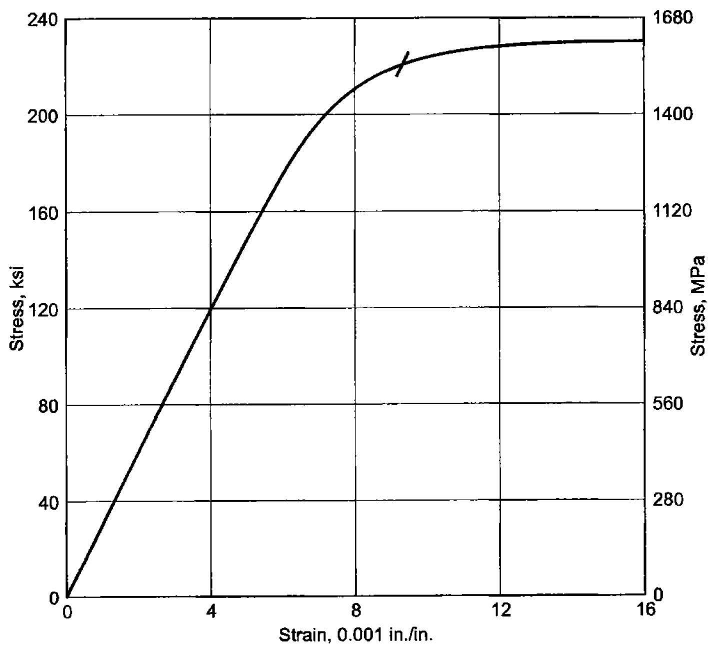
Source: P.W. Johnson, Jr., Armco Steel Corp., Baltimore, MD, personal communication with C.I. Hickey, Jr., Feb 1973. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1510, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 21



SS.113 13-8 PH Mo H1000 stainless steel bar, stress-strain curves at room and low temperatures

Bar diameter = 19.05 mm (0.75 in.). Aging treatment: 538 °C (1000 °F), 4 h, air cooled. Data represent one test from one heat, according to Armco Data Bulletin S-24, 1984. Composition: Fe-13Cr-8Ni-2Mo. UNS S13800

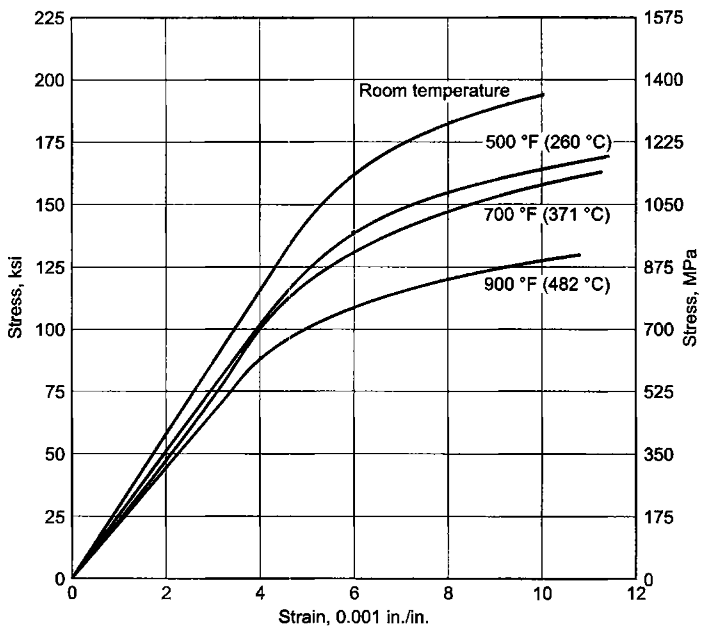
Source: P.W. Johnson, Jr., Armco Steel Corp., Baltimore, MD, personal communication with C.I. Hickey, Jr., Feb 1973. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1510, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 21



SS.114 13-8 PH Mo H1000 stainless steel bar, compressive stress-strain curve

Bar size = 50.8 × 152.4 mm (2 × 6 in.). Aging treatment: 538 °C (1000 °F), 4 h, air cooled. Composition: Fe-13Cr-8Ni-2Mo. UNS S13800

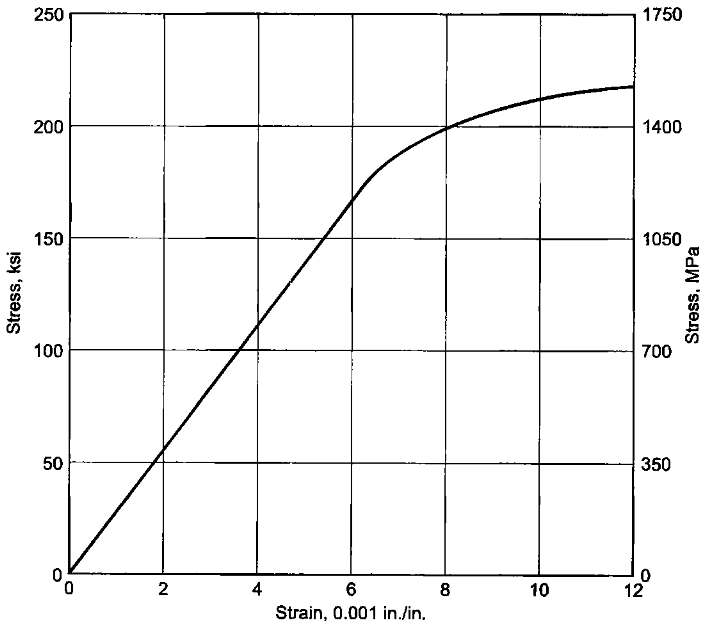
Source: P.W. Johnson, Jr., Armco Steel Corp., Baltimore, MD, personal communication with C.I. Hickey, Jr., Feb 1973. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1510, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 19



SS.115 13-8 PH Mo H1000 stainless steel forging, compressive stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Forging size = 101.6 × 127 mm (4 × 5 in.). Aging treatment: 538 °C (1000 °F), 4 h, air cooled. Composition: Fe-13Cr-8Ni-2Mo. UNS S13800

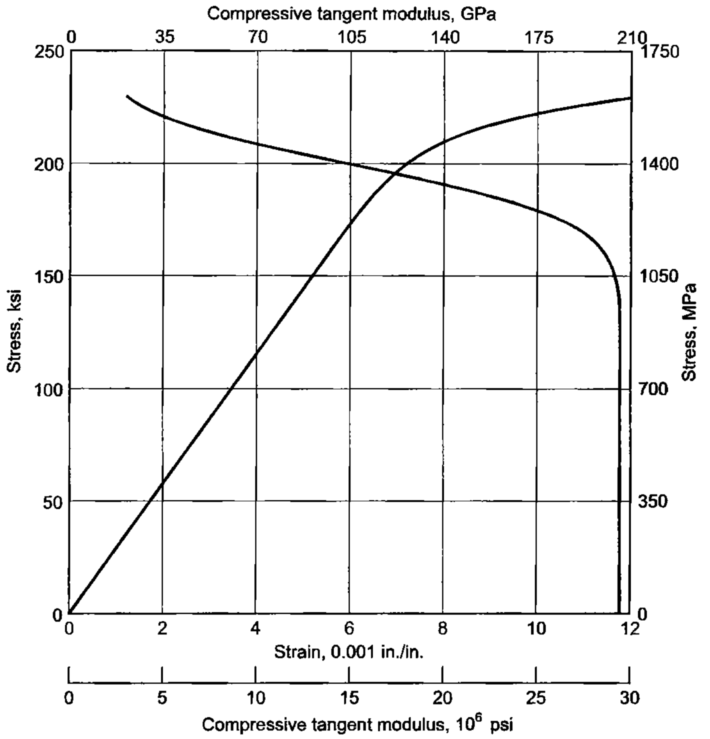
Source: O.L. Deel and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," AFML-TR-72-196, Vol 2, Sept 1972. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1510, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 23



SS.116 13-8 PH Mo H1000 stainless steel bar, typical tensile stress-strain curve at room temperature

Test direction: longitudinal. Bar thickness = 19.05–50.8 mm (0.750–2.000 in.). Aging treatment: 538 °C (1000 °F), 4 h, air cooled. Ramberg-Osgood parameter: n = 17. Composition: Fe-13Cr-8Ni-2Mo. UNS S13800

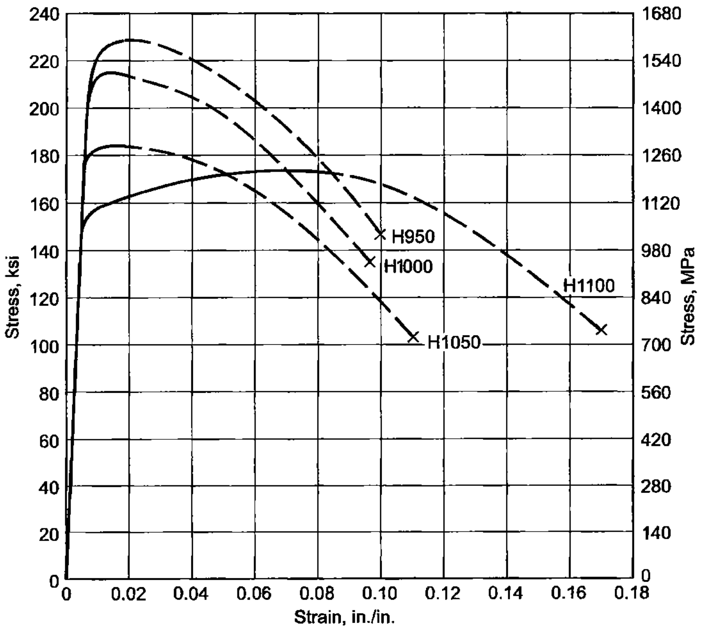
Source: *MIL-HDBK-5H,* Dec 1998, p 2-157



SS.117 13-8 PH Mo H1000 stainless steel bar, typical compressive stress-strain and compressive tangent modulus curves at room temperature

Test direction: longitudinal. Bar thickness = 22.225–50.8 mm (0.875–2.000 in.). Aging treatment: 538 °C (1000 °F), 4 h, air cooled. Ramberg-Osgood parameter: n = 17. Composition: Fe-13Cr-8Ni-2Mo. UNS S13800

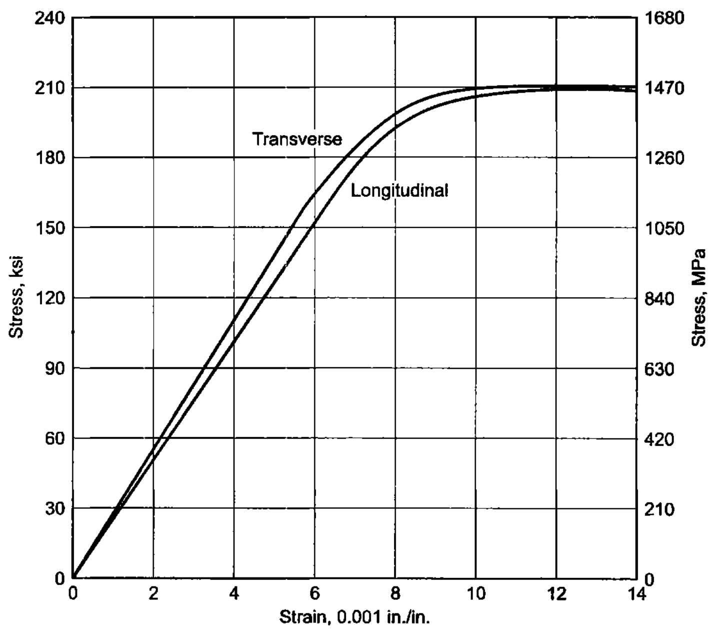
Source: *MIL-HDBK-5H*, Dec 1998, p 2-157



SS.118 13-8 PH Mo stainless steel bar, typical tensile stress-strain curves (full range) at room temperature for various heat treat conditions

Test direction: longitudinal. Based on one heat. Composition: Fe-13Cr-8Ni-2Mo. UNS S13800

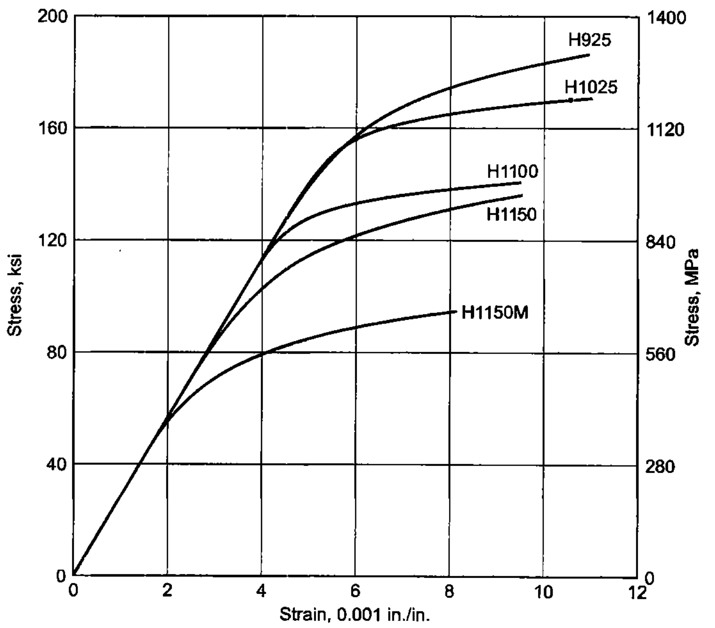
Source: *MIL-HDBK-5H*, Dec 1998, p 2-158



SS.119 14-8 PH Mo SRH1050 stainless steel sheet, stress-strain curves

Test direction: longitudinal and transverse. Sheet thickness = 1.27 mm (0.050 in.). SRH aging treatment: 927 ° C (1700 °F), 1 h, –73 °C (–100 °F), 8 h, 566 °C (1050 °F), 1 h, air cooled. Composition: Fe-14Cr-8Ni-2.5Mo-Al. UNS S14800

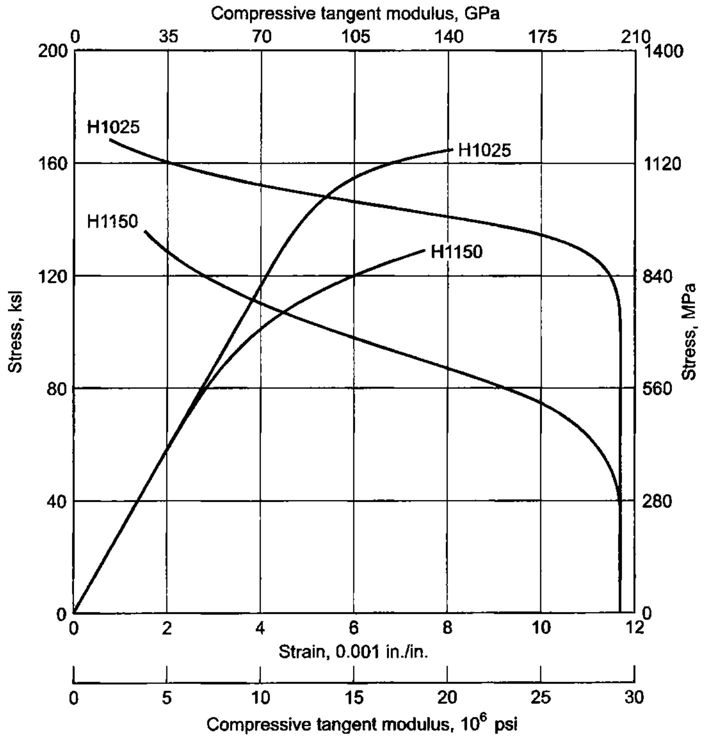
Source: "Fatigue Evaluation of PH14-8Mo (SRH1050) Alloy," Armco Steel Corp., Advanced Materials Div., 17 Sept 1969. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1507, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 8



SS.120 15-5 PH stainless steel bar, typical tensile stress-strain curves at room temperature for various heat treat conditions

Test direction: longitudinal. Bar thickness = 25.4–31.75 mm (1.000–1.250 in.). Ramberg-Osgood parameters: n(H925) = 13, n(H1025) = 24, n(H1100) = 22, n(H1150) = 9.0, n(H1150M) = 7.8. Composition: Fe-15Cr-5Ni-4Cu. UNS S15500

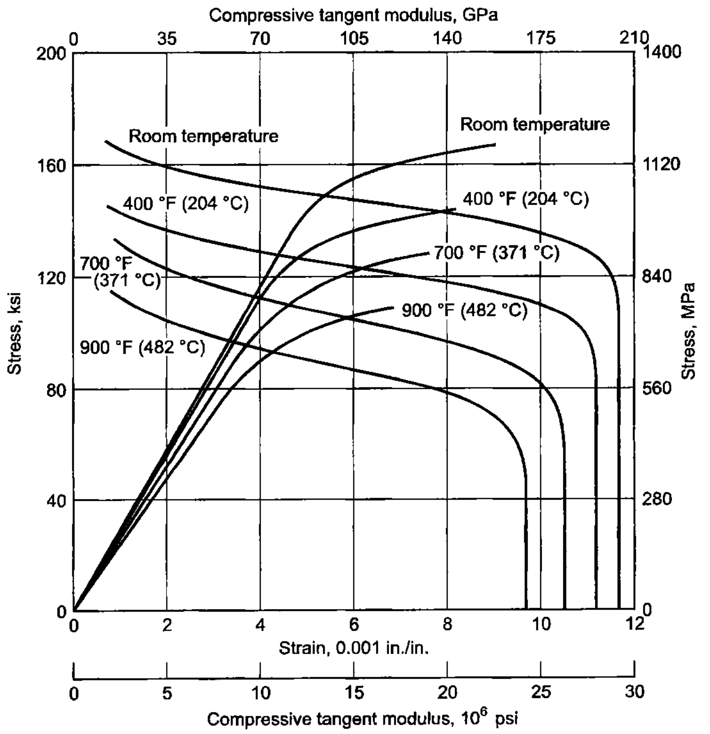
Source: *MIL-HDBK-5H,* Dec 1998, p 2-169



SS.121 15-5 PH stainless steel bar, typical compressive stress-strain and compressive tangent modulus curves at room temperature for various heat treat conditions

Test direction: long transverse. Bar thickness = 38.0–139.7 mm (1.500–5.500 in.). Ramberg-Osgood parameters: *n*(H1025) = 20, *n*(H1150) = 7.8. Composition: Fe-15Cr-5Ni-4Cu. UNS S15500

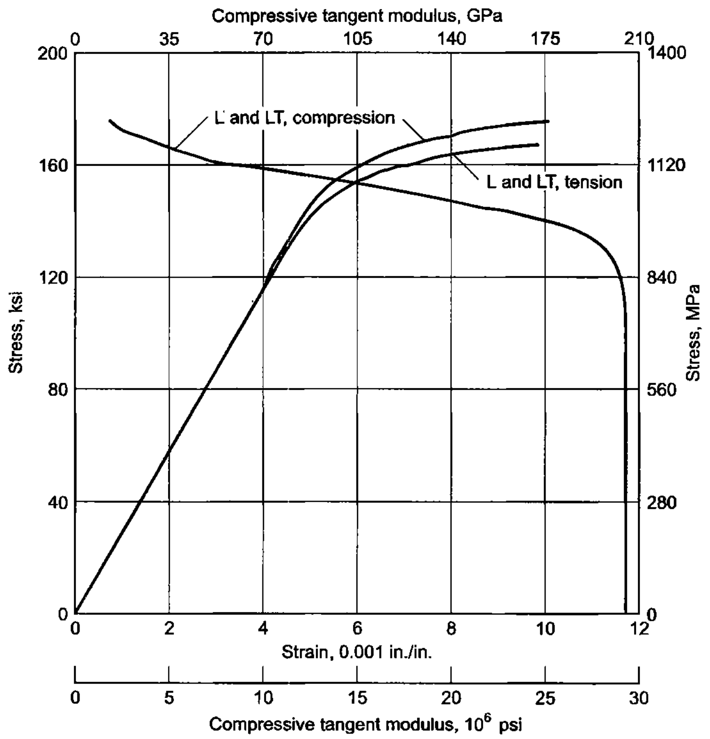
Source: *MIL-HDBK-5H*, Dec 1998, p 2-169



SS.122 15-5 PH H1025 stainless steel bar, typical compressive stress-strain and compressive tangent modulus curves at various temperatures

Test direction: longitudinal. Bar thickness = 38.0–142.24 mm (1.500–5.600 in.). 0.5 h exposure. Ramberg-Osgood parameters: *n*(room temperature) = 22, *n*(400 °F) = 18, *n*(700 °F) = 12, *n*(900 °F) = 11. Composition: Fe-15Cr-5Ni-4Cu. UNS S15500

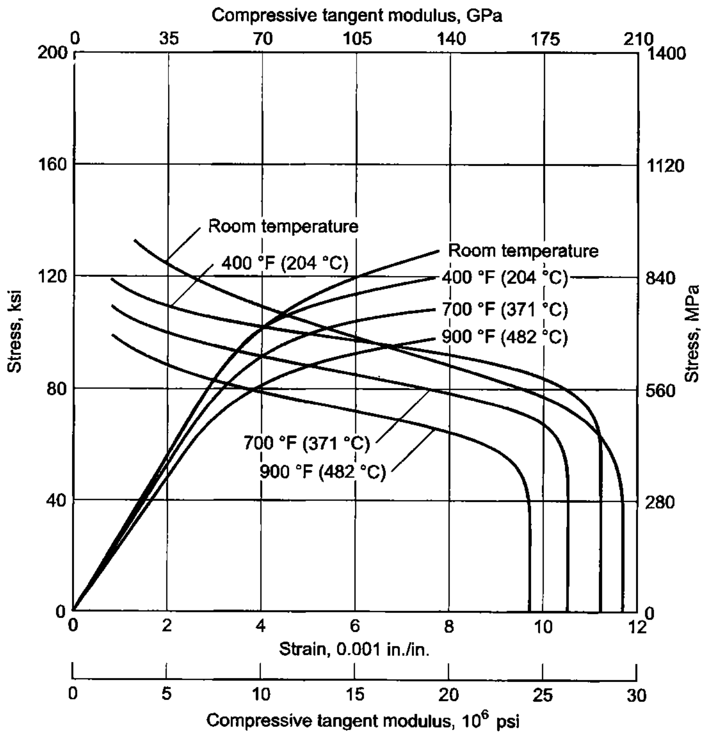
Source: *MIL-HDBK-5H*, Dec 1998, p 2-171



SS.123 15-5 PH H1025 stainless steel plate, typical tensile and compressive stress-strain and compressive tangent modulus curves

Test direction: L, longitudinal; LT, long transverse. Plate thickness = 38.0–139.7 mm (1.500–5.500 in.). Ramberg-Osgood parameters: n(L, tension) = 23, n(LT, tension) = 23, n(L, compression) = 20, n(LT, compression) = 21. Composition: Fe-15Cr-5Ni-4Cu. UNS S15500

Source: *MIL-HDBK-5H,* Dec 1998, p 2-172



SS.124 15-5 PH H1150 stainless steel bar, typical compressive stress-strain and compressive tangent modulus curves at various temperatures

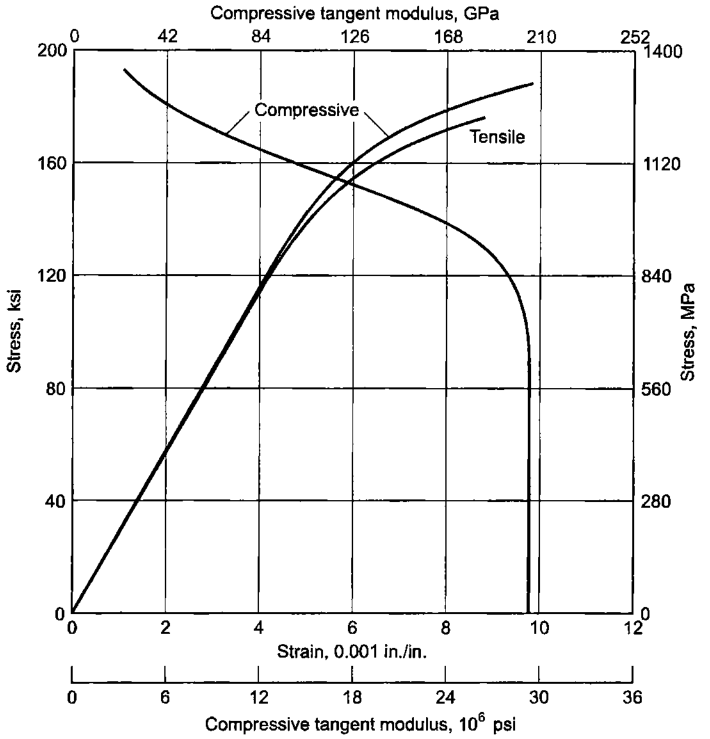
Test direction: longitudinal. 0.5 h exposure. Ramberg-Osgood parameters: n(room temperature) = 8.5, n(400 °F) = 14, n(700 °F) = 12, n(900 °F) = 10. Composition: Fe-15Cr-5Ni-4Cu. UNS S15500

Source: *MIL-HDBK-5H,* Dec 1998, p 2-176

SS.125 15-5 PH H935 stainless steel casting, typical tensile and compressive stress-strain and compressive tangent modulus curves

Casting thickness = 12.7–47.625 mm (0.500–1.875 in.). 0.5 h exposure. Ramberg-Osgood parameters: n(tension) = 12, n(compression) = 12. Composition: Fe-15Cr-5Ni-4Cu. UNS S15500

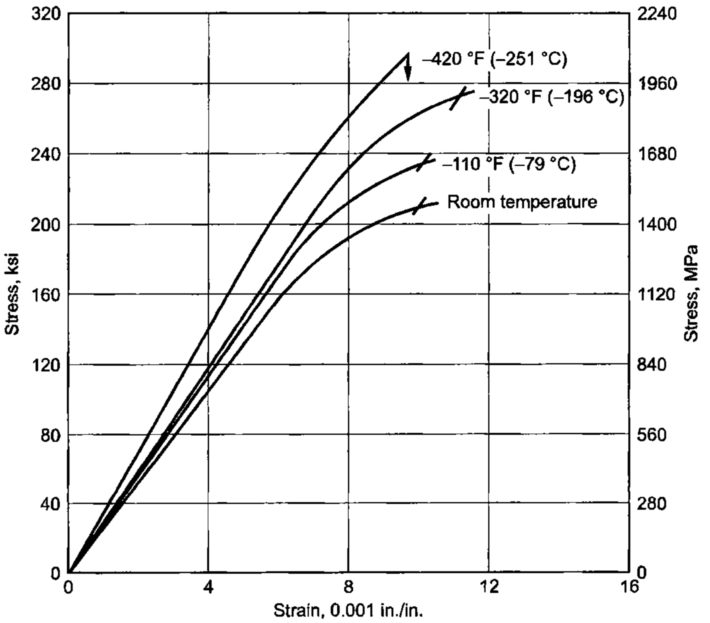
Source: *MIL-HDBK-5H,* Dec 1998, p 2-170

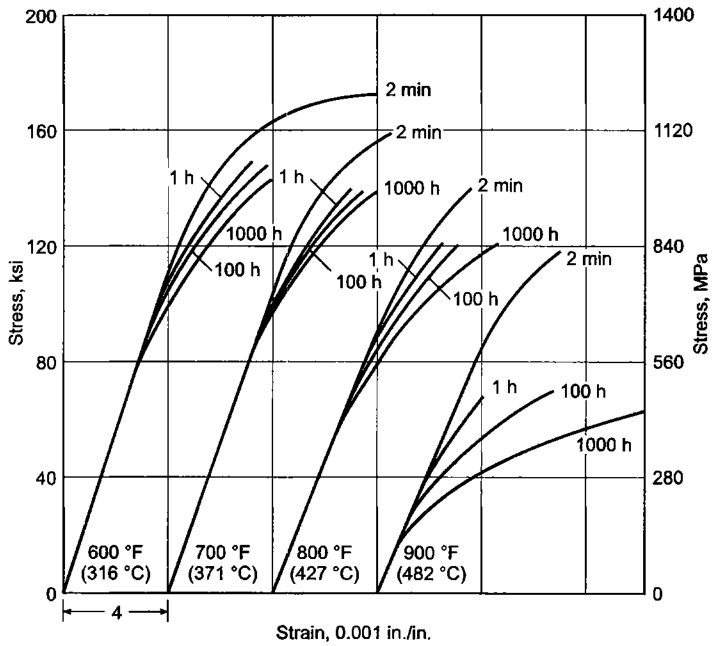


SS.126 15-7 PH RH950 stainless steel sheet, stress-strain curves at room and low temperatures

Sheet thickness = 1.626 mm (0.064 in.). Composition: Fe-15Cr-7Ni-2.5Mo. UNS S15700

Source: L.P. Rice, J.E. Campbell, and W.F. Simmons, "The Evaluation of the Effects of Very Low Temperatures on the Properties of Aircraft and Missile Metals," WADD TR 60-254, Feb 1960, p 40. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1503, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 11

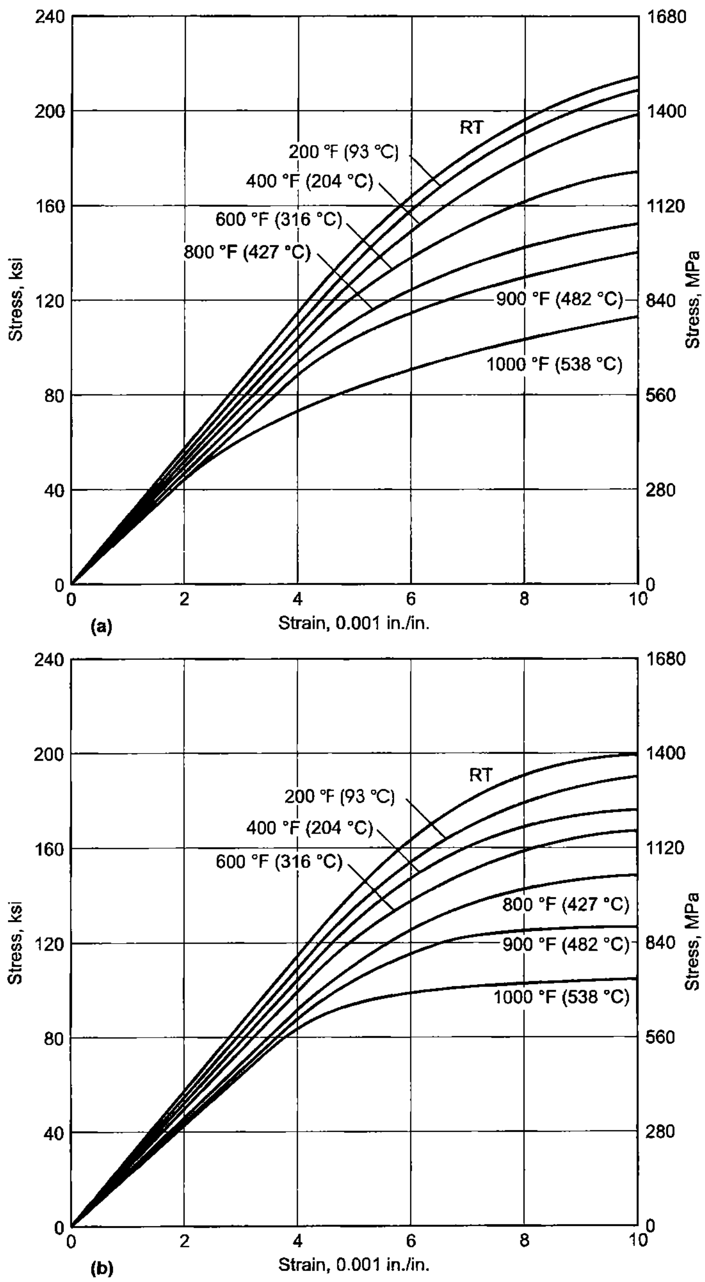




SS.127 15-7 PH RH950 stainless steel sheet, isochronous stress-strain curves at various temperatures

Sheet thickness = 1.27 mm (0.050 in.). Composition: Fe-15Cr-7Ni-2.5Mo. UNS S15700

Source: "Armco 17-7 PH and PH 15-7Mo," Armco Steel Corp., July 1968, p 37. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1503, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 19



SS.128 15-7 PH RH950 (a) and TH1050 (b) stainless steel sheet, typical tensile stress-strain curves at room and elevated temperatures

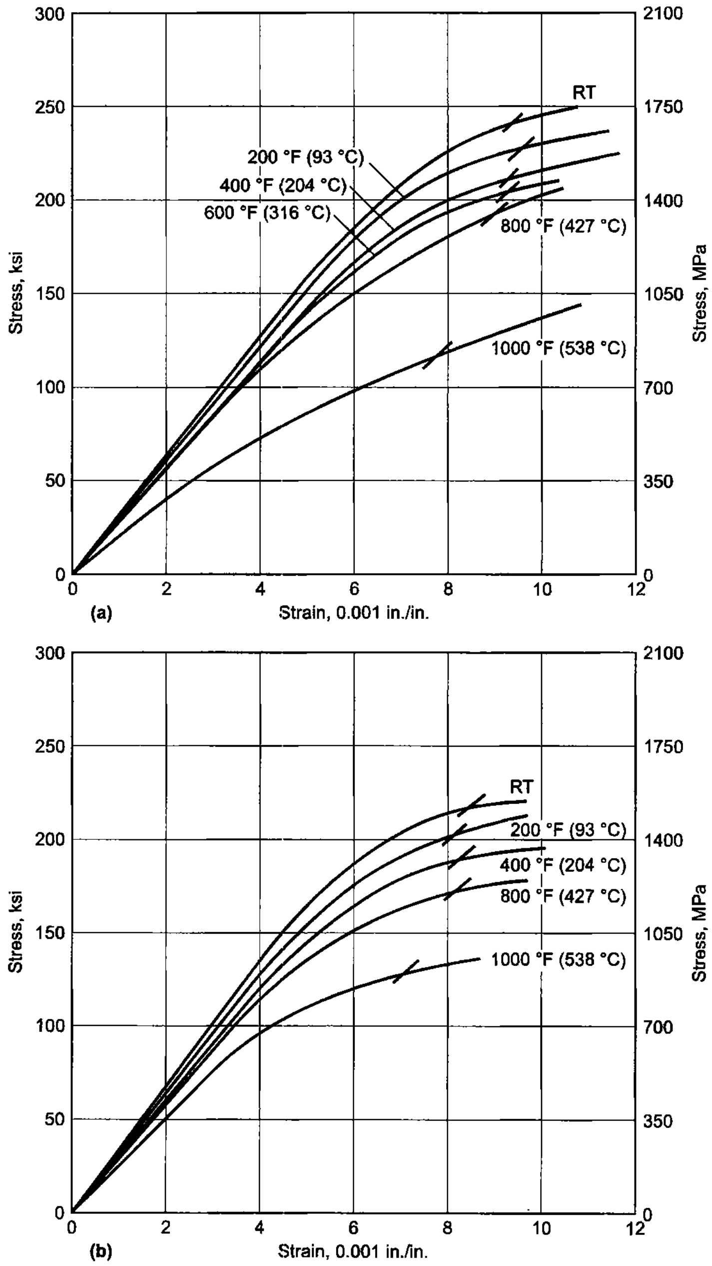
Sheet thickness = 1.27 mm (0.050 in.). RT, room temperature. Composition: Fe-15Cr-7Ni-2.5Mo. UNS S15700

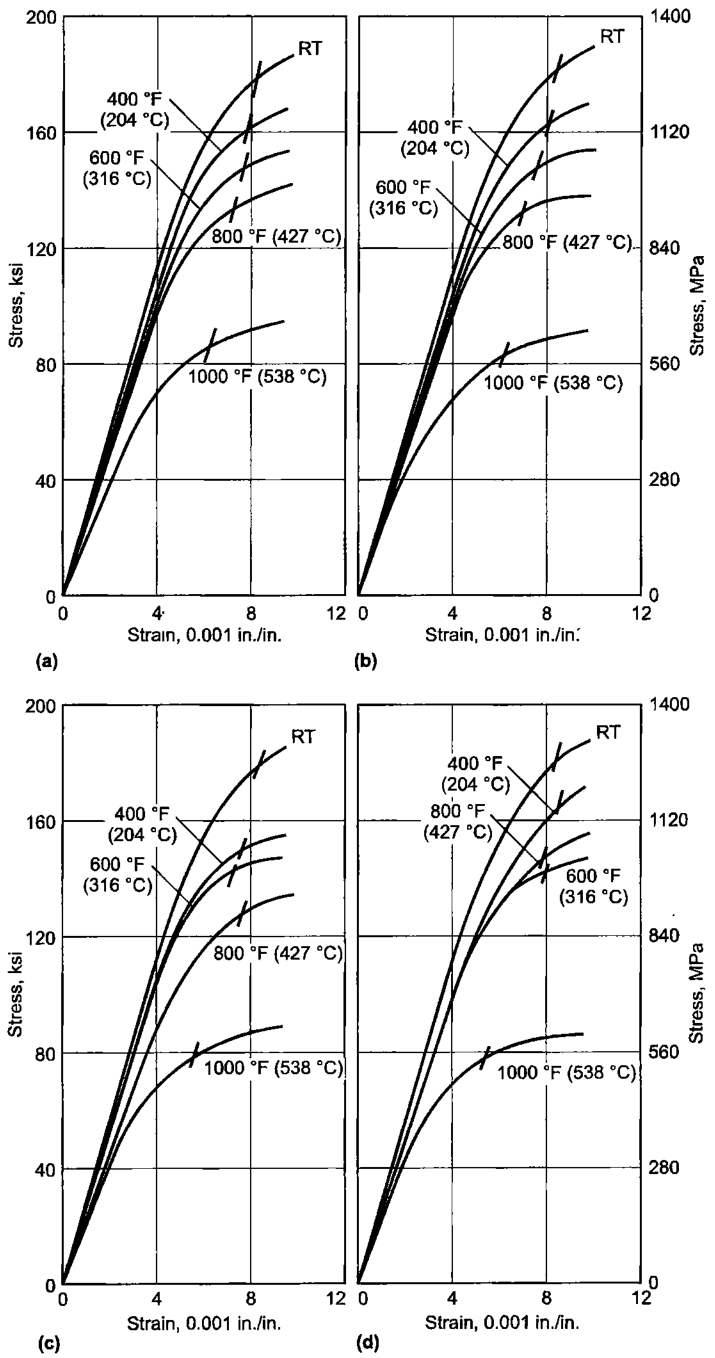
Source: *Armco Precipitation Hardening Stainless Steel Technical Manual,* Armco Steel Corp., 1 March 1958. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1503, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 10

SS.129 15-7 PH RH950 (a) and TH1050 (b) stainless steel sheet, typical compressive stress-strain curves at room and elevated temperatures

Sheet thickness = 1.27 mm (0.050 in.). RT, room temperature. Composition: Fe-15Cr-7Ni-2.5Mo. UNS S15700

Source: "Armco 17-7 PH and PH 15-7Mo," Armco Steel Corp., July 1968, p 29. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1503, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 15

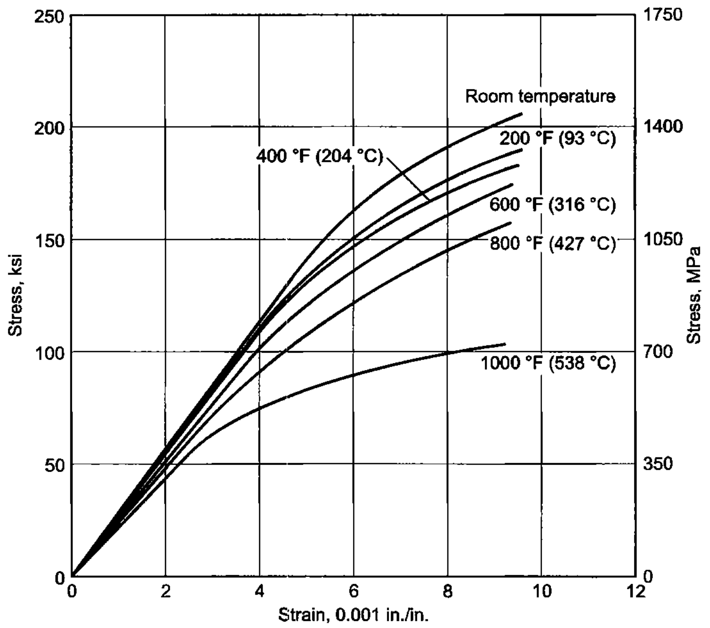




SS.130 15-7 PH TH1050 stainless steel sheet, typical tensile stress-strain curves at room and elevated temperatures for various exposure times

Sheet thickness = 1.27 mm (0.050 in.). RT, room temperature. Exposure times: (a) 30 min, (b) 10 h, (c) 100 h, and (d) 1000 h. Composition: Fe-15Cr-7Ni-2.5Mo. UNS S15700

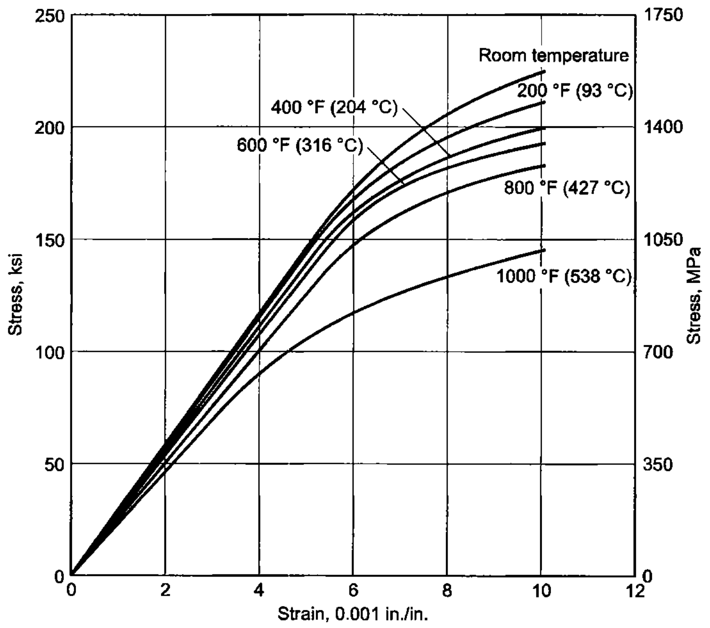
Source: M.M. Lemcoe and A. Trevino, Jr., "Determination of the Effect of Elevated Temperature Materials Properties of Several High Temperature Alloys," ASD TDR-61-529, June 1962, p 194–197. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1503, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 11



SS.131 15-7 PH TH1050 stainless steel sheet, typical tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal. 0.5 h exposure. Ramberg-Osgood parameters: *n*(room temperature) = 8.3, *n*(200 °F) = 6.6, *n*(400 °F) = 7.5, *n*(600 °F) = 5.5, *n*(800 °F) = 4.7, *n*(1000 °F) = 6.6. Composition: Fe-15Cr-7Ni-2.5Mo. UNS S15700

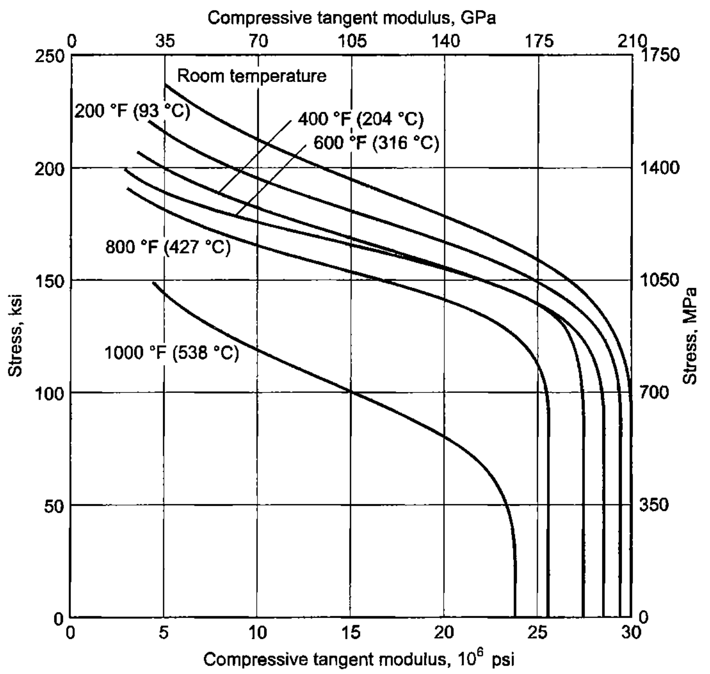
Source: *MIL-HDBK-5H,* Dec 1998, p 2-181



SS.132 15-7 PH TH1050 stainless steel sheet, typical compressive stress-strain curves at room and elevated temperatures

0.5 h exposure. Ramberg-Osgood parameters: *n*(room temperature) = 9.3, *n*(200 °F) = 10, *n*(400 °F) = 11, *n*(600 °F) = 14, *n*(800 °F) = 12, *n*(1000 °F) = 6.3. Composition: Fe-15Cr-7Ni-2.5Mo. UNS S15700

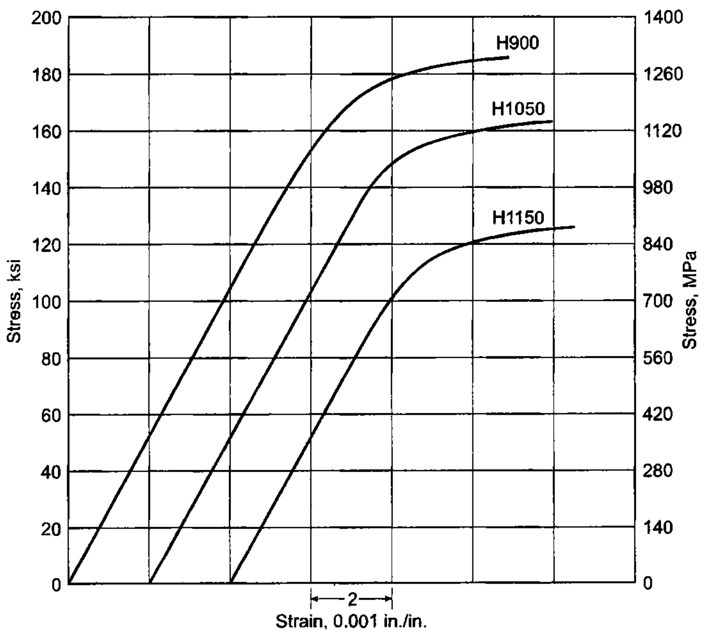
Source: *MIL-HDBK-5H,* Dec 1998, p 2-181



SS.133 15-7 PH TH1050 stainless steel sheet, typical compressive tangent modulus curves at room and elevated temperatures

0.5 h exposure. Ramberg-Osgood parameters: n(room temperature) = 9.3, n(200 °F) = 10, n(400 °F) = 11, n(600 °F) = 14, n(800 °F) = 12, n(1000 °F) = 6.3. Composition: Fe-15Cr-7Ni-2.5Mo. UNS S15700

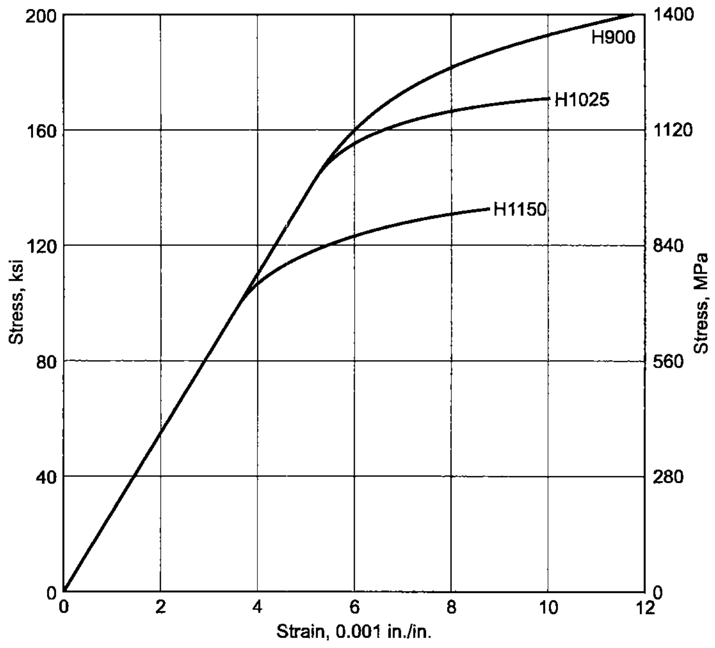
Source: *MIL-HDBK-5H,* Dec 1998, p 2-182



SS.134 17-4 PH stainless steel bar, stress-strain curves for various heat treat conditions

Composition: Fe-17Cr-4Ni-4Cu. UNS S17400

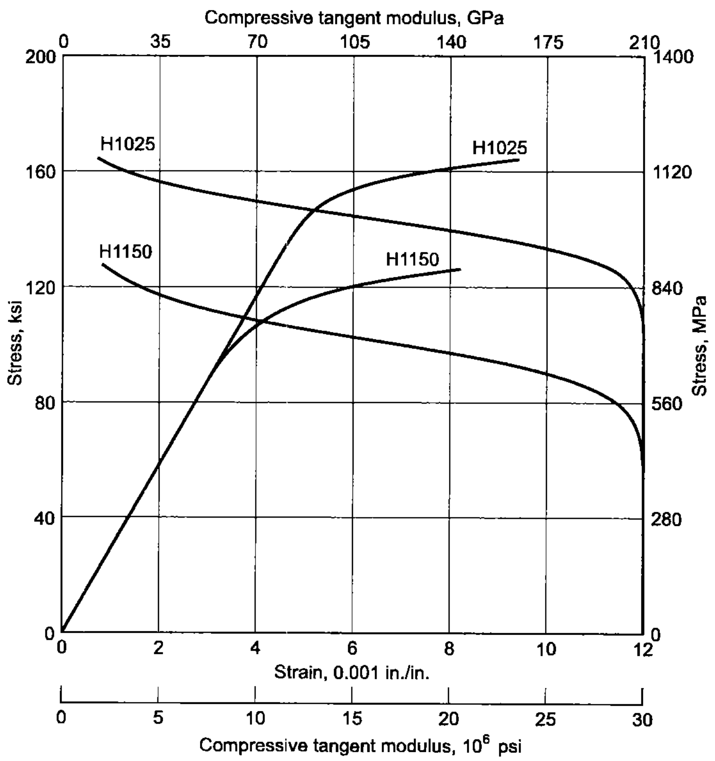
Source: W.J. Lanning, "Torsion Properties of 17-4PH and 15-5PH Stainless Steel Bars," Advanced Materials Div., Armco Steel Corp., 16 March 1972. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1501, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 7



SS.135 17-4 PH stainless steel bar, typical stress-strain curves for various heat treat conditions

Test direction: longitudinal. Bar thickness = 25.4–114.3 mm (1.000–4.500 in.). Ramberg-Osgood parameters: n(H900) = 11, n(H1025) = 24, n(H1150) = 13. Composition: Fe-17Cr-4Ni-4Cu. UNS S17400

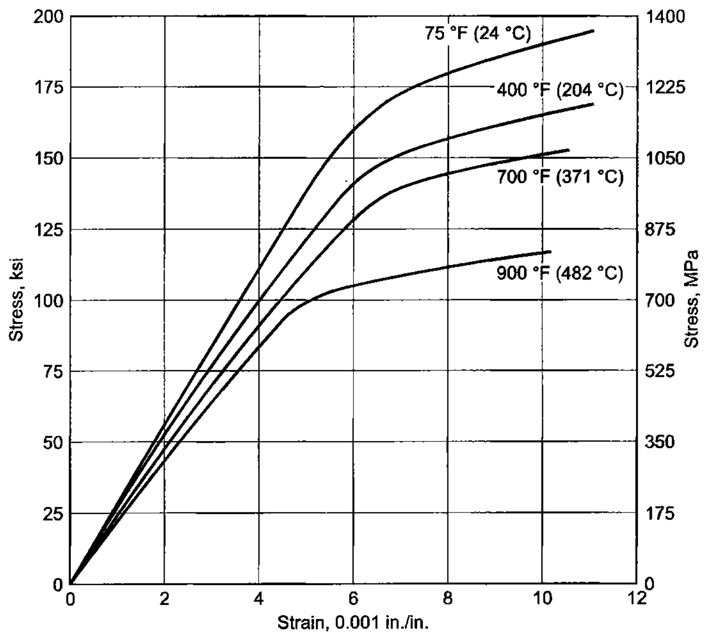
Source: *MIL-HDBK-5H,* Dec 1998, p 2-202



SS.136 17-4 PH stainless steel bar, typical compressive stress-strain and compressive tangent modulus curves at room temperature for various heat treat conditions

Test direction: longitudinal. Bar thickness: 25.4–114.3 mm (1.000–4.500 in.). Ramberg-Osgood parameters: n(H1025) = 22, n(H1150) = 13. Composition: Fe-17Cr-4Ni-4Cu. UNS S17400

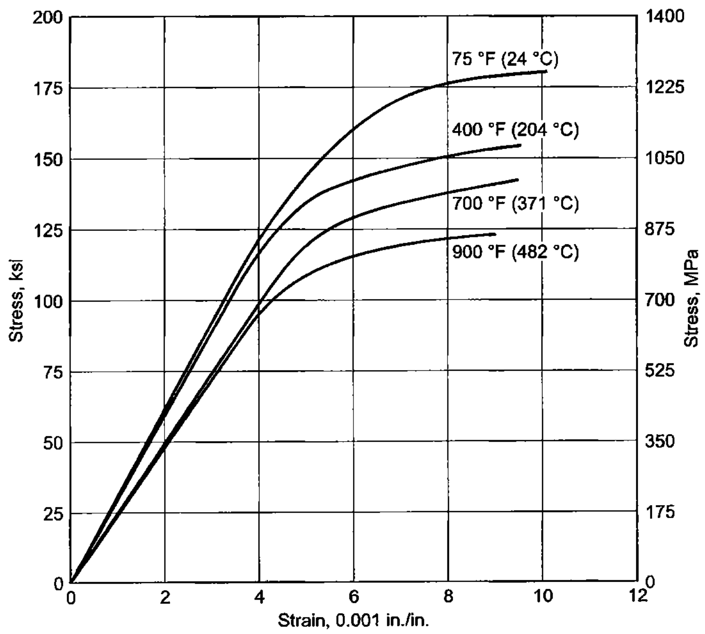
Source: *MIL-HDBK-5H,* Dec 1998, p 2-202



SS.137 17-4 PH H900 stainless steel bar, typical tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Composition: Fe-17Cr-4Ni-4Cu. UNS S17400

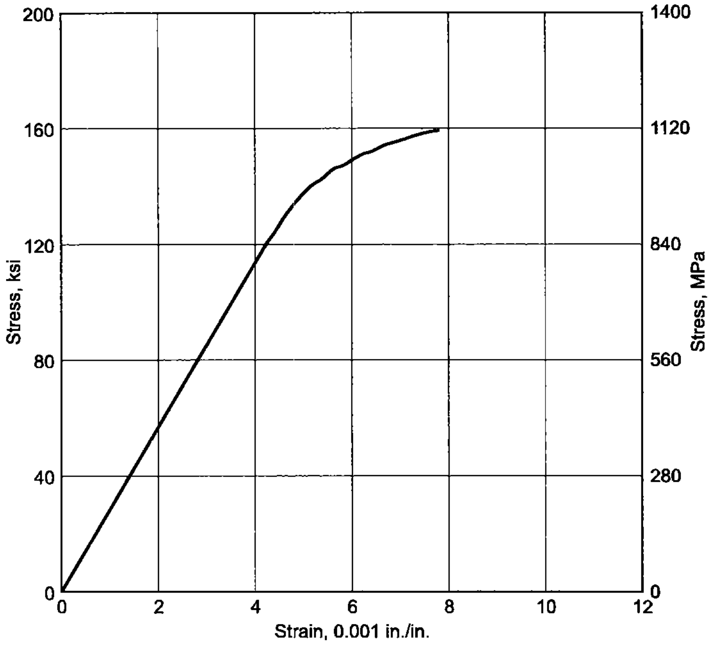
Source: O.L. Deel and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," AFML-TR-72-196, Vol 1, Battelle Columbus Laboratories, Sept 1972. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1501, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 11



SS.138 17-4 PH H900 stainless steel bar, compressive stress-strain curves at room and elevated temperatures

Composition: Fe-17Cr-4Ni-4Cu. UNS S17400

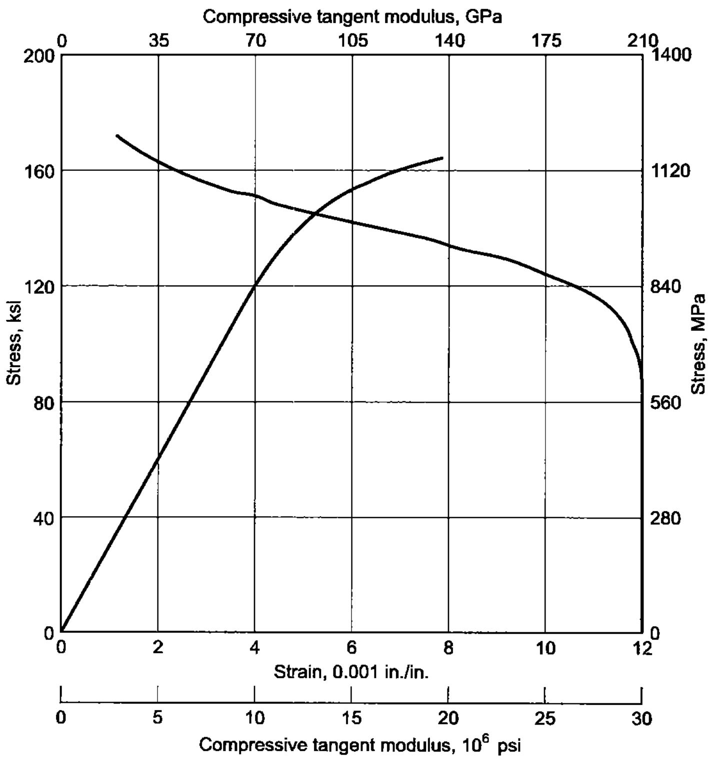
Source: O.L. Deel and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," AFML-TR-72-196, Vol 1, Battelle Columbus Laboratories, Sept 1972. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1501, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 16



SS.139 17-4 PH H1000 stainless steel casting, typical tensile stress-strain curve at room temperature

Casting thickness = 9.525–76.2 mm (0.375–3.000 in.). Ramberg-Osgood parameter: $n = 16$. Composition: Fe-17Cr-4Ni-4Cu. UNS S17400

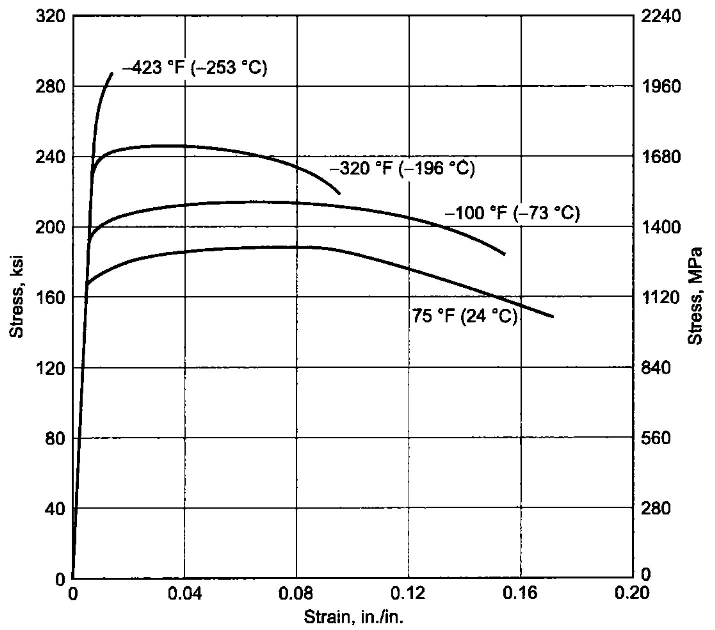
Source: *MIL-HDBK-5H,* Dec 1998, p 2-203



SS.140 17-4 PH H1000 stainless steel casting, typical compressive stress-strain and compressive tangent modulus curves at room temperature

Casting thickness = 9.525–76.2 mm (0.375–3.000 in.). Ramberg-Osgood parameter: $n = 13$. Composition: Fe-17Cr-4Ni-4Cu. UNS S17400

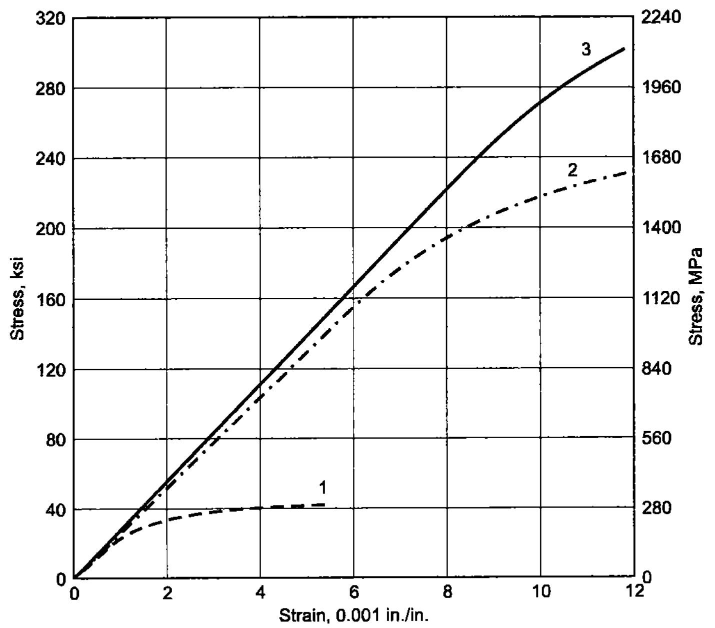
Source: *MIL-HDBK-5H,* Dec 1998, p 2-203



SS.141 17-4 PH H1100 stainless steel bar, complete stress-strain curves at room and low temperatures

Composition: Fe-17Cr-4Ni-4Cu. UNS S17400

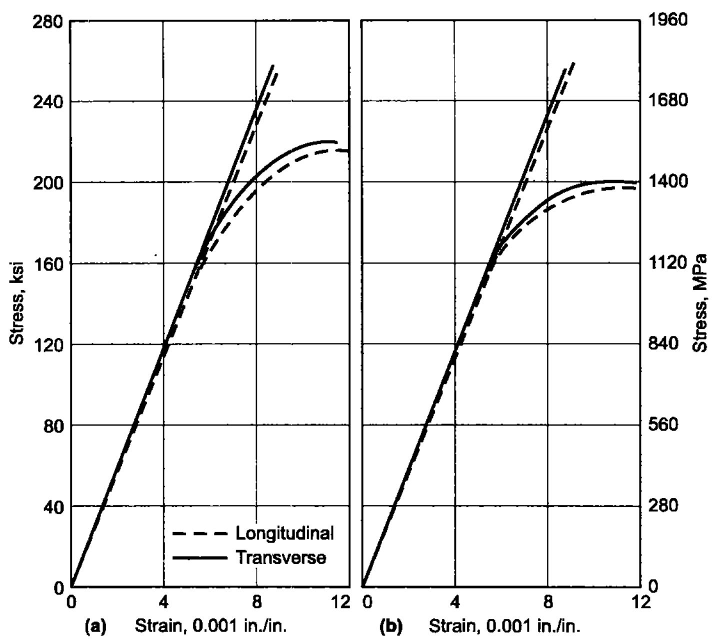
Source: K.A. Warren and R.P. Reed, *Tensile and Impact Properties of Selected Materials from 20 to 300 K,* Monograph 63, National Bureau of Standards, 28 June 1963. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1501, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 11



SS.142 17-7 PH stainless steel spring wire, tensile stress-strain curves at room temperature for various heat treat conditions

Curve 1, 5.08 mm (0.200 in.) diam, condition A; curve 2, 2.032 mm (0.080 in.) diam, condition C; curve 3, 2.032 mm (0.080 in.) diam, condition CH900. Composition: Fe-17Cr-7Ni-1Al. UNS S17700

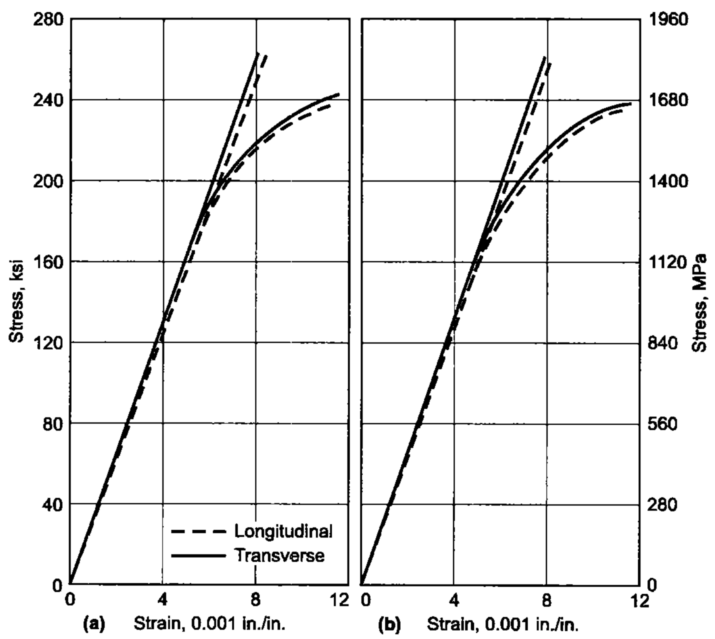
Source: "Armco 17-7 PH Precipitation-Hardening Stainless Steel, Bar, Rod and Wire," Bulletin No. S-29e, Armco Stainless Steel Div., April 1983. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1502, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 16



SS.143 17-7 PH stainless steel sheet, typical tensile stress-strain curves for heat treat condition RH950 (a) and TH1050 (b)

Test direction: longitudinal and transverse. Sheet thickness = 1.27 mm (0.050 in.). Composition: Fe-17Cr-7Ni-1Al. UNS S17700

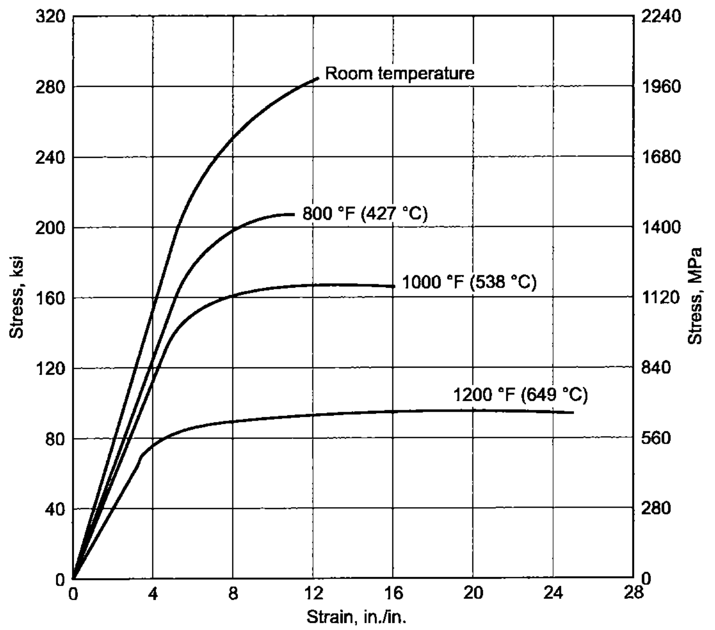
Source: "Armco 17-7 H and PH 15-7Mo," Armco Steel Corp., 1966. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1502, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 16



SS.144 17-7 PH stainless steel sheet, typical compressive stress-strain curves for heat treat condition RH950 (a) and TH1050 (b)

Test direction: longitudinal and transverse. Sheet thickness = 1.27 mm (0.050 in.). Tested at room temperature. Composition: Fe-17Cr-7Ni-1Al. UNS S17700

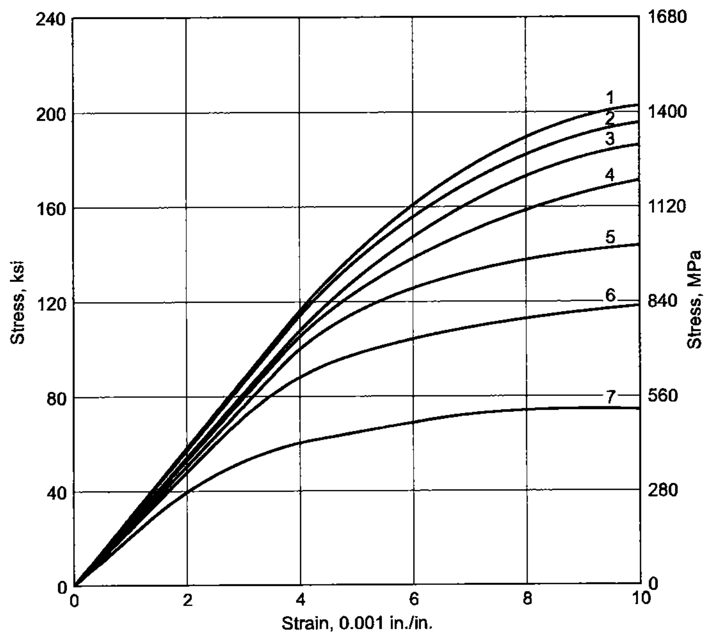
Source: "Armco 17-7 H and PH 15-7Mo," Armco Steel Corp., 1966. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1502, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 18



SS.145 17-7 PH CH900 stainless steel sheet, tensile stress-strain curves at room and elevated temperatures under conditions of rapid heating, rapid loading, and short time at temperature

Sheet thickness = 1.016 mm (0.040 in.). Strain rate = 0.1/s. Heated to test temperature in 10 s and held for 10 s prior to test. Composition: Fe-17Cr-7Ni-1Al. UNS S17700

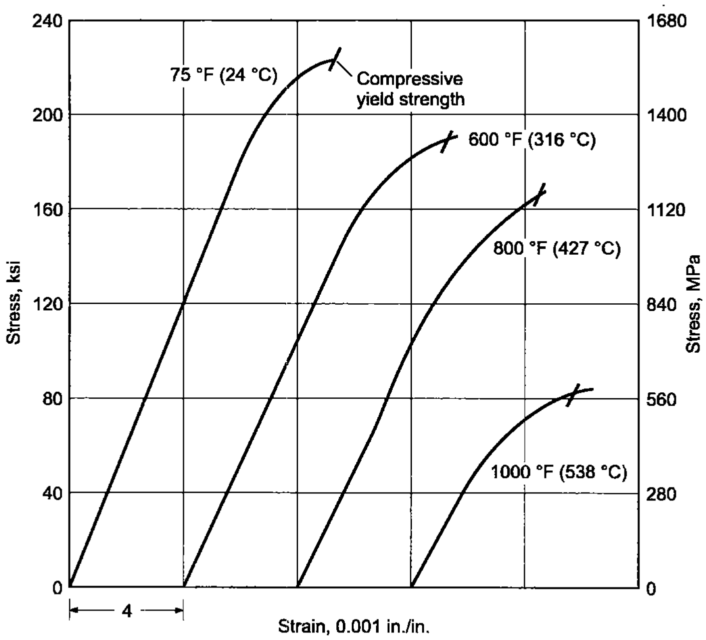
Source: J.R. Kattus, "Tensile and Creep Rupture Properties of Structural Alloys under Conditions of Rapid Heating, Rapid Loading, and Short Times at Temperature," Southern Research Institute Report 3962-867-2-I to International Nickel Co., 10 April 1959. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1502, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 19



SS.146 17-7 PH RH950 stainless steel sheet, tensile stress-strain curves at various temperatures

Sheet thickness = 1.27 mm (0.050 in.). Curve 1: room temperature; curve 2: 93 °C (200 °F); curve 3: 204 °C (400 °F); curve 4: 316 °C (600 °F); curve 5: 427 °C (800 °F); curve 6: 482 °C (900 °F); curve 7: 538 °C (1000 °F). Composition: Fe-17Cr-7Ni-1Al. UNS S17700

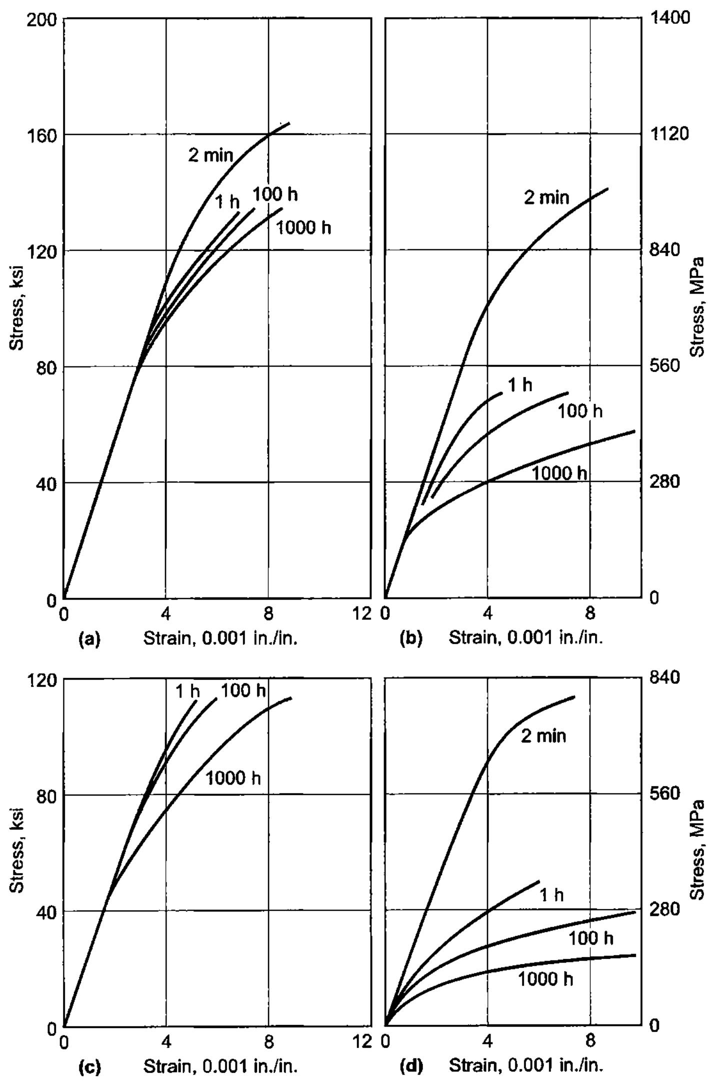
Source: *Armco Precipitation Hardening Stainless Steels Technical Data Manual*, Armco Steel Corp., 1 Nov 1957. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1502, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 19



SS.147 17-7 PH RH950 stainless steel sheet, compressive stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Sheet thickness = 1.575 mm (0.062 in.). Composition: Fe-17Cr-7Ni-1Al. UNS S17700

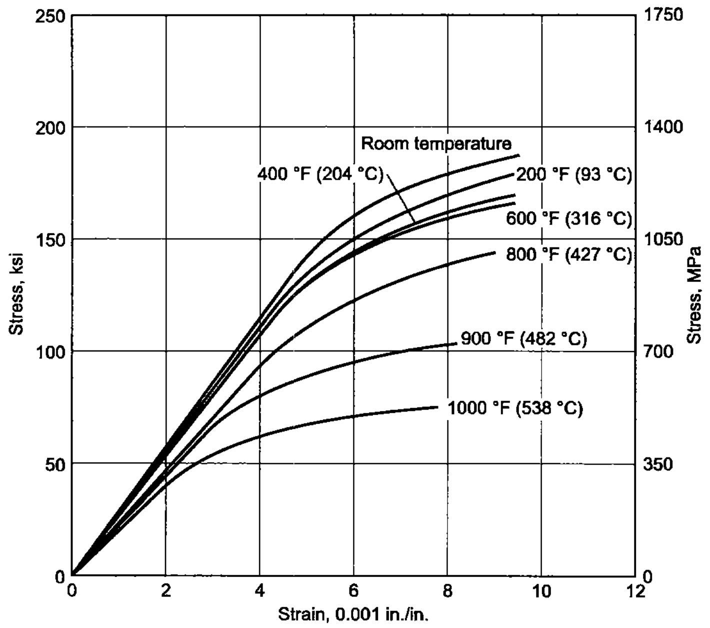
Source: J.R. Kattus, J.B. Preston, and H.L. Lessley, "Determination of Tensile, Compressive, Bearing, and Shear Properties of Sheet Steels at Elevated Temperatures," WADC Technical Report 58-365, Nov 1958. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1502, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 24



SS.148 17-7 PH RH950 stainless steel sheet, isochronous stress-strain curves

Sheet thickness = 1.27 mm (0.050 in.). (a) 316 °C (600 °F). (b) 427 °C (800 °F). (c) 371 °C (700 °F). (d) 482 °C (900 °F). Composition: Fe-17Cr-7Ni-1Al. UNS S17700

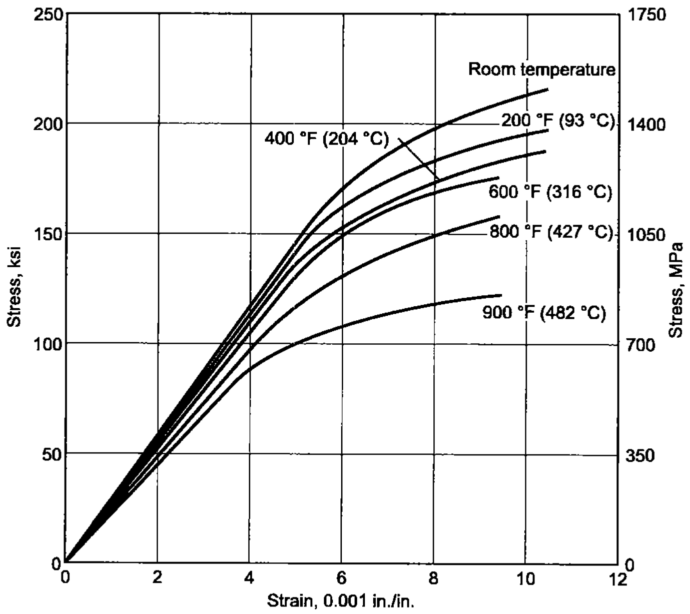
Source: *Armco Precipitation Hardening Stainless Steels Technical Data Manual,* Armco Steel Corp., 1 Nov 1957. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1502, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 30



SS.149 17-7 PH TH1050 stainless steel sheet, typical tensile stress-strain curves at room and elevated temperatures

0.5 h exposure. Ramberg-Osgood parameters *n*(room temperature) = 12, *n*(200 °F) = 8.3, *n*(400 °F) = 9.0, *n*(600 °F) = 12, *n*(800 °F) = 8.3, *n*(900 °F) = 8.0, *n*(1000 °F) = 7.7. Composition: Fe-17Cr-7Ni-1Al. UNS S17700

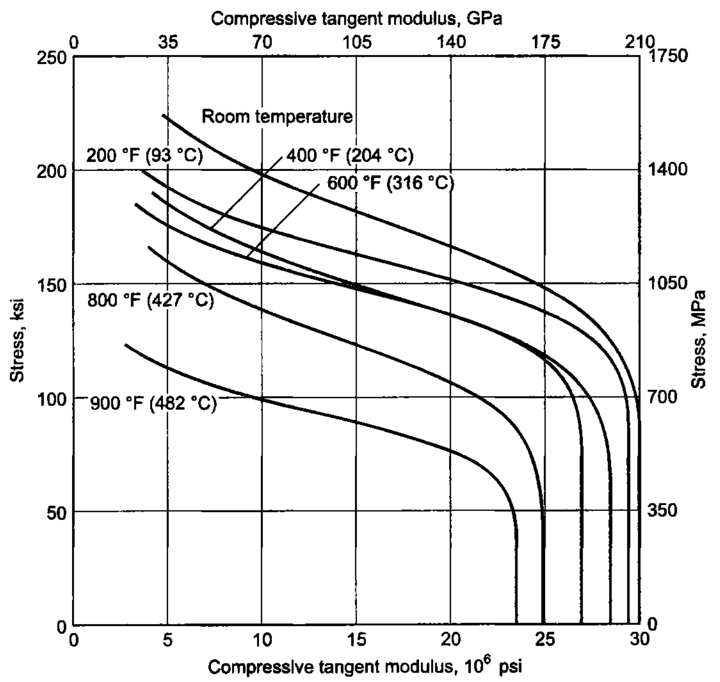
Source: *MIL-HDBK-5H,* Dec 1998, p 2-212



SS.150 17-7 PH TH1050 stainless steel sheet, typical compressive stress-strain curves at room and elevated temperatures

0.5 h exposure. Ramberg-Osgood parameters: *n*(room temperature) = 9.3, *n*(200 °F) = 11, *n*(400 °F) = 9.3, *n*(600 °F) = 11, *n*(800 °F) = 8.3, *n*(900 °F) = 9.3. Composition: Fe-17Cr-7Ni-1Al. UNS S17700

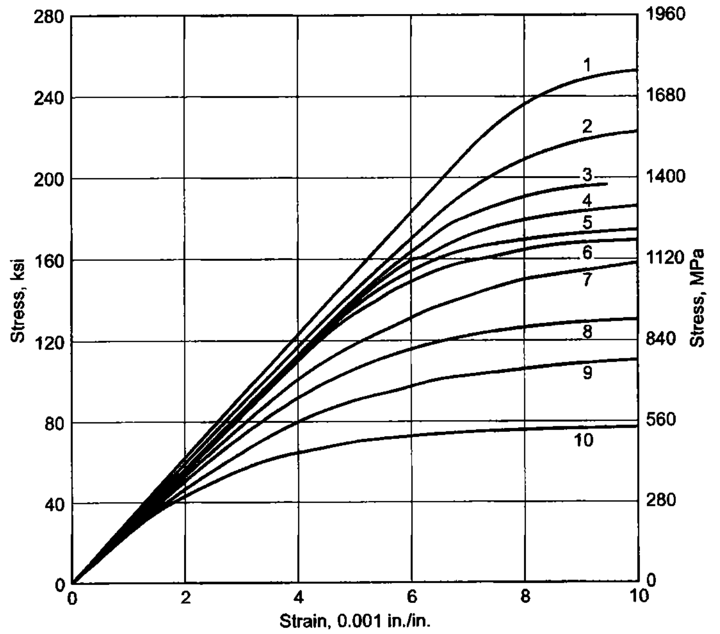
Source: *MIL-HDBK-5H,* Dec 1998, p 2-212



SS.151 17-7 PH TH1050 stainless steel sheet, typical compressive tangent modulus curves at room and elevated temperatures

0.5 h exposure. Ramberg-Osgood parameters: n(room temperature) = 9.3, n(200 °F) = 11, n(400 °F) = 9.3, n(600 °F) = 11, n(800 °F) = 8.3, n(900 °F) = 9.3. Composition: Fe-17Cr-7Ni-1Al. UNS S17700

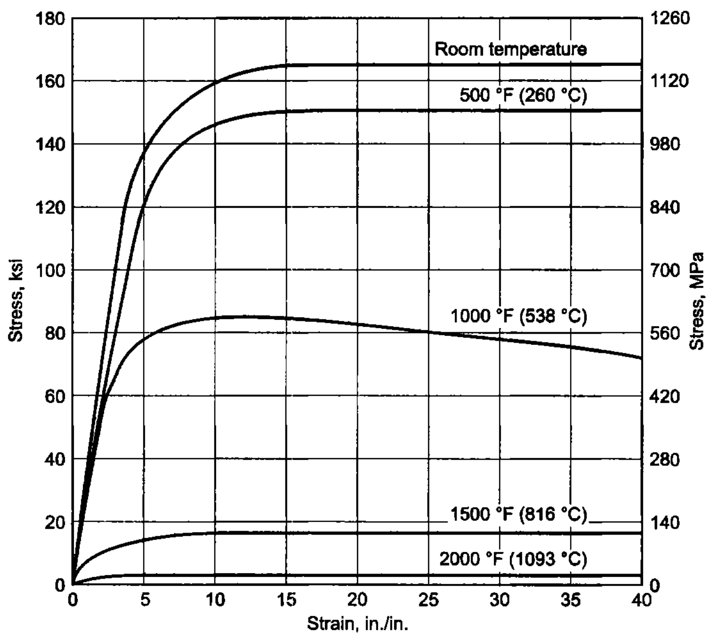
Source: *MIL-HDBK-5H,* Dec 1998, p 2-213



SS.152 17-7 PH TH1050 stainless steel sheet, tensile stress-strain curves at various temperatures

RT, room temperature. Sheet thickness = 2.032 mm (0.080 in.) for low temperatures (below RT), 1.27 mm (0.050 in.) for RT and above. Curve 1: –253 °C (–423 °F); curve 2: –196 °C (–320 °F); curve 3: –79 °C (–110 °F); curve 4: RT; curve 5: 93 °C (200 °F); curve 6: 204 °C (400 °F); curve 7: 316 °C (600 °F); curve 8: 427 °C (800 °F); curve 9: 482 °C (900 °F); curve 10: 538 °C (1000 °F). Composition: Fe-17Cr-7Ni-1Al. UNS S17700

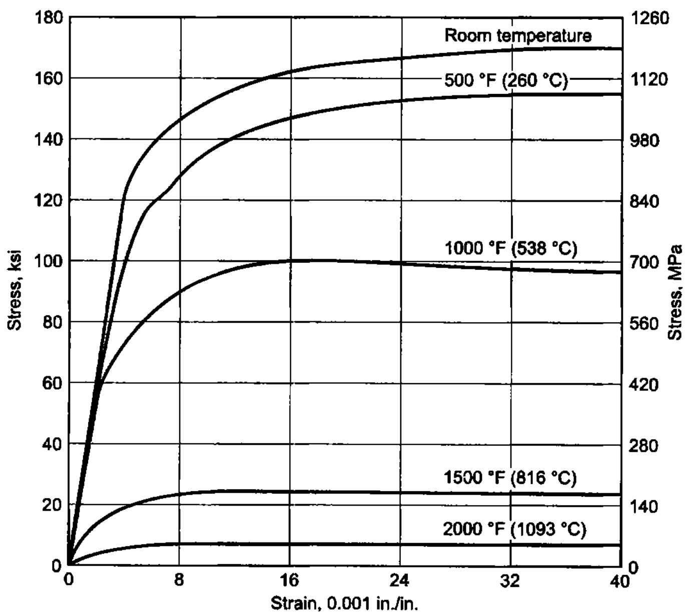
Source: *Armco Precipitation Hardening Stainless Steels Technical Data Manual,* Armco Steel Corp., 1 Nov 1957 and A.L. McGee, J.E. Campbell, R.L. Carlson, and G.K. Manning, "The Mechanical Properties of Certain Aircraft Structural Metals at Very Low Temperatures," WADC TR 58-386, Nov 1958. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1502, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 19



SS.153 17-7 PH TH1050 stainless steel sheet, tensile stress-strain curves at room and elevated temperatures

Strain rate 0.0002/s. Composition: Fe-17Cr-7Ni-1Al. UNS S17700

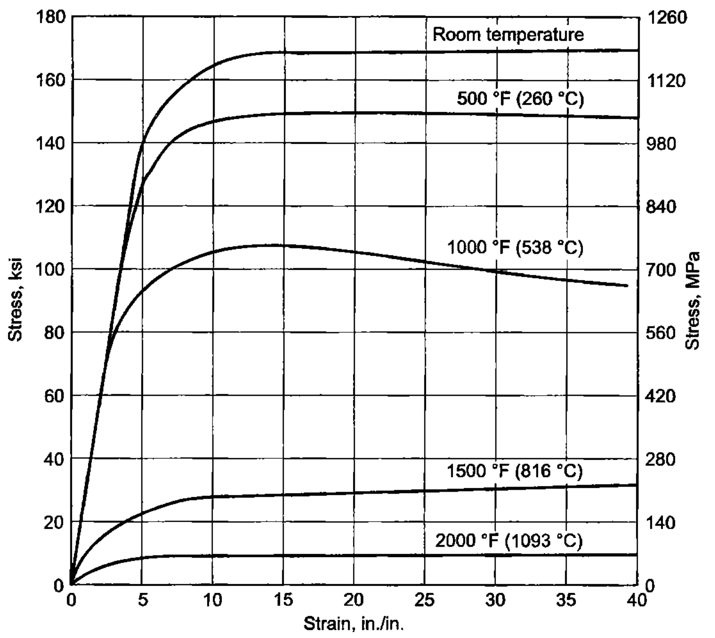
Source: A.C. Wilhelm and J.R. Kattus, "Determination of the Mechanical Properties of Aircraft Structural Materials at Very High Temperatures after Rapid Heating," Part 3, "The Effects of Simultaneous Heating and Loading on the Tensile Properties of Typical Structural Alloys," WADC TR 57-647, Part 3, Nov 1960. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1502, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 20



SS.154 17-7 PH TH1050 stainless steel sheet, tensile stress-strain curves at room and elevated temperatures

Strain rate 0.002/s. Composition: Fe-17Cr-7Ni-1Al. UNS S17700

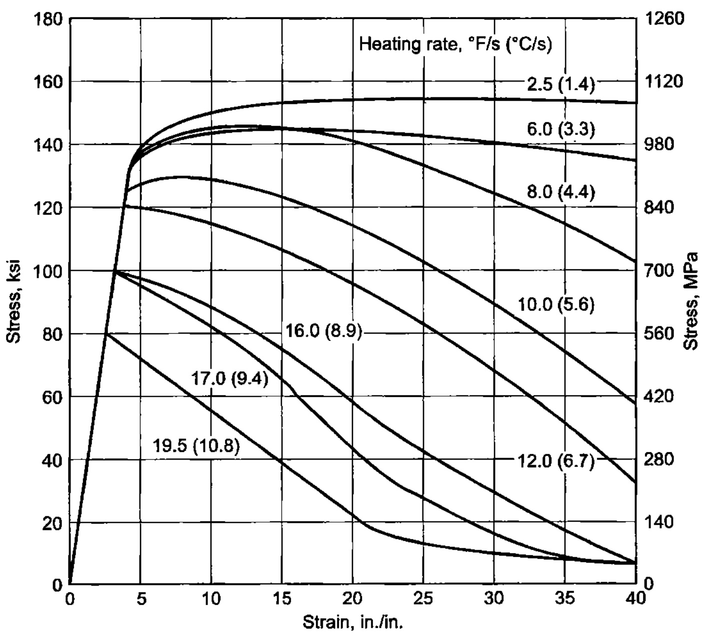
Source: A.C. Wilhelm and J.R. Kattus, "Determination of the Mechanical Properties of Aircraft Structural Materials at Very High Temperatures after Rapid Heating," Part 3, "The Effects of Simultaneous Heating and Loading on the Tensile Properties of Typical Structural Alloys," WADC TR 57-647, Part 3, Nov 1960. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1502, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 20



SS.155 17-7 PH TH1050 stainless steel sheet, tensile stress-strain curves at room and elevated temperatures

Strain rate 0.02/s. Composition: Fe-17Cr-7Ni-1Al. UNS S17700

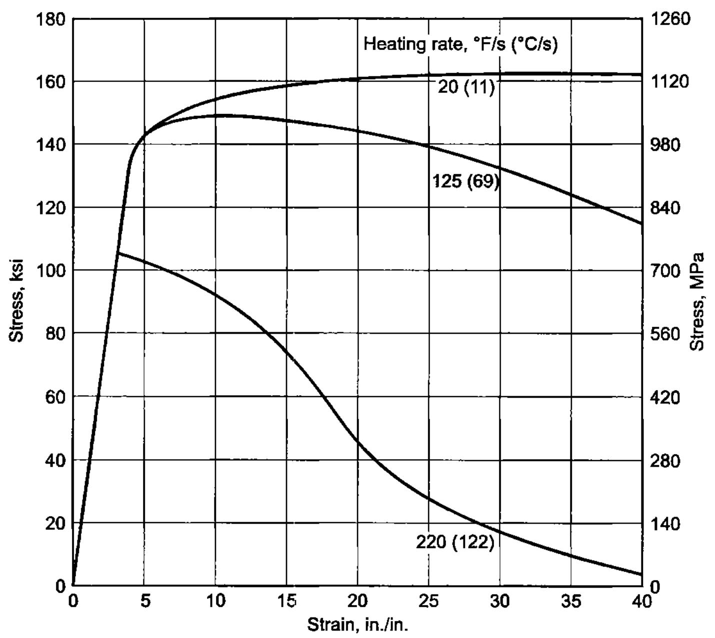
Source: A.C. Wilhelm and J.R. Kattus, "Determination of the Mechanical Properties of Aircraft Structural Materials at Very High Temperatures after Rapid Heating," Part 3, "The Effects of Simultaneous Heating and Loading on the Tensile Properties of Typical Structural Alloys," WADC TR 57-647, Part 3, Nov 1960. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1502, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 21



SS.156 17-7 PH TH1050 stainless steel sheet, tensile stress-strain curves with effect of various heating rates

Specimens simultaneously loaded at strain rate of 0.0002/s and heated at rate shown. Composition: Fe-17Cr-7Ni-1Al. UNS S17700

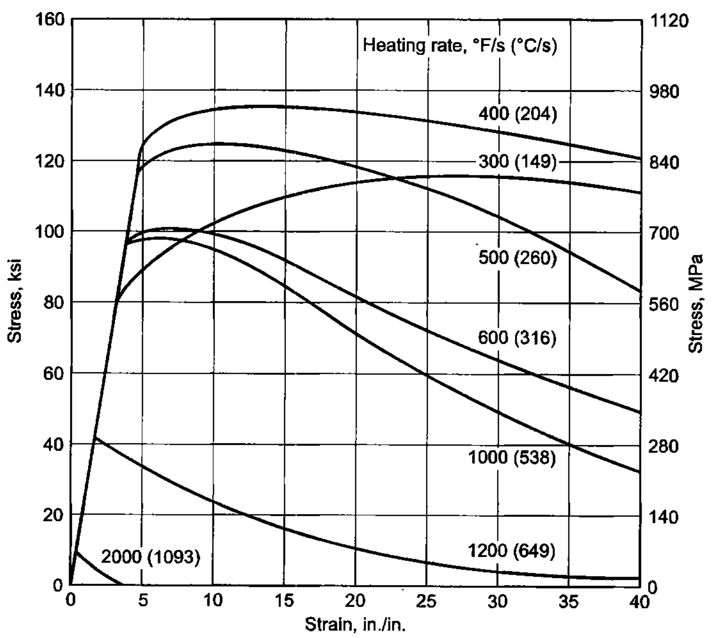
Source: A.C. Wilhelm and J.R. Kattus, "Determination of the Mechanical Properties of Aircraft Structural Materials at Very High Temperatures after Rapid Heating," Part 3, "The Effects of Simultaneous Heating and Loading on the Tensile Properties of Typical Structural Alloys," WADC TR 57-647, Part 3, Nov 1960. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1502, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 21



SS.157 17-7 PH TH1050 stainless steel sheet, tensile stress-strain curves with effect of various heating rates

Specimens simultaneously loaded at strain rate of 0.002/s and heated at rate shown. Composition: Fe-17Cr-7Ni-1Al. UNS S17700

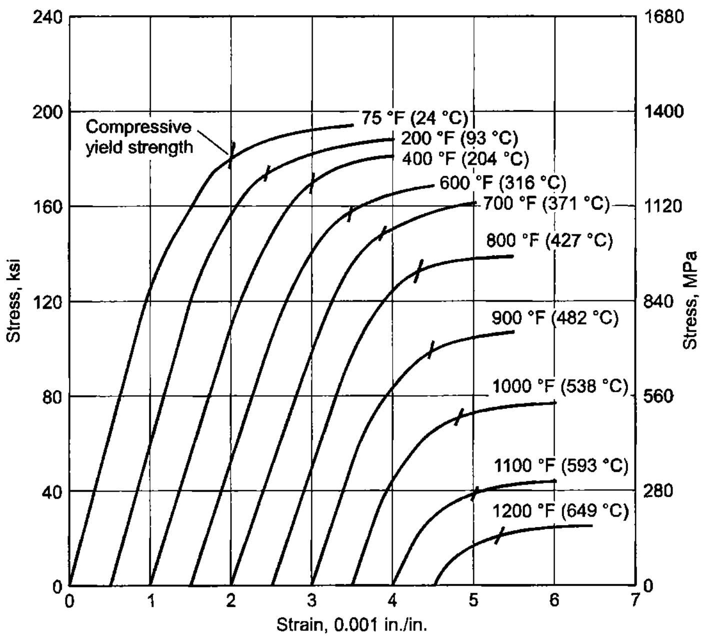
Source: A.C. Wilhelm and J.R. Kattus, "Determination of the Mechanical Properties of Aircraft Structural Materials at Very High Temperatures after Rapid Heating," Part 3, "The Effects of Simultaneous Heating and Loading on the Tensile Properties of Typical Structural Alloys," WADC TR 57-647, Part 3, Nov 1960. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1502, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 22



SS.158 17-7 PH TH1050 stainless steel sheet, tensile stress-strain curves with effect of various heating rates

Specimens simultaneously loaded at strain rate of 0.02/s and heated at rate shown. Composition: Fe-17Cr-7Ni-1Al. UNS S17700

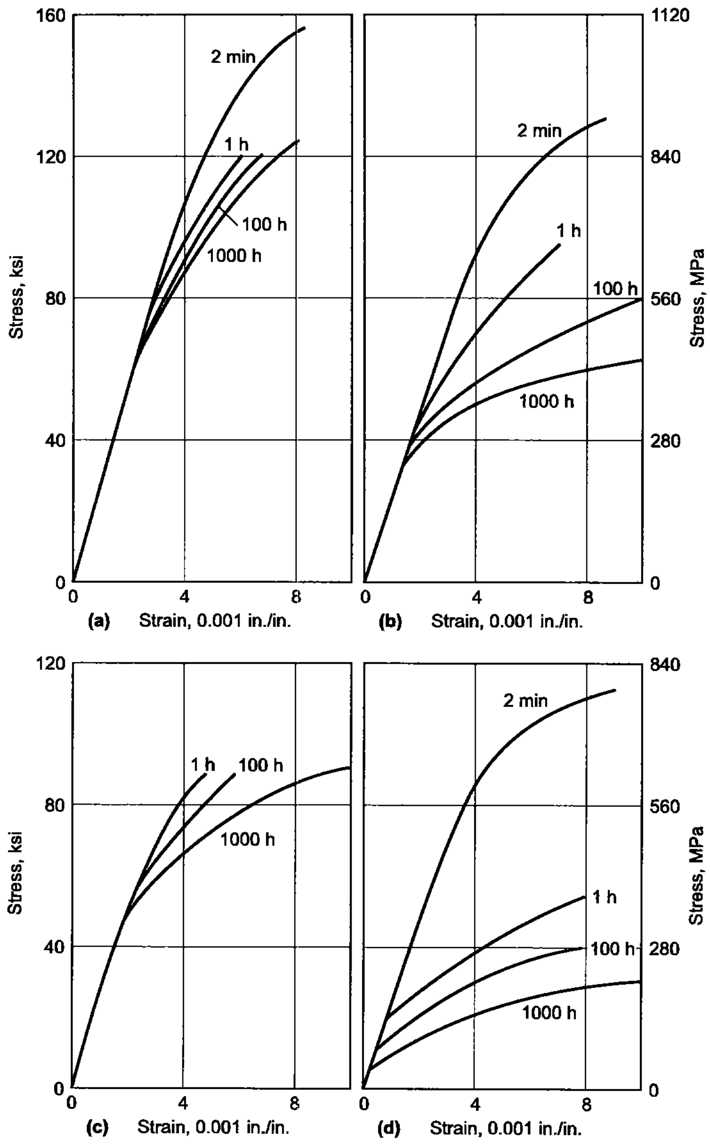
Source: A.C. Wilhelm and J.R. Kattus, "Determination of the Mechanical Properties of Aircraft Structural Materials at Very High Temperatures after Rapid Heating," Part 3, "The Effects of Simultaneous Heating and Loading on the Tensile Properties of Typical Structural Alloys," WADC TR 57-647, Part 3, Nov 1960. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1502, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 22



SS.159 17-7 PH TH1050 stainless steel sheet, compressive stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Sheet thickness = 1.27 mm (0.050 in.). Specimens loaded at strain rate of 0.002/min. Composition: Fe-17Cr-7Ni-1Al. UNS S17700

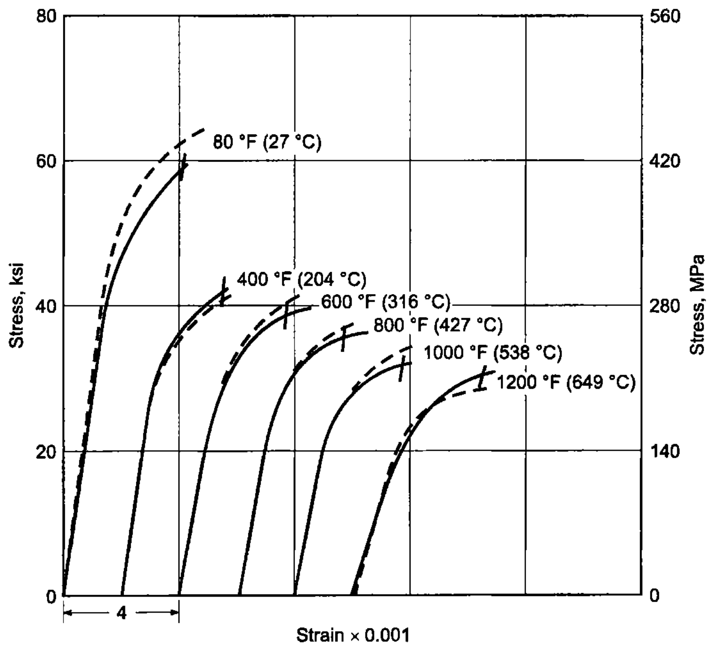
Source: B.A. Stein, "Compressive Stress-strain curves Properties of 17-7 PH and AM 350 Stainless-Steel Sheet at Elevated Temperatures," NACA TN 4074, 19 Aug 1957. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1502, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 24



SS.160 17-7 PH TH1050 stainless steel sheet, isochronous stress-strain curves

Sheet thickness = 1.27 mm (0.050 in.). (a) 316 °C (600 °F). (b) 427 °C (800 °F). (c) 371 °C (700 °F). (d) 538 °C (1000 °F). Composition: Fe-17Cr-7Ni-1Al. UNS S17700

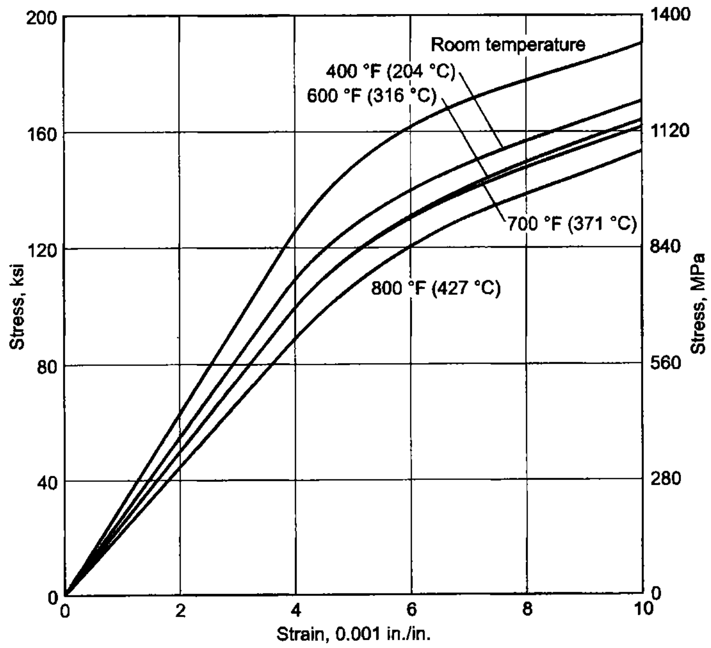
Source: *Armco Precipitation Hardening Stainless Steels Technical Data Manual*, Armco Steel Corp., 1 Nov 1957. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1502, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 31



SS.161 AM-350 annealed stainless steel sheet, tensile and compressive stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Sheet thickness = 1.626 mm (0.064 in.). Solid curves, tension; dashed curves, compression. Composition: Fe-17Cr-4Ni-3Mo. UNS S35000

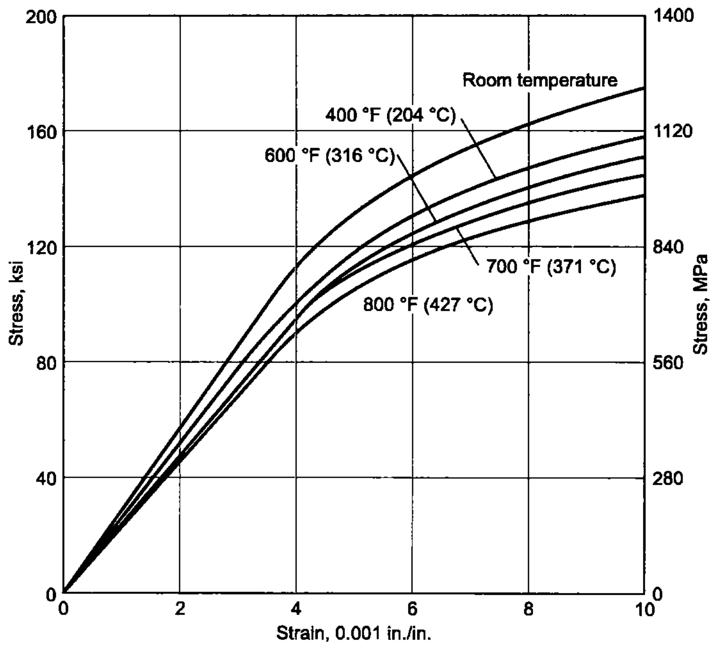
Source: R.G. Henning and A.W. Brisbane, "Mechanical Properties of AM-350 Potomac A, Potomac M and Vascojet 1000 Steel Alloys in the Annealed Condition," ASD-TDR-63-116, May 1963. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1504, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 11



SS.162 AM-350 double aged stainless steel sheet, compressive stress-strain curves at room and elevated temperatures

Sheet thickness = 1.626 mm (0.064 in.). Composition: Fe-17Cr-4Ni-3Mo. UNS S35000

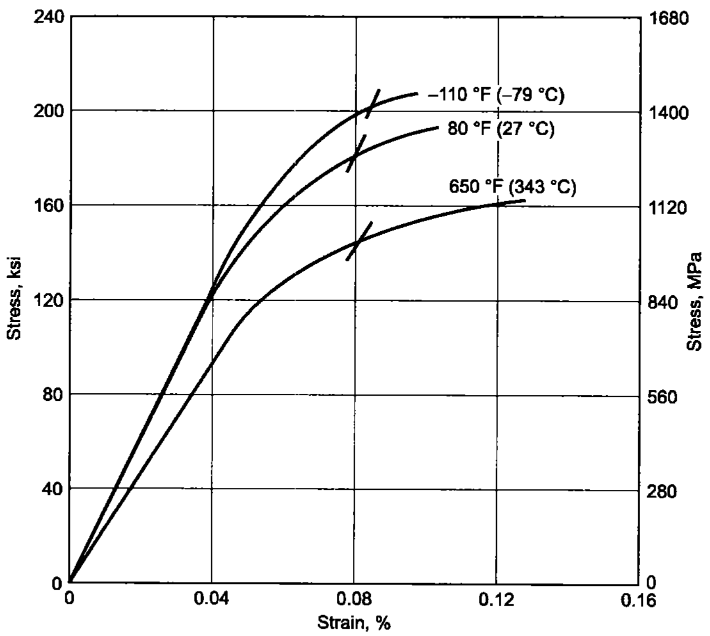
Source: "Room and Elevated Temperature Tensile and Compressive Properties of Type AM-350," Data sheet 86-11457-350, Allegheny Ludlum Steel Corp., 1958. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1504, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 14



SS.163 AM-350 double aged stainless steel sheet, tensile stress-strain curves at room and elevated temperatures

Sheet thickness = 1.626 mm (0.064 in.). Composition: Fe-17Cr-4Ni-3Mo. UNS S35000

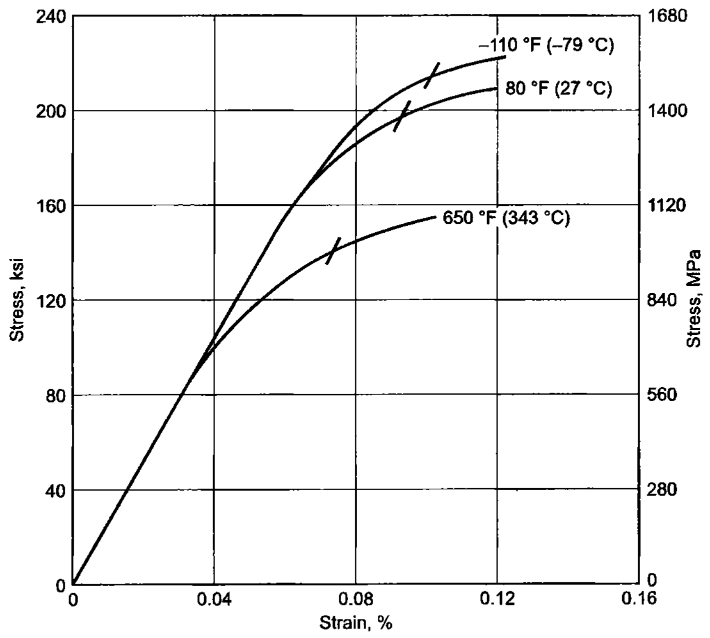
Source: "Room and Elevated Temperature Tensile and Compressive Properties of Type AM-350," Data sheet 86-11457-350, Allegheny Ludlum Steel Corp., 1958. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1504, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 11



SS.164 AM-350 20% CRT stainless steel sheet, tensile stress-strain curves at room and various temperatures

CRT: annealed to condition H, cold rolled 20%, 3 h, tempered 441 °C (825 °F), 3 h. Composition: Fe-17Cr-4Ni-3Mo. UNS S35000

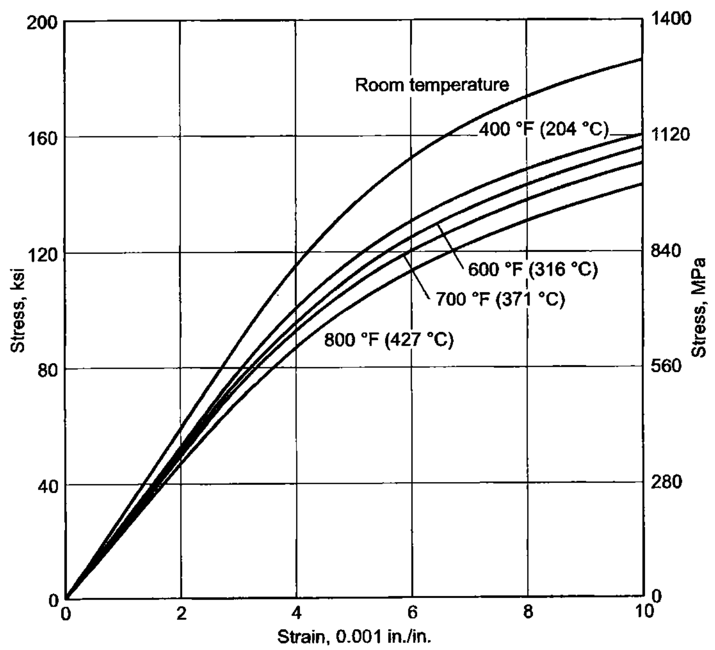
Source: *Aerospace Structural Metals Handbook*, Vol 2, Code 1504, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



SS.165 AM-350 30% CRT stainless steel sheet, tensile stress-strain curves at room and various temperatures

CRT: annealed to condition H, cold rolled 30%, 3 h, tempered 441 °C (825 °F), 3 h. Composition: Fe-17Cr-4Ni-3Mo. UNS S35000

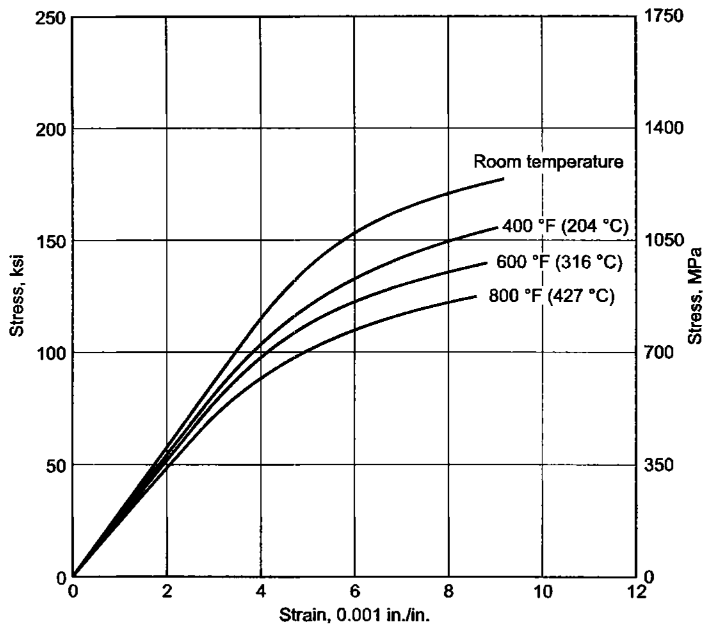
Source: *Aerospace Structural Metals Handbook*, Vol 2, Code 1504, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



SS.166 AM-350 SCT850 stainless steel sheet, tensile stress-strain curves at room and elevated temperatures

Sheet thickness = 1.067 mm (0.042 in.). SCT, subcooled and tempered. Composition: Fe-17Cr-4Ni-3Mo. UNS S35000

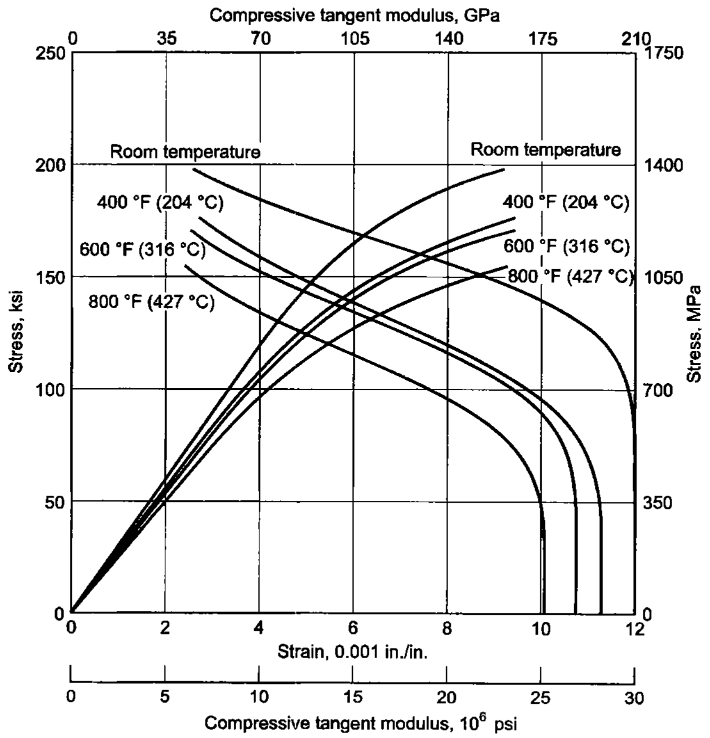
Source: "Room and Elevated Temperature Tensile and Compressive Properties of Type AM-350," Data sheet 86-11457-350, Allegheny Ludlum Steel Corp., 1958. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1504, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 11



SS.167 AM-350 SCT850 stainless steel sheet, typical tensile stress-strain curves at room and elevated temperatures

0.5 h exposure. SCT, subcooled and tempered. Ramberg-Osgood parameters: n(room temperature) = 10, n(400 °F) = 7.0, n(600 °F) = 7.5, n(800 °F) = 6.5. Composition: Fe-17Cr-4Ni-3Mo. UNS S35000

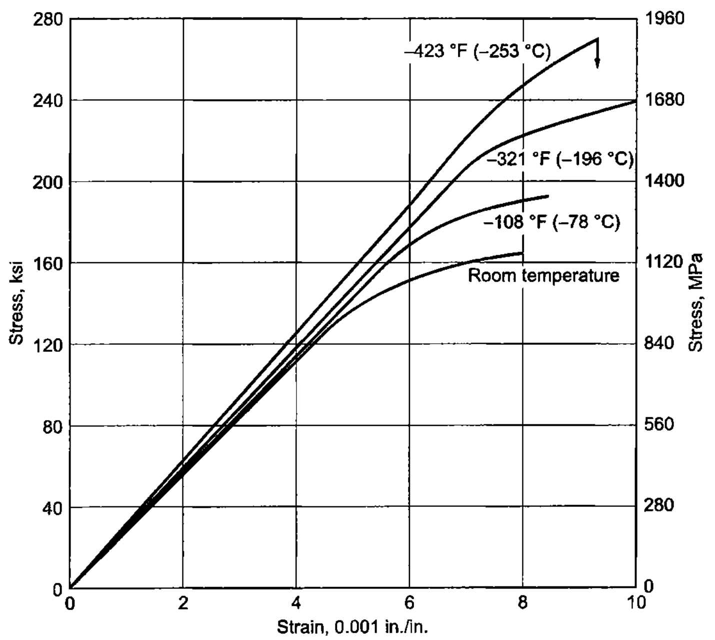
Source: *MIL-HDBK-5H,* Dec 1998, p 2-122



SS.168 AM-350 SCT850 stainless steel sheet, typical compressive stress-strain and compressive tangent modulus curves at room and elevated temperatures

0.5 h exposure. SCT, subcooled and tempered. Ramberg-Osgood parameters: n(room temperature) = 9.3, n(400 °F) = 6.2, n(600 °F) = 6.8, n(800 °F) = 6.2. Composition: Fe-17Cr-4Ni-3Mo. UNS S35000

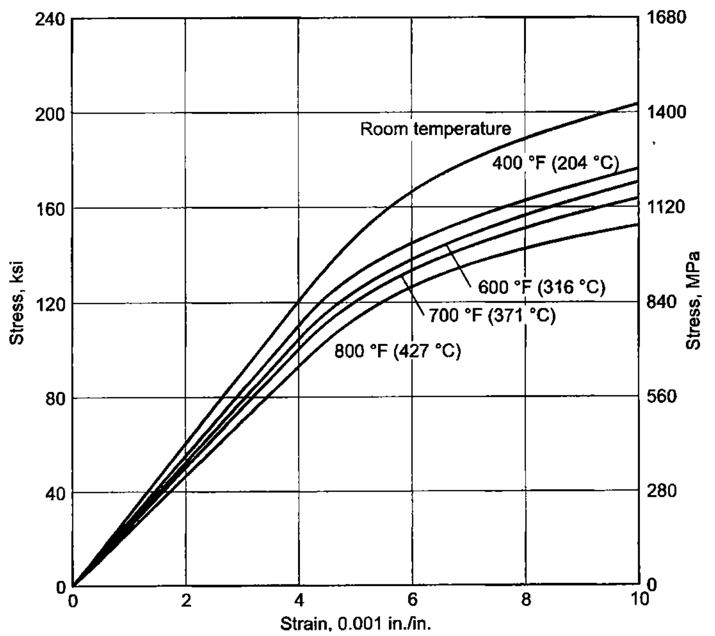
Source: *MIL-HDBK-5H,* Dec 1998, p 2-122



SS.169 AM-350 SCT850 stainless steel sheet, tensile stress-strain curves at room and low temperatures

Sheet thickness = 1.626 mm (0.064 in.). SCT850: annealed to condition L, subcooled −73 °C (−100 °F), 3 h, tempered 441–468 °C (825–875 °F), 3 h. Composition: Fe-17Cr-4Ni-3Mo. UNS S35000

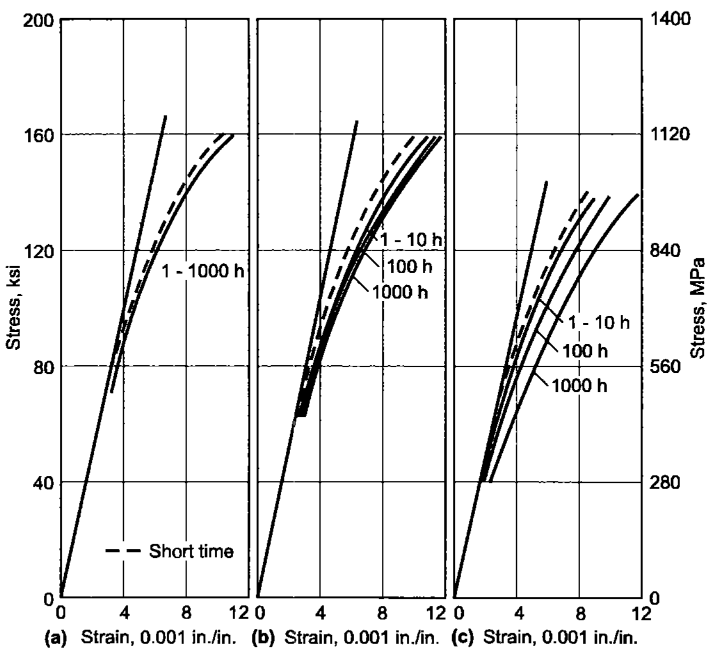
Source: R.L. McGee, J.E. Campbell, R.L. Carlson, and G.K. Manning, "The Mechanical Properties of Certain Structural Metals at Very Low Temperature," WADC-TR 58-386, June 1958. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1504, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



SS.170 AM-350 SCT850 stainless steel sheet, compressive stress-strain curves at room and elevated temperatures

Sheet thickness = 1.067 mm (0.042 in.). Treatment SCT850: annealed to condition L, subcooled −73 °C (−100 °F), 3 h, tempered 441–468 °C (825–875 °F), 3 h. Composition: Fe-17Cr-4Ni-3Mo. UNS S35000

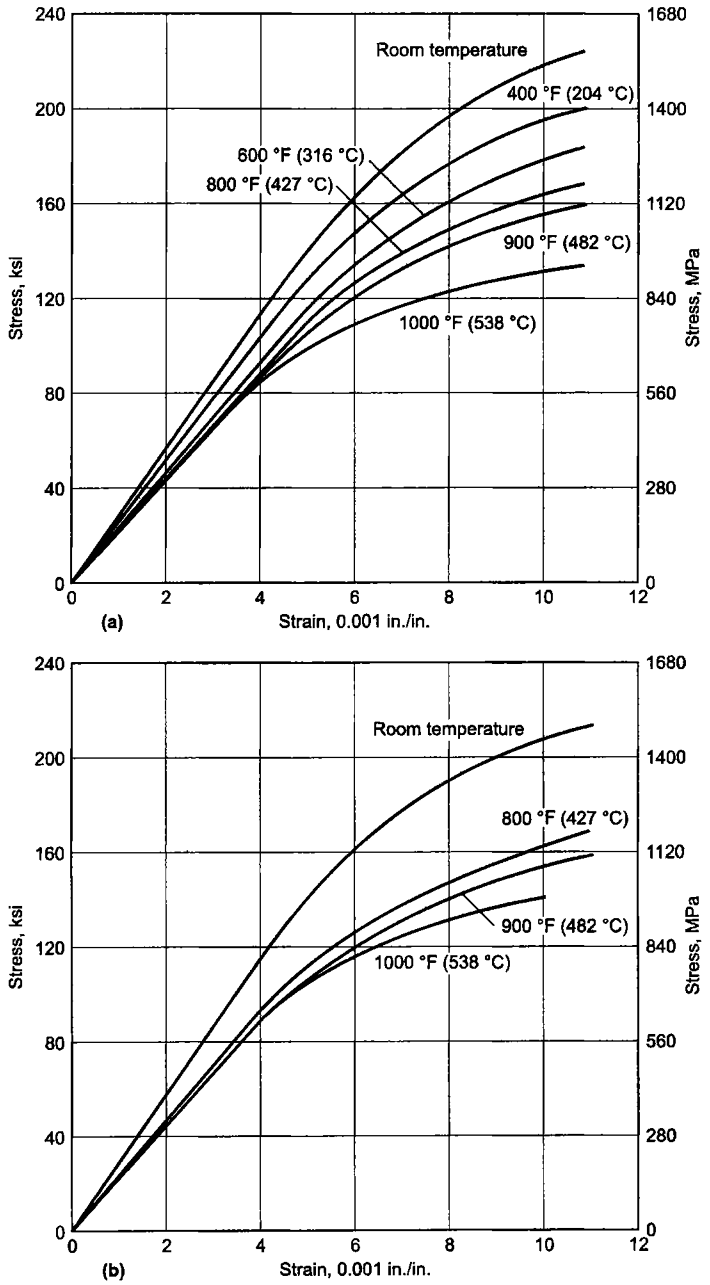
Source: "Room and Elevated Temperature Tensile and Compressive Properties of Type AM-350," Data sheet 86-11457-350, Allegheny Ludlum Steel Corp., 1958. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1504, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 14



SS.171 AM-350 SCT850 stainless steel sheet, isochronous stress-strain curves at various temperatures

Sheet thickness = 1.016–1.651 mm (0.040–0.065 in.). SCT850: annealed to condition L, subcooled –73 °C (–100 °F), 3 h, tempered 441–468 °C (825–875 °F), 3 h. (a) 316 °C (600 °F); (b) 371 °C (700 °F); (c) 427 °C (800 °F). Composition: Fe-17Cr-4Ni-3Mo. UNS S35000

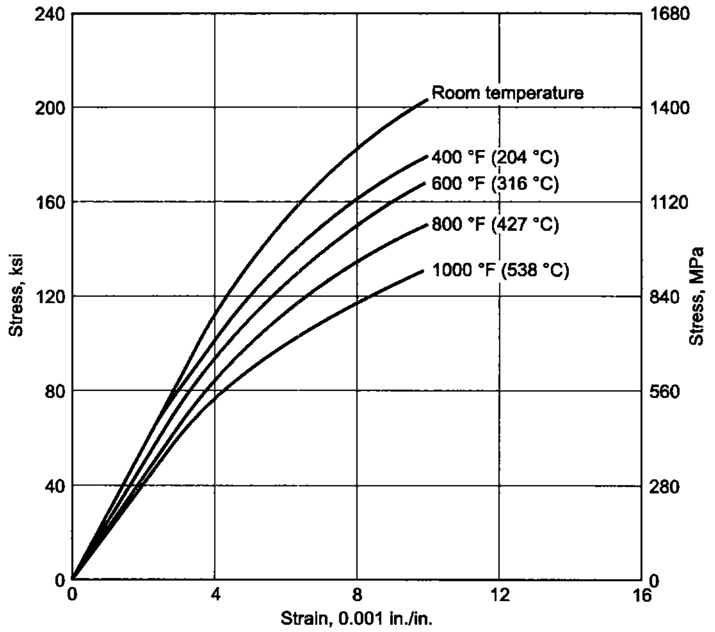
Source: "Creep Data AM-350 and AM-355 Alloys," Data Sheet 119-121658S...," Allegheny Ludlum Steel Corp. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1504, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 19



SS.172 AM-355 CRT stainless steel sheet, tensile stress-strain curves at room and elevated temperatures

Test direction: (a) longitudinal and (b) transverse. Sheet thickness = 1.422 mm (0.056 in.). CRT: cold rolled and tempered. hardness = 50–51 HRC. (a) longitudinal (b) transverse. Composition: Fe-15.5Cr-4.5Ni-3Mo. UNS S35500

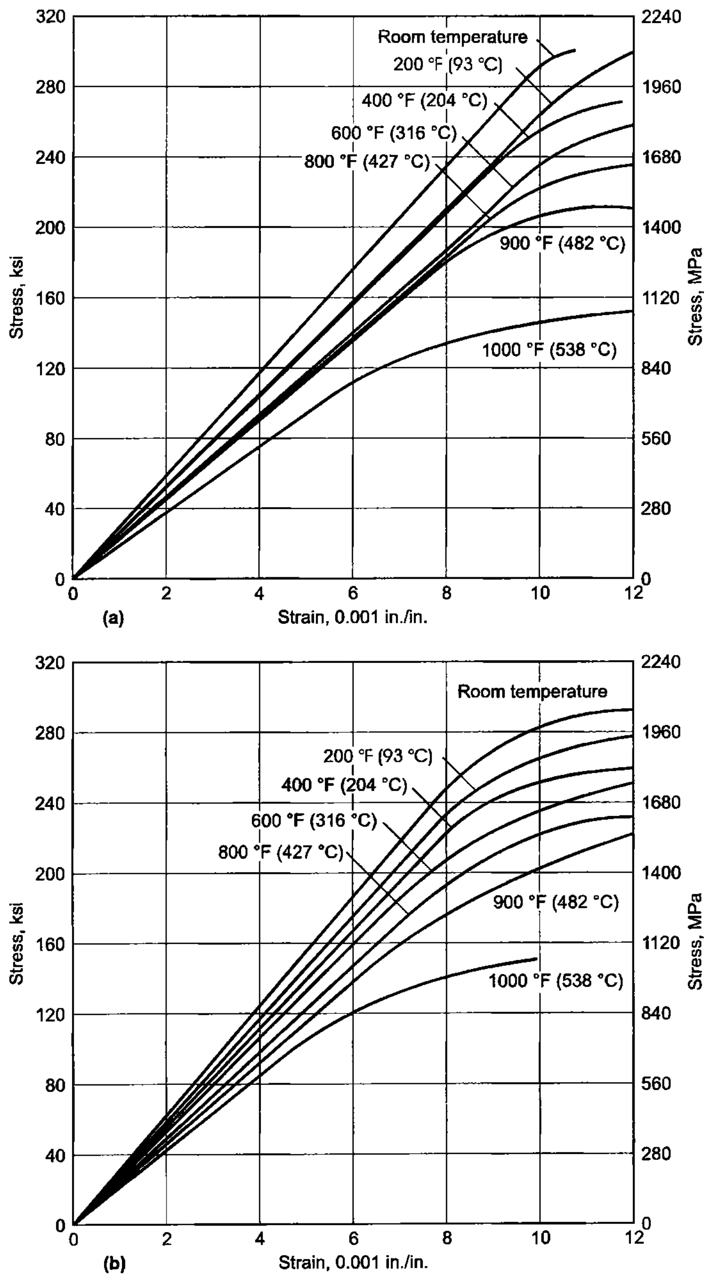
Source: Data sheet 121-12159-355, Allegheny Ludlum, 1959. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1505, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 11



SS.173 AM-355 CRT stainless steel sheet, compressive stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Sheet thickness = 1.422 mm (0.056 in.). CRT: cold rolled and tempered. Hardness = 50–51 HRC. Specimen size = 68.58 × 15.875 × 1.422 mm (2.7 × 0.625 × 0.056 in.); gage length = 38.1 mm (1.5 in.). Composition: Fe-15.5Cr-4.5Ni-3Mo. UNS S35500

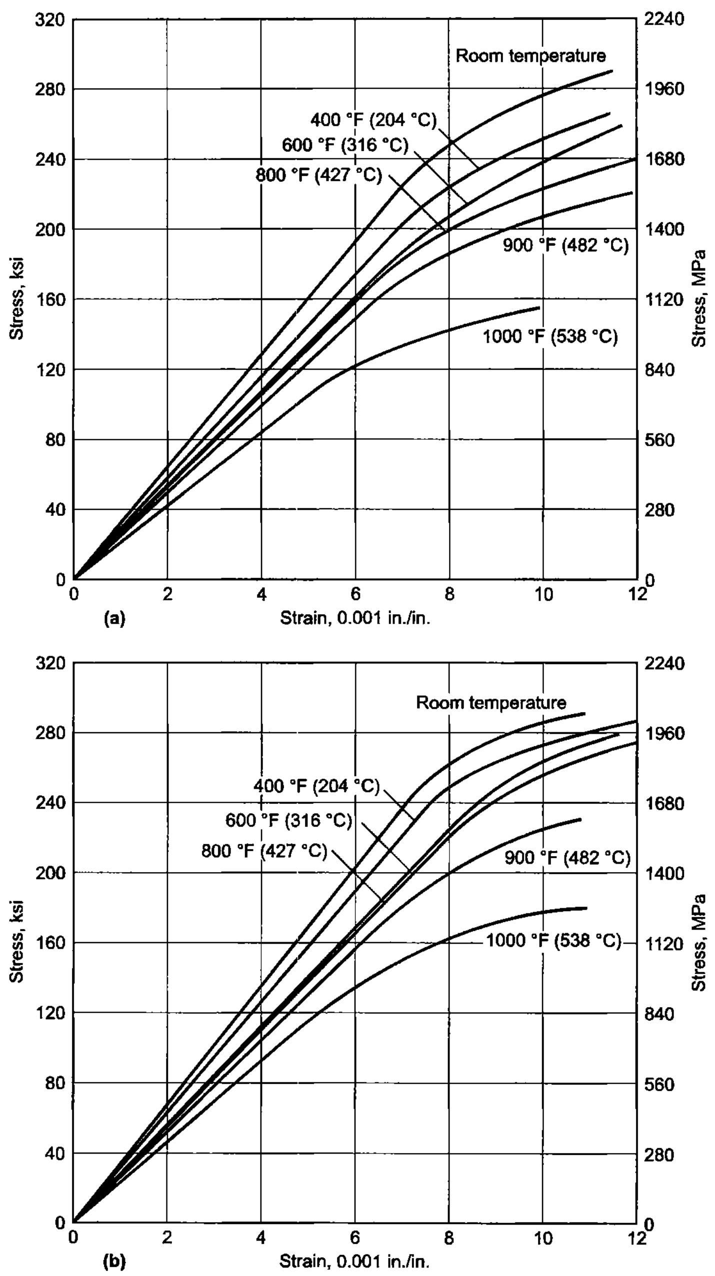
Source: Data sheet 121-12159-355, Allegheny Ludlum, 1959. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1505, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 14



SS.174 AM-355 SCCRT stainless steel sheet, tensile stress-strain curves at room and elevated temperatures

Test direction: (a) longitudinal and (b) transverse. Sheet thickness = 0.457 mm (0.018 in.). SCCRT: subcooled, cold rolled, tempered. RT, room temperature. Composition: Fe-15.5Cr-4.5Ni-3Mo. UNS S35500

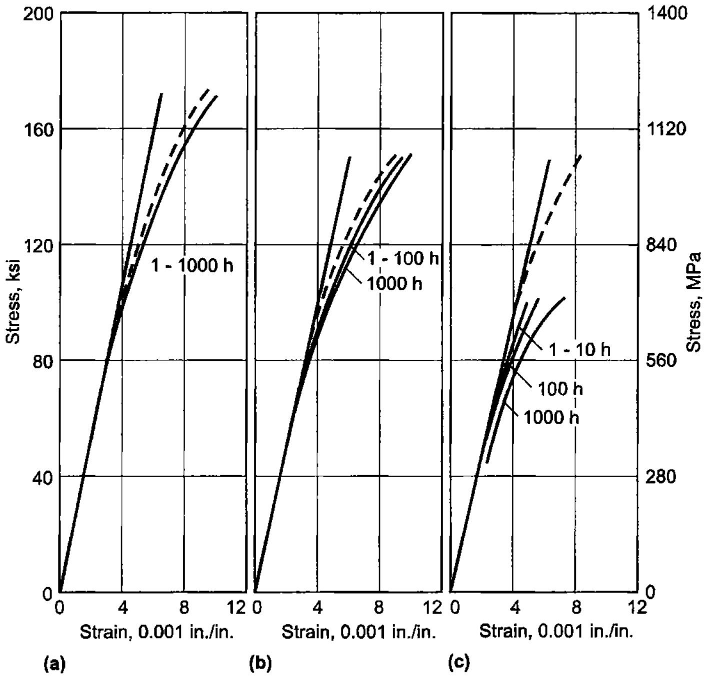
Source: "Room and Elevated Temperature Tensile and Compressive Properties of SCCRT AM-355," Data sheet 114-82158-355, Allegheny Ludlum Steel Corp., 1958. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1505, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



SS.175 AM-355 SCCRT stainless steel sheet, compressive stress-strain curves at room and elevated temperatures

Test direction: (a) longitudinal and (b) transverse. Sheet thickness = 0.457 mm (0.018 in.). SCCRT: subcooled, cold rolled, tempered. RT, room temperature. Composition: Fe-15.5Cr-4.5Ni-3Mo. UNS S35500

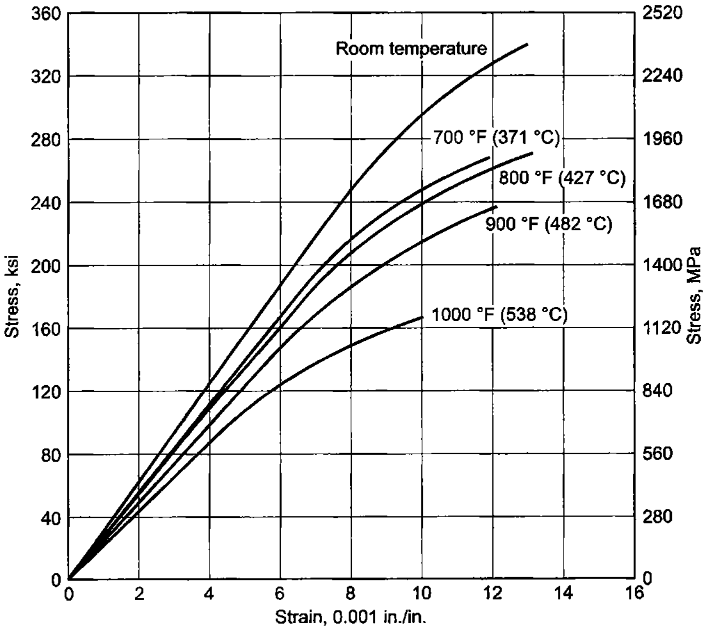
Source: "Room and Elevated Temperature Tensile and Compressive Properties of SCCRT AM-355," Data sheet 114-82158-355, Allegheny Ludlum Steel Corp., 1958. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1505, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 14



SS.176 AM-355 SCT stainless steel sheet, isochronous tensile stress-strain curves at various temperatures

SCT: subcooled and tempered. (a) 316 °C (600 °F). (b) 371 °C (700 °F). (c) 427 °C (800 °F). Composition: Fe-15.5Cr-4.5Ni-3Mo. UNS S35500

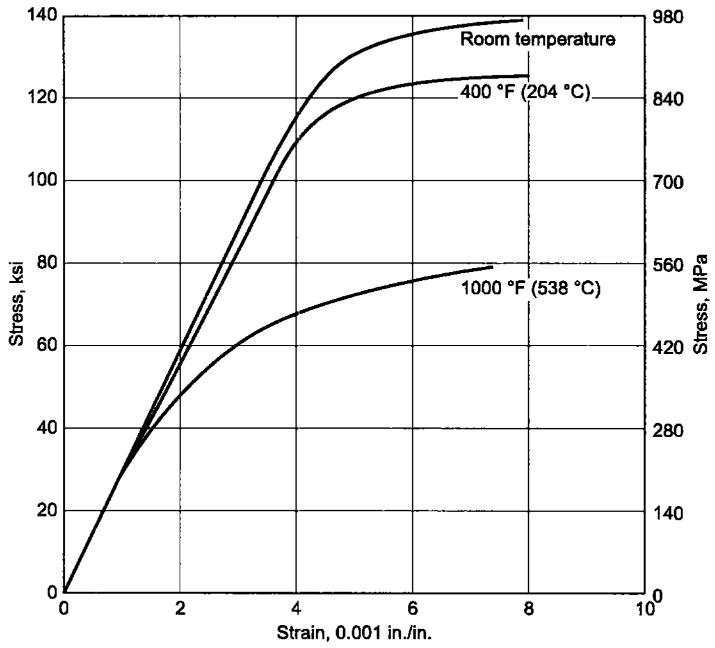
Source: "Creep Data AM-350 and AM-355 Alloys," Data sheet 119-121658-5, Allegheny Ludlum Steel Corp., 1959. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1505, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 18



SS.177 AM-355 XH stainless steel sheet, tensile stress-strain curves at room and elevated temperatures

Test direction: transverse. Sheet thickness = 0.203 mm (0.008 in.). Heat treatment: mill solution treated and water quenched, tempered 399 °C (750 °F), 5 min. Hardness = 54 HRC. Composition: Fe-15.5Cr-4.5Ni-3Mo. UNS S35500

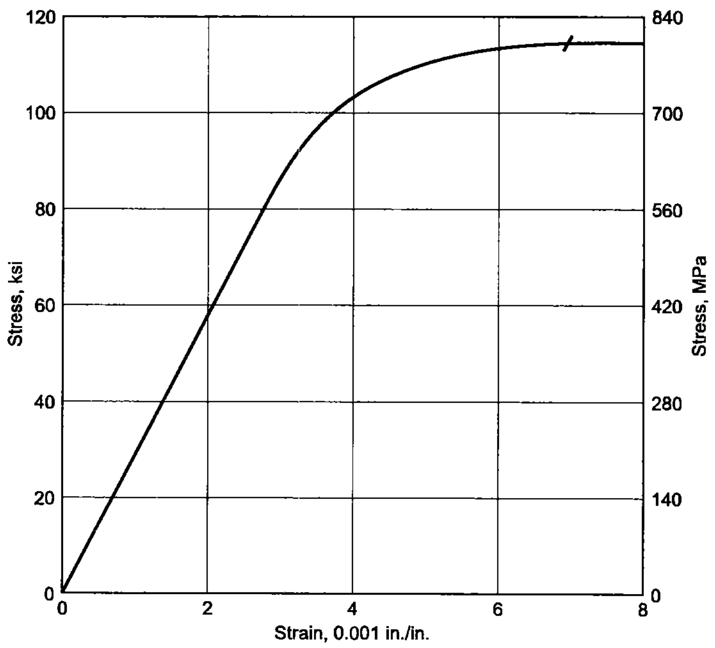
Source: Data sheet 130-10859-355, Allegheny Ludlum, 1959. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1505, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



SS.178 AM-362 stainless steel bar, tensile stress-strain curves at room and elevated temperatures

Bar diameter = 25.4 mm (1 in.). Heat treatment: 816 °C (1500 °F), 1 h, air cooled, 566 °C (1050 °F), 2 h. Composition: Fe-15Cr-7Ni-0.88Ti. UNS S36200

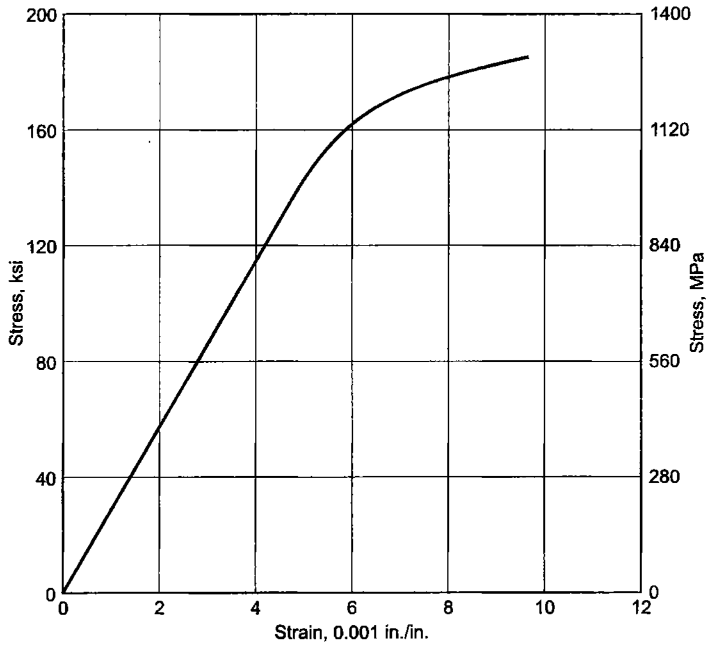
Source: "Properties of AM 362 Maraging Stainless Steel," Sheet-197-11763-362, Allegheny-Ludlum Steel Co., Research Data Center, Nov 1963. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1512, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 13



SS.179 AM-363 stainless steel strip, tensile stress-strain curve at room temperature

Composition: Fe(0.04C)-11.5Cr-4Ni-0.3Ti

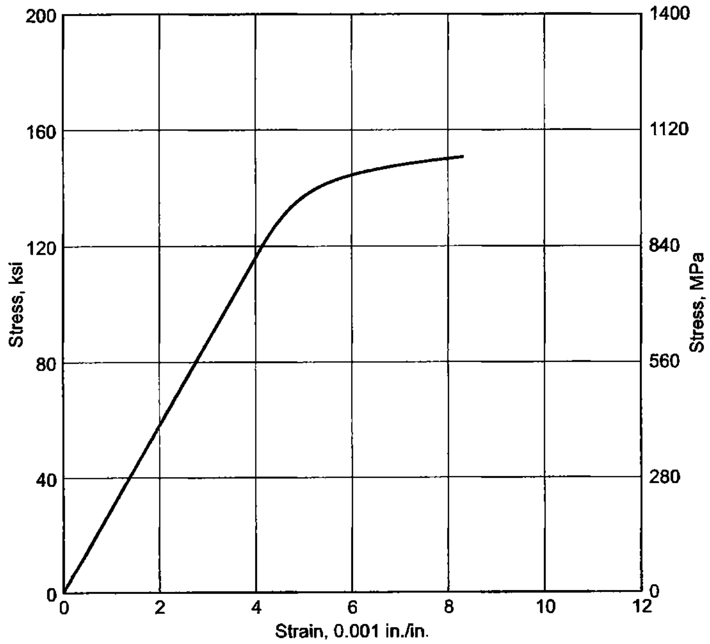
Source: "AM-363 Strip for Structural Applications," Preliminary Data Sheet, Allegheny Ludlum Steel Corp., 11 Feb 1963. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1409, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 2



SS.180 Custom 450 H900 stainless steel bar, typical tensile stress-strain curve at room temperature

Test direction: longitudinal and long transverse. Bar thickness = 25.4–304.8 mm (1.000–12.000 in.). Ramberg-Osgood parameter: n = 16. Composition: Fe-15Cr-6Ni-1.5Cu-1.1Ti-(Nb > 8C). UNS S45000

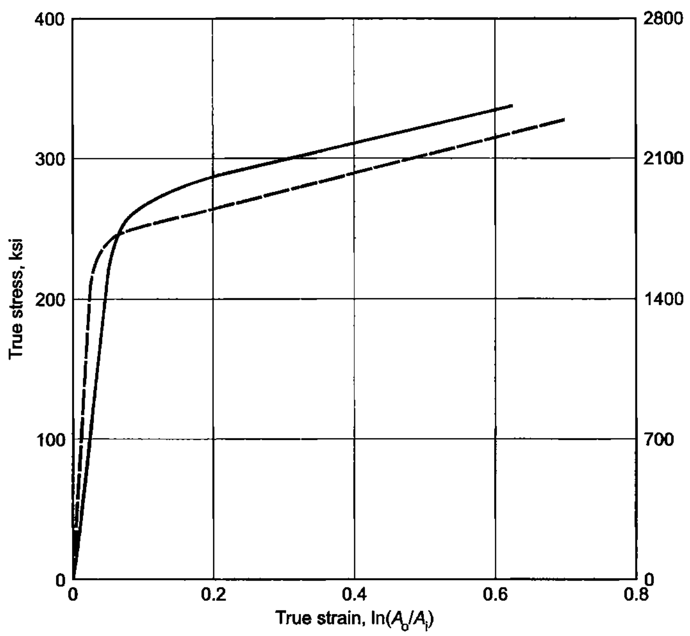
Source: *MIL-HDBK-5H*, Dec 1998, p 2-135



SS.181 Custom 450 H1050 stainless steel bar, typical tensile stress-strain curve at room temperature

Test direction: longitudinal and long transverse. Bar thickness = 25.4–304.8 mm (1.000–12.000 in.). Ramberg-Osgood parameter: n = 26. Composition: Fe-15Cr-6Ni-1.5Cu-1.1Ti-(Nb > 8C). UNS S45000

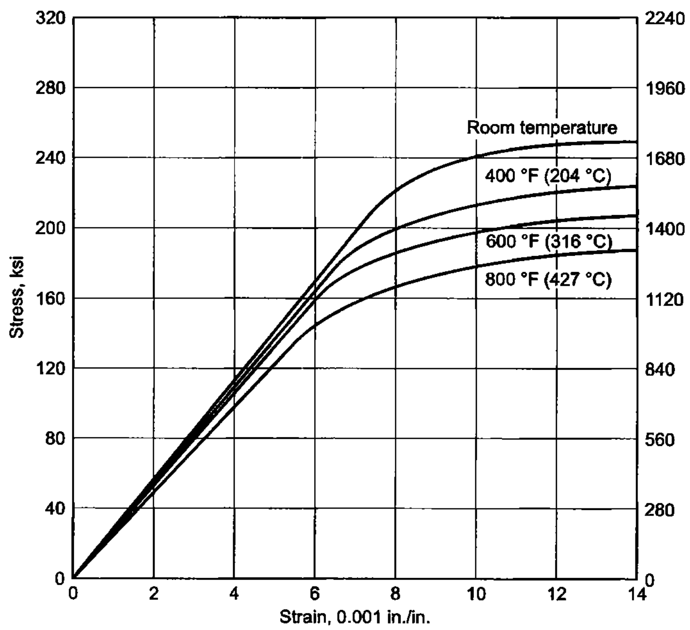
Source: *MIL-HDBK-5H*, Dec 1998, p 2-139



SS.182 Custom 455 annealed stainless steel bar, true stress-strain curves

Heat treatment: annealed 816 °C (1500 °F), 1 h, water quenched; (solid curve): + aged 482 °C (900 °F), 4 h, air cooled; (dashed curve): + aged 510 °C (950 °F), 4 h, air cooled. Composition: Fe-(low C)-12Cr-8Ni-2Cu-1.1Ti-(Nb + Ta). UNS S45500

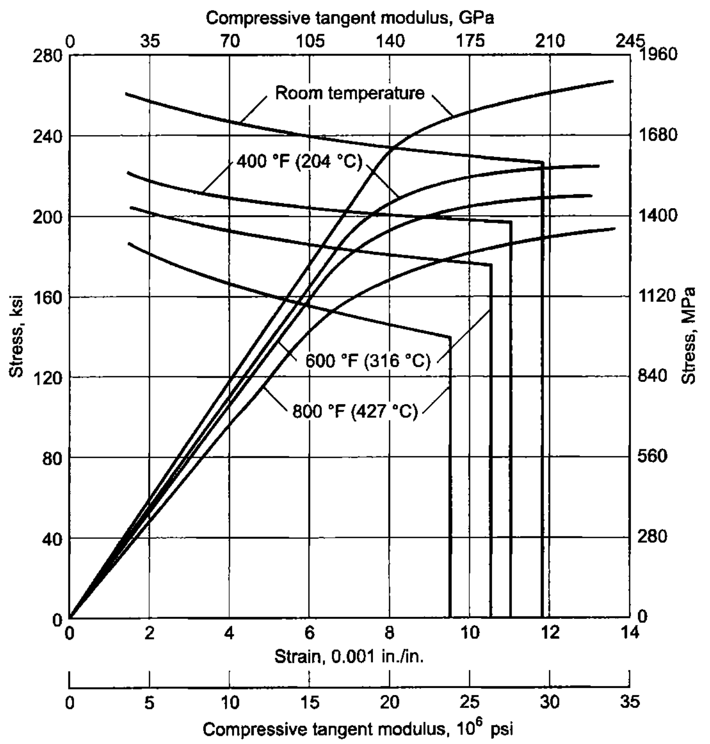
Source: Private communication with N.B. Schmidt, Carpenter Technology Corp., Reading, PA, 8 Jan 1974, and unpublished data sheets. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1514, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 6



SS.183 Custom 455 annealed stainless steel bar, typical stress-strain curves at room and elevated temperature

Test direction: longitudinal. Bar diameter = 19.05 mm (0.75 in.). Heat treatment: annealed plus aged 510 °C (950 °F), 4 h, air cooled. Composition: Fe-(low C)-12Cr-8Ni-2Cu-1.1Ti-(Nb + Ta). UNS S45500

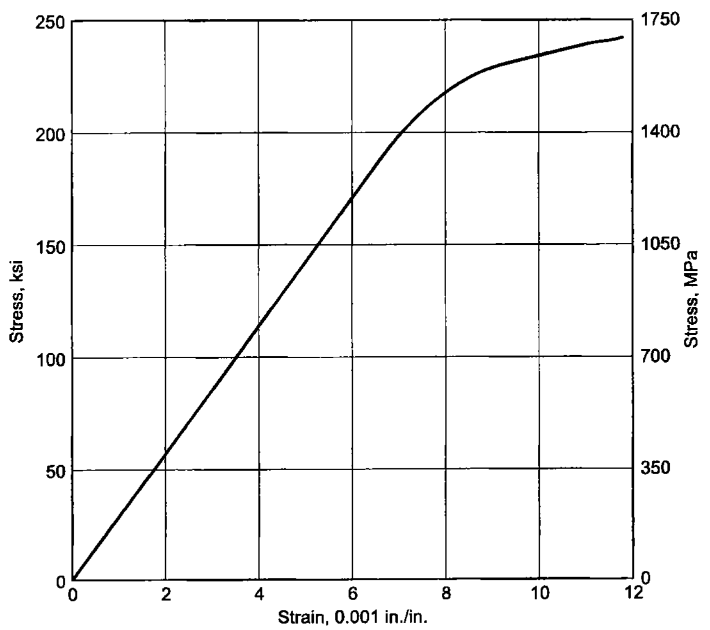
Source: O.L. Deel and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," Technical Report AFML-TR-71-249, Battelle Columbus Laboratories, Dec 1971. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1514, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 10



SS.184 Custom 455 annealed stainless steel bar, typical compressive stress-strain and compressive tangent modulus curves at room and elevated temperatures

Test direction: longitudinal. Bar diameter = 19.05 mm (0.75 in.). Heat treatment: annealed plus aged 510 °C (950 °F), 4 h, air cooled. RT, room temperature. Composition: Fe-(low C)-12Cr-8Ni-2Cu-1.1Ti-(Nb + Ta). UNS S45500

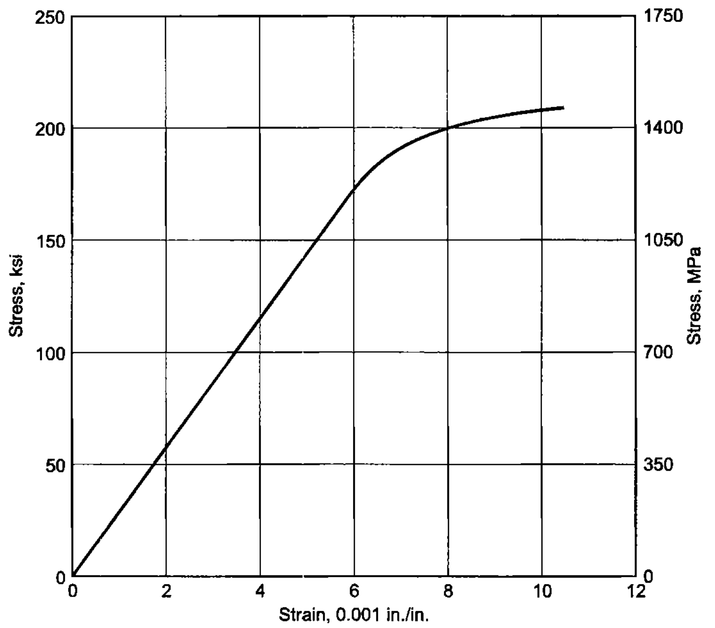
Source: O.L. Deel and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," Technical Report AFML-TR-71-249, Battelle Columbus Laboratories, Dec 1971. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1514, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 14



SS.185 Custom 455 H950 stainless steel bar, typical tensile stress-strain curve at room temperature

Test direction: longitudinal and long transverse. Bar thickness = 25.4–152.4 mm (1.000–6.000 in.). Ramberg-Osgood parameter: $n = 22$. Composition: Fe-(low C)-12Cr-8Ni-2Cu-1.1Ti-(Nb + Ta). UNS S45500

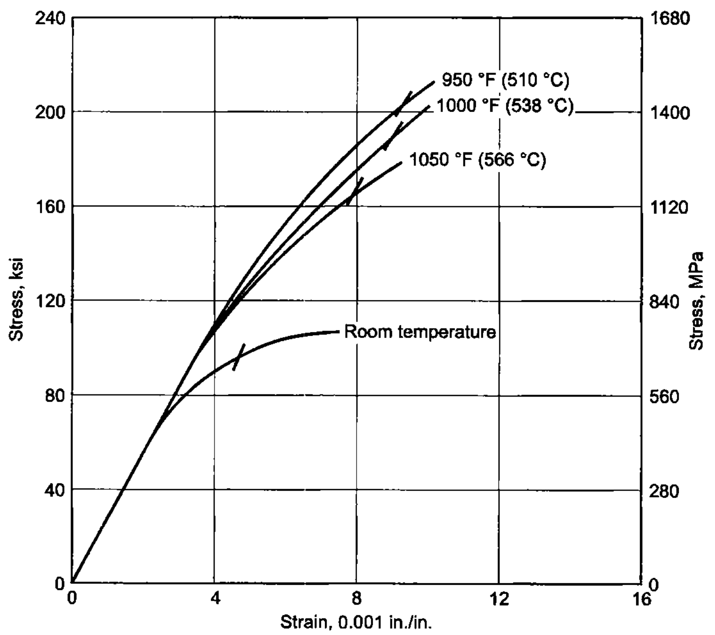
Source: *MIL-HDBK-5H,* Dec 1998, p 2-146



SS.186 Custom 455 H1000 stainless steel bar, typical stress-strain curve at room temperature

Test direction: longitudinal and long transverse. Bar thickness = 25.4–152.4 mm (1.000–6.000 in.). Ramberg-Osgood parameter: $n = 25$. Composition: Fe-(low C)-12Cr-8Ni-2Cu-1.1Ti-(Nb + Ta). UNS S45500

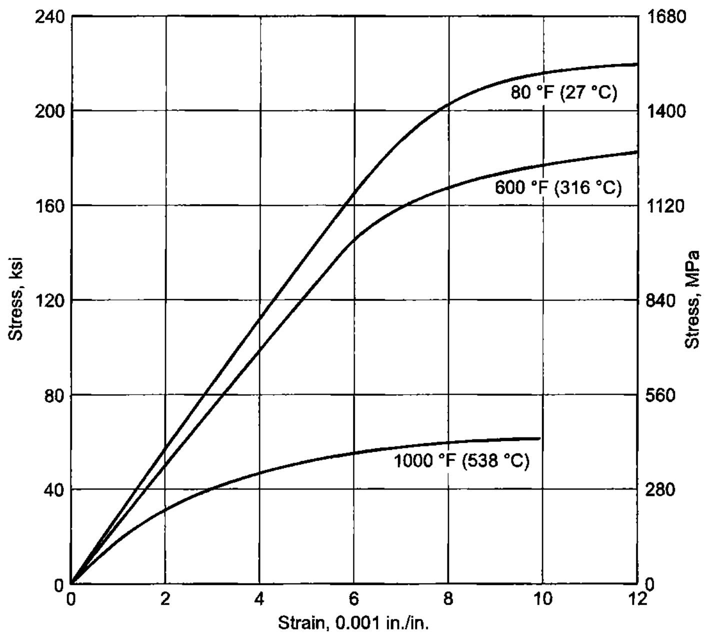
Source: *MIL-HDBK-5H*, Dec 1998, p 2-150



SS.187 Fe-17Cr-7Ni-Ti stainless steel sheet, typical tensile stress-strain curves at room temperature for different aging temperatures

Sheet thickness = 1.651 mm (0.065 in.). Composition: Fe-17Cr-7Ni-Ti. UNS S17600

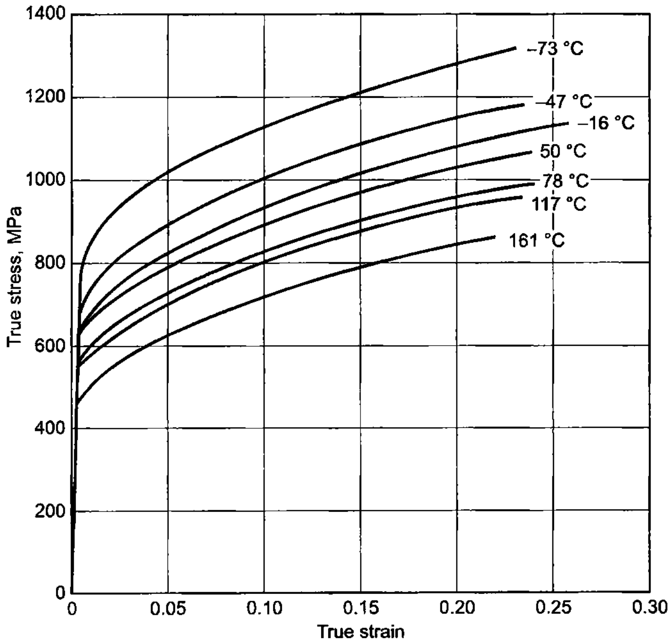
Source: *Contributions to the Metallurgy of Steel: High Temperature High Strength Alloys*, AISI, Feb 1963, p 88. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1511, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 4



SS.188 Fe-17Cr-7Ni-Ti stainless steel sheet, typical tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal and transverse. Sheet thickness = 1.626 mm (0.064 in.). Heat treatment: Solution annealed plus aged 538 °C (1000 °F), 0.5 h. Composition: Fe-17Cr-7Ni-Ti. UNS S17600

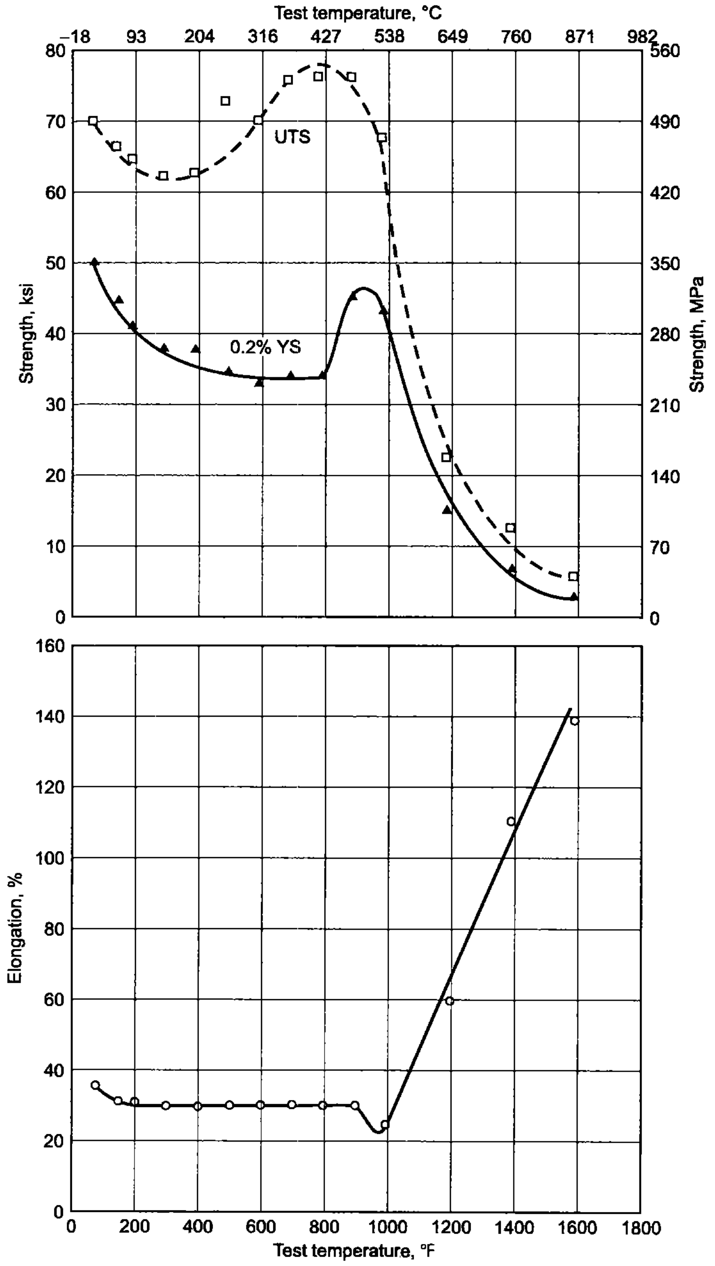
Source: P.J. Hughes, J.E. Inge, and S.B. Prosser, "Tensile and Compressive Stress-Strain Curves Properties of Some High-Strength Sheet Alloys at Elevated Temperatures," NACA TN 3315, Nov 1954, p 19. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1511, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 5



SS.189 AL 2205 stainless steel, true stress-strain curves at various temperatures

Strain rate = 0.0167/s. Composition: Fe-22Cr-5.5Ni-3Mo-N. UNS S31803

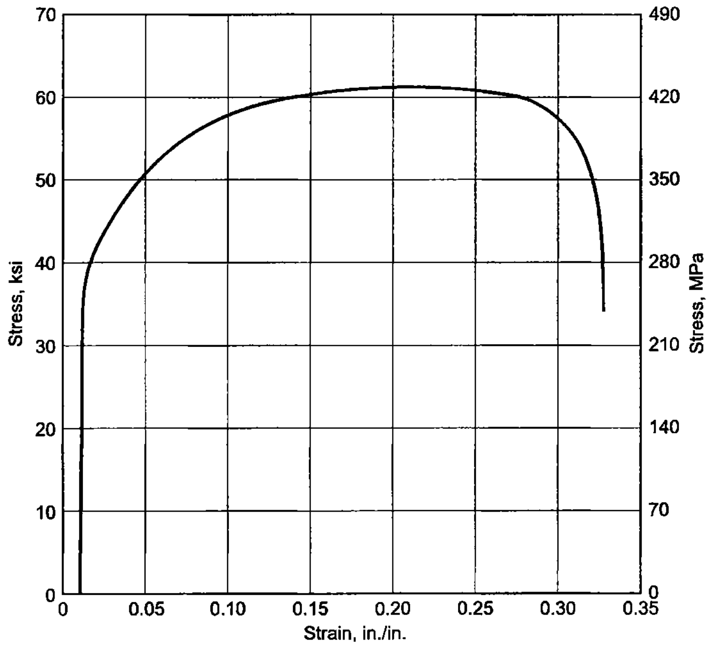
Source: C.L. Beech, "Effect of Temperature and Strain Rate on the Mechanical Properties and Deformation Behavior of a Duplex Stainless Steel," M.S. thesis, Colorado School of Mines, Golden, CO, 1989. As published in G. Krauss, *Steels: Heat Treatment Processing and Principles,* 1990, p 394



SS.190 XM-27 stainless steel, typical tensile properties at elevated temperatures

Short-time tests on high-chromium ferritic samples show pronounced decrease in strength with increasing temperature above 538 °C (1000 °F). Increase in strength at 427–538 °C (800–1000 °F) is due to precipitation hardening, which goes with the 475 °C (885 °F) embrittlement phenomenon typical of high-chromium ferritic stainless steels. UTS, ultimate tensile strength; YS, yield strength. UNS S44627

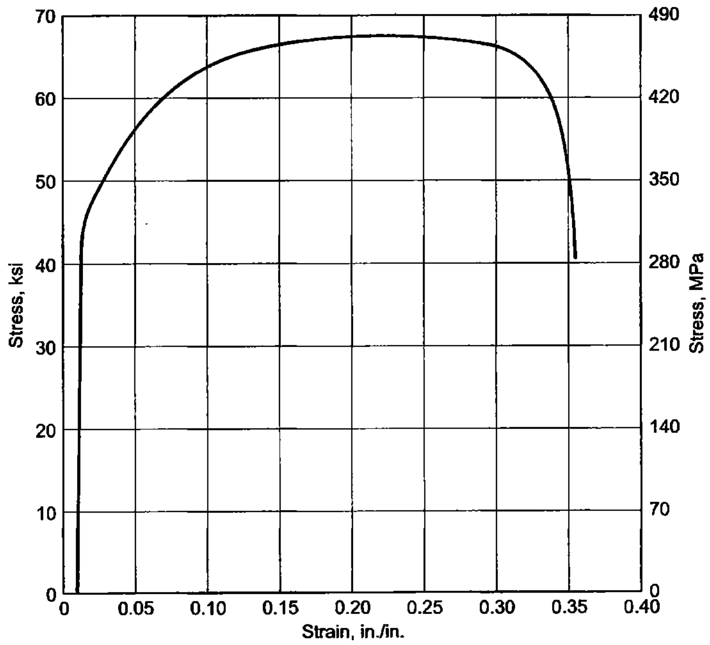
Source: F.K. Kies and C.D. Swartz, High Temperature Properties of High Purity Ferritic Stainless Steel, *J. Test. Eval.*, Vol 2 (No. 2), 1974, p 118–124. As published in E-Brite Alloy Product Data, Allegheny Ludlum Steel Corp., 1980, p 14



SS.191 409 stainless steel sheet, room temperature longitudinal stress-strain

Sheet thickness = 1.499 mm (0.059 in.). Tests were run per ASTM Standard E 8. Standard flat samples 2 × 12.7 mm (0.5 in.) wide. Data shown are typical and should not be construed as maximum or minimum values for specification or for final design. Data on any particular piece of material may vary from those shown.. UNS S40900

Source: Courtesy Allegheny Ludlum in private communication, March 2002

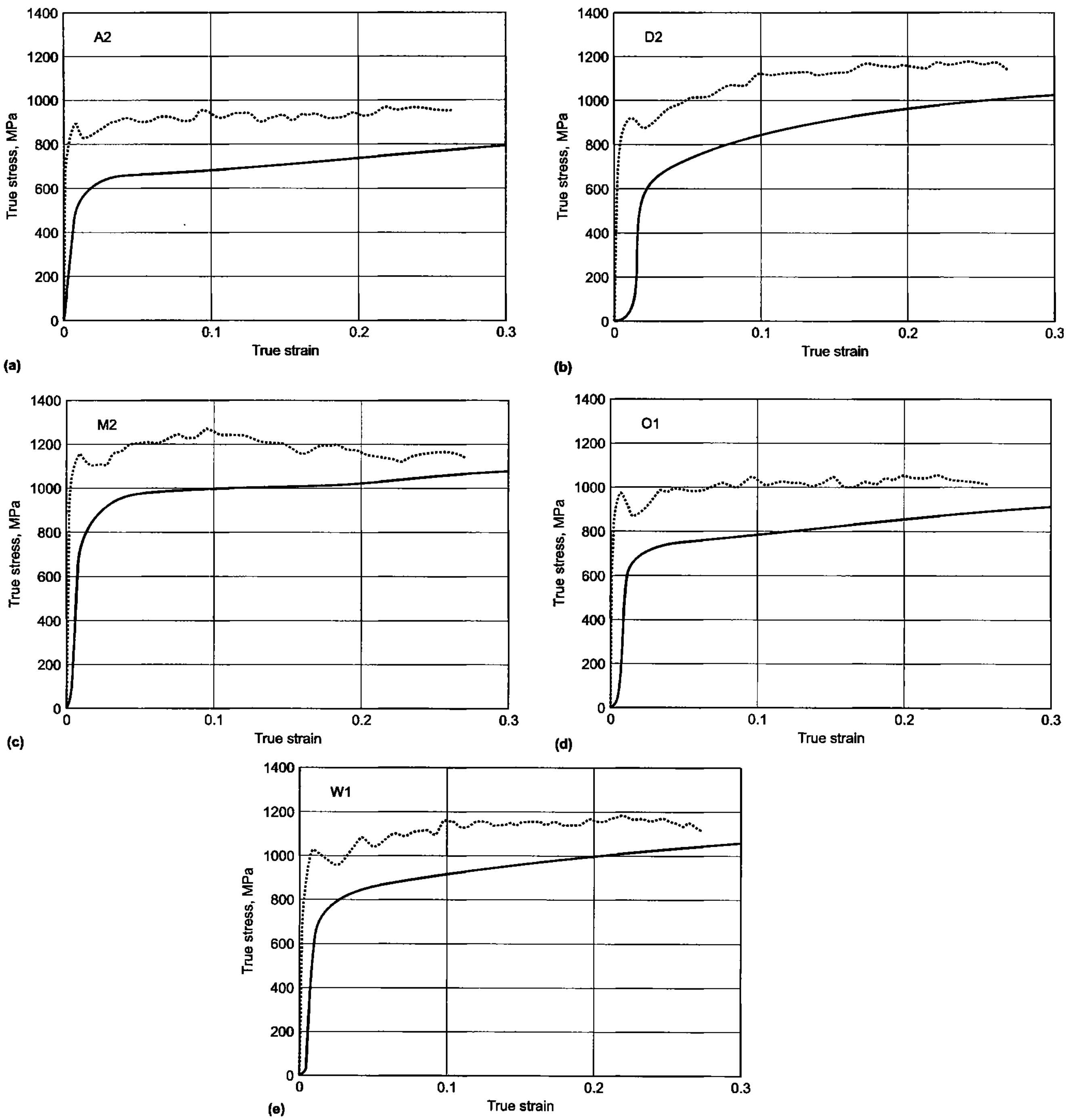


SS.192 439 stainless steel sheet, room temperature longitudinal stress-strain

Sheet thickness = 1.549 mm (0.061 in.). Tests were run per ASTM Standard E-8. Standard flat samples 2 × 12.7 mm (0.5 in.) wide. Data shown are typical and should not be construed as maximum or minimum values for specification or for final design. Data on any particular piece of material may vary from those shown. UNS S43035

Source: Courtesy Allegheny Ludlum in private communication, March 2002

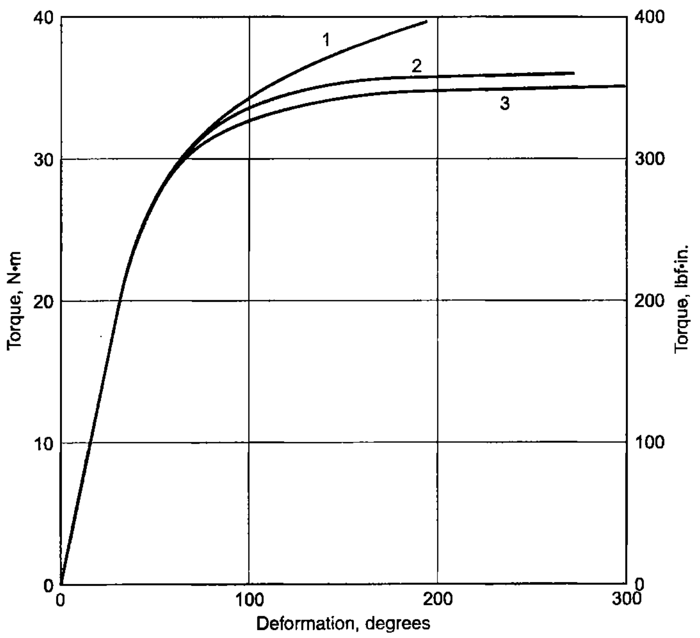
Tool Steel (TS)



TS.001 Tool steel, uniaxial compressive true stress-strain curves

Solid curves, quasi-static strain rate ≈0.001/s; dashed curves, dynamic strain rate = 2000/s. Quasi-static tests used a servohydraulic machine. High-rate tests used a compression split Hopkins pressure bar. Specimens were 4–6 mm diam, 8–12 mm long. Compositions: A2 (UNS T30102), Fe-1C-5.1Cr-1.15Mo-0.3V; D2 (UNS T30402), Fe-1.5C-12Cr-0.95Mo; M2 (UNS T11302), Fe-1.0C-0.27Mn-0.3Si-4.1Cr-5Mo-6.12W-1.98V; O1 (UNS T31501), Fe-0.92C-1.2Mn-0.5Cr-0.5W; W1 (UNS T72301), Fe-1.1C-0.25Mn-0.25Si.

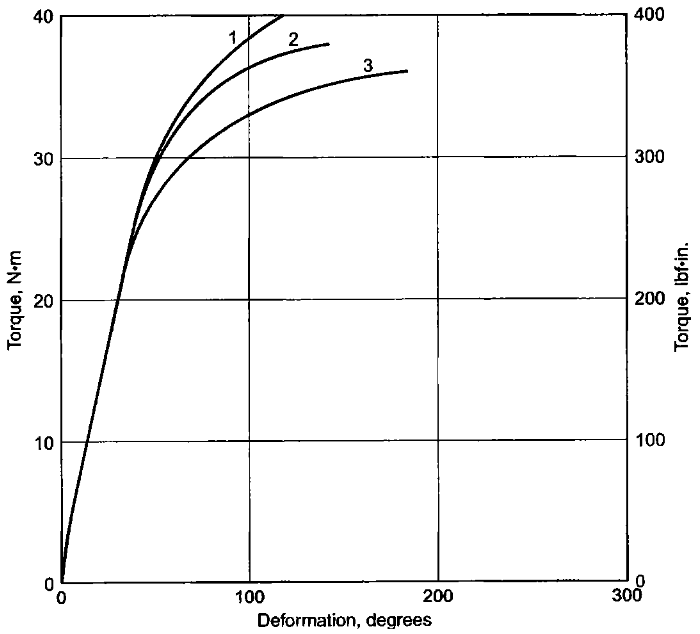
Source: G. Subhash, Dynamic Indentation Testing, *Mechanical Testing and Evaluation,* Vol 8, *ASM Handbook,* 2000, p 525



TS.002 D2 high-carbon high-chromium cold-work tool steel, torsional stress-strain curves with effect of tempering temperature

Specimens air cooled 1010 °C and then tempered: curve 1, 175 °C, 60.6 HRC; curve 2, 290 °C, 58.2 HRC; curve 3, 400 °C, 57.3 HRC. Typical composition: Fe-2.1C-12.5Cr-0.3Ni. UNS T30402

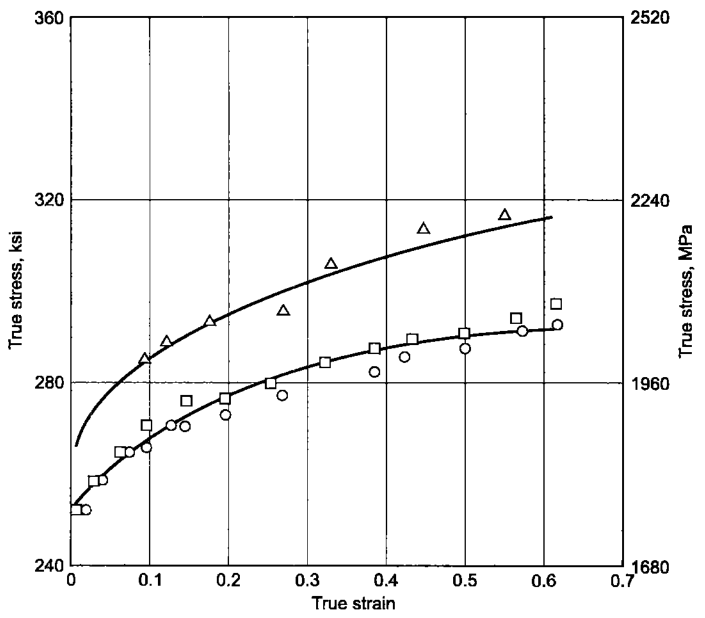
Source: Teledyne VASCO data. As published in G.A. Roberts, G. Krauss, and R.L. Kennedy, *Tool Steels*, 5th ed., ASM International, 1998, p 213



TS.003 D3 high-carbon high-chromium cold-work tool steel, torsional stress-strain curves with effect of tempering temperature

Specimens quenched in oil at 970 °C to maximum hardness and then tempered: curve 1, 175 °C, 64.5 HRC; curve 2, 290 °C, 60.5 HRC; curve 3, 400 °C, 59 HRC. Typical composition: Fe-1.6C-13Cr-0.75Mo-0.3V. UNS T30403

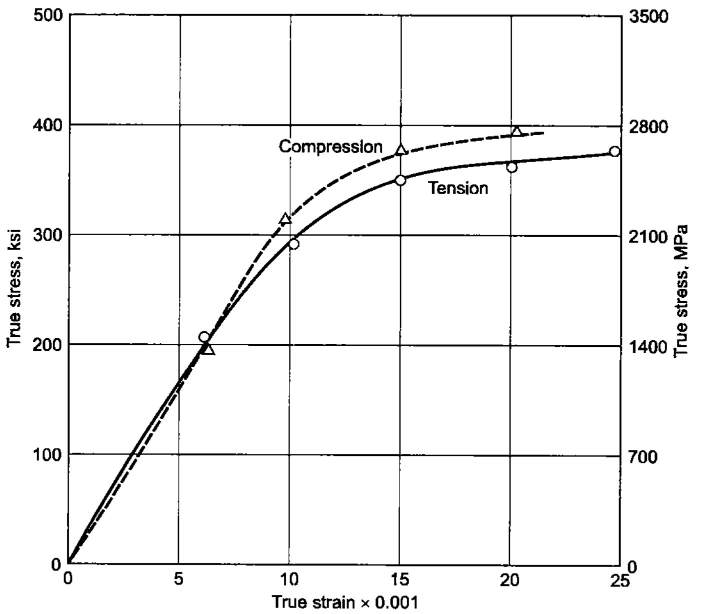
Source: Teledyne VASCO data. As published in G.A. Roberts, G. Krauss, and R.L. Kennedy, *Tool Steels*, 5th ed., ASM International, 1998, p 213



TS.004 H-11 Mod chromium hot-work tool steel bar, true tensile and compressive stress-strain curves

Bar diameter = 51 mm (0.2 in.) for tension, 8.458 mm (0.333 in.) for compression. Heat treatment: 1010 °C (1850 °F), 2 h, oil quenched, triple tempered, 566 °C (1050 °F), 1 h, air cooled. Data points: triangle, compression using special machine for alignment and Teflon lubricant; circle, tensile with intermittent die drawing to eliminate necking; square, tensile with data corrected for necking. Composition: Fe-0.4C-5Cr-1.3Mo-0.5V. UNS T20821

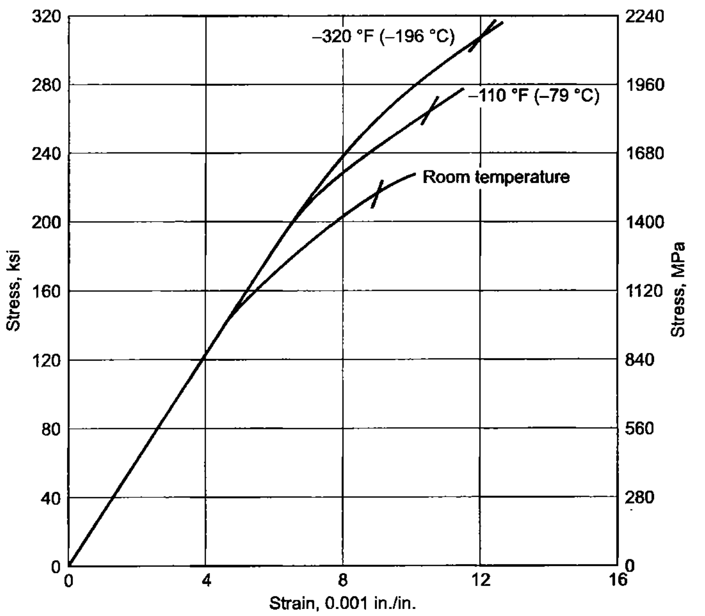
Source: R. Chait, Factors Influencing the Strength Differential in High Strength Steels, *Metall. Trans.*, Vol 3, Feb 1972, p 365–371. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1218, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 22



TS.005 H-11 Mod chromium hot-work tool steel bar, true tensile and compressive stress-strain curves

Bar diameter 51 mm (0.2 in.). Specimen machined from ausformed 15.748 mm (0.62 in.) diam bar. Consumable electrode vacuum melted bar hot worked at 1093 °C (2000 °F) from 63.5–38.1 mm (2.5–1.5 in.) diam, air cooled, double annealed 704 °C (1300 °F), 3 h, 649 °C (1200 °F), 2 h, 1038 °C (1900 °F), 1 h, air cooled to 566 °C (1050 °F), rolled to 83% plastic deformation at 566 °C (1050 °F), oil quenched, double tempered, 538 °C (1000 °F), 2 h to 60 HRC. Data points: triangle, compression; circle, tension. Ultimate strength = 2570 MPa (373 ksi); tensile yield strength = 2026 MPa (294 ksi); reduction in area = 33%. Composition: Fe-0.4C-5Cr-1.3Mo-0.5V. UNS T20821

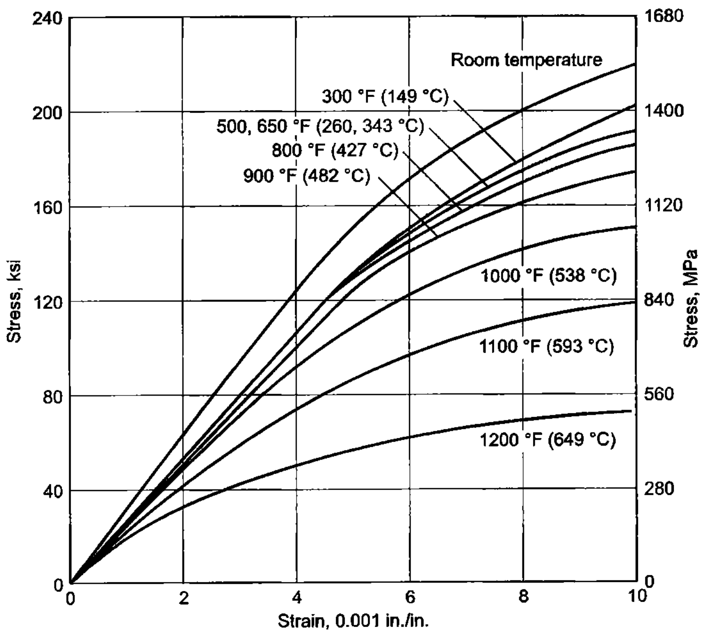
Source: J.E. Matheny, Jr., "Low Cycle Fatigue Properties of the Ausformed Steel," University of Illinois, T & A.M. Report No. 308, Feb 1968. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1218, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 22



TS.006 H-11 Mod chromium hot-work tool steel sheet, tensile stress-strain curves at room and low temperatures

Preheated 788 °C (1450 °F), 20–30 min, 1010 °C (1850 °F), 20 min, air cooled, triple tempered, 524 °C (975 °F), 1 h (each). After second temper, sheet ground to 1.524 mm (0.060 in.) to remove decarburization. Composition: Fe-0.4C-5Cr-1.3Mo-0.5V. UNS T20821

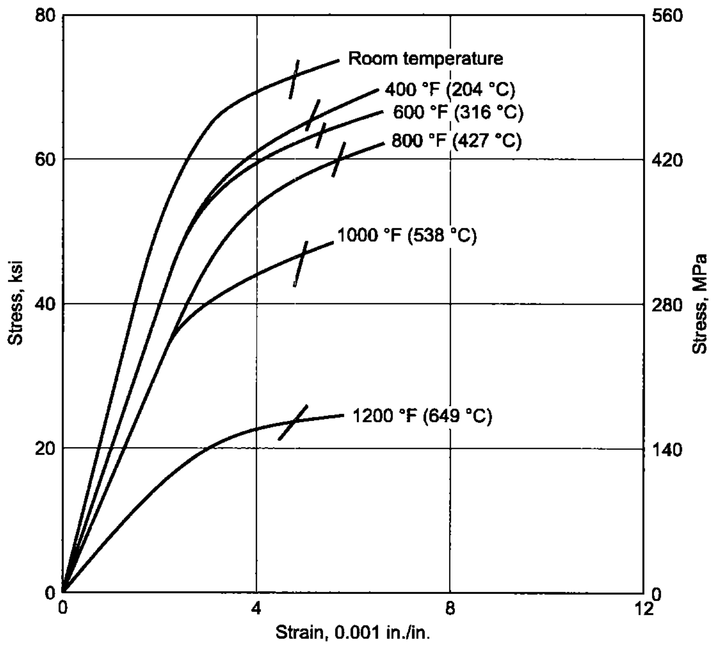
Source: L.P. Rice, J.E. Cambell, and W.F. Simmons, "Evaluation of the Effects of Very Low Temperature on Properties of Aircraft and Missile Metals," WADD TR 60-214, Feb 1960. As published in *Aerospace Structural Metals Handbook,* Vol 1, Code 1218, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 27



TS.007 H-11 Mod chromium hot-work tool steel, tensile stress-strain curves at room and elevated temperatures

Heat treated to 50 HRC; ultimate tensile strength = 1791 MPa (260 ksi). Composition: Fe-0.4C-5Cr-1.3Mo-0.5V. UNS T20821

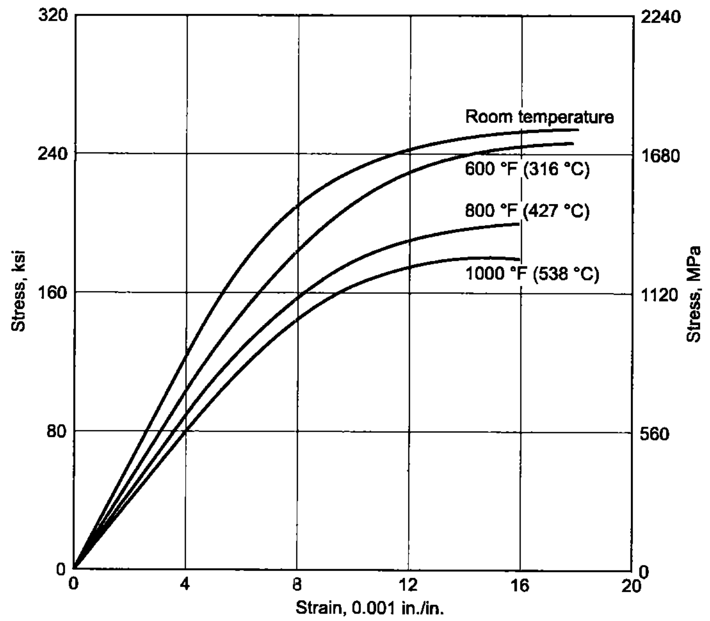
Source: "Vascojet 1000 for Ultra High Strength Structural Requirements," Vanadium Alloys Steel Co., 1959. As published in *Aerospace Structural Metals Handbook,* Vol 1, Code 1218, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 27



TS.008 H-11 Mod chromium hot-work (annealed) tool steel sheet, tensile stress-strain curves at room and elevated temperatures

Sheet thickness = 1.626 mm (0.064 in.). Composition: Fe-0.4C-5Cr-1.3Mo-0.5V. UNS T20821

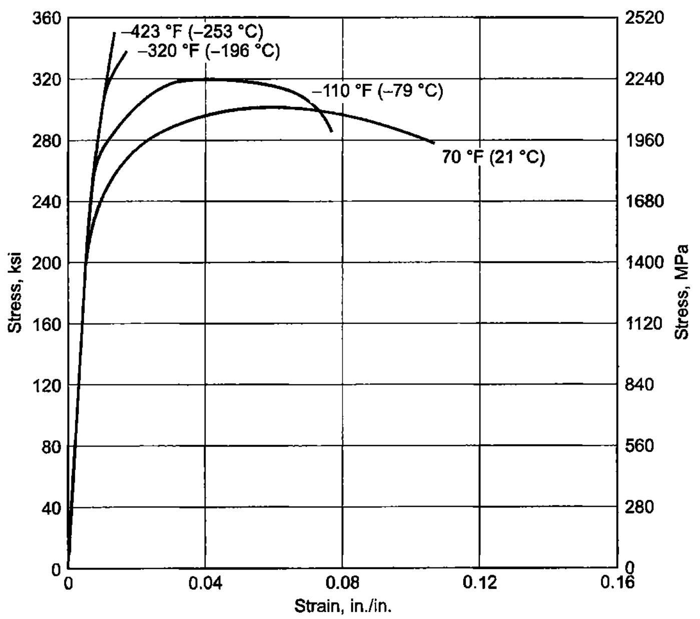
Source: R.G. Henning and A.W. Brisbane, "Mechanical Properties of AM 350, Potomac A, Potomac M, and Vasco Jet-1000 Steel Alloys in the Annealed Condition," ASD TDR-63-116, May 1963. As published in *Aerospace Structural Metals Handbook,* Vol 1, Code 1218, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 27



TS.009 H-11 Mod chromium hot-work tool steel sheet, tensile stress-strain curves at room and elevated temperatures

Sheet thickness = 2.286 mm (0.090 in.). Heat treated to ultimate tensile strength of 1929 MPa (280 ksi): 1010 °C (1850 °F), 30 min, air cooled, 538 °C (1000 °F), 2 × 3 h, 552 °C (1025 °F), 2 × 3 h. Composition: Fe-0.4C-5Cr-1.3Mo-0.5V. UNS T20821

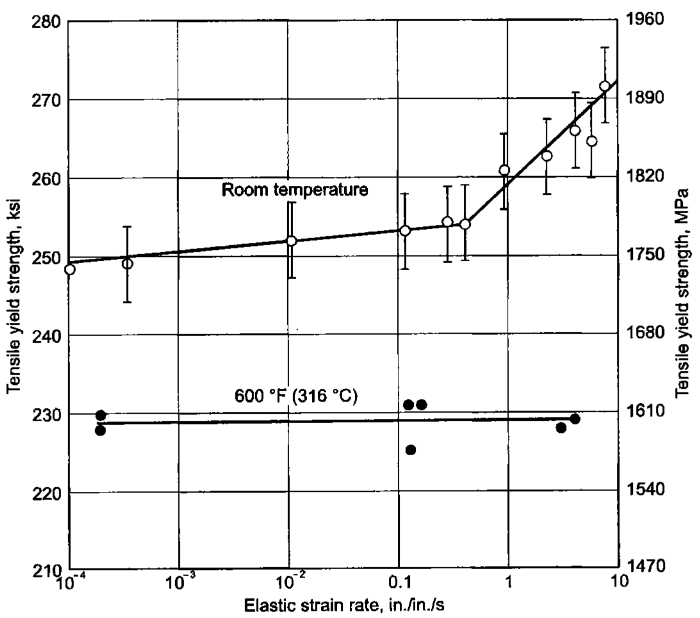
Source: "AISI H 11 or Potomac A," Data Sheet, Allegheny Ludlum Steel Corp., Sept 1959. As published in *Aerospace Structural Metals Handbook,* Vol 1, Code 1218, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 27



TS.010 H-11 Mod chromium hot-work tool steel bar, tensile stress-strain curves at room and low temperatures

Sheet thickness = 19.05 mm (0.75 in.). Heat treatment: 1010 °C (1850 °F), 1 h, air cooled, tempered twice 552 °C (1025 °F), 0.75 h, air cooled. Composition: Fe-0.4C-5Cr-1.3Mo-0.5V. UNS T20821

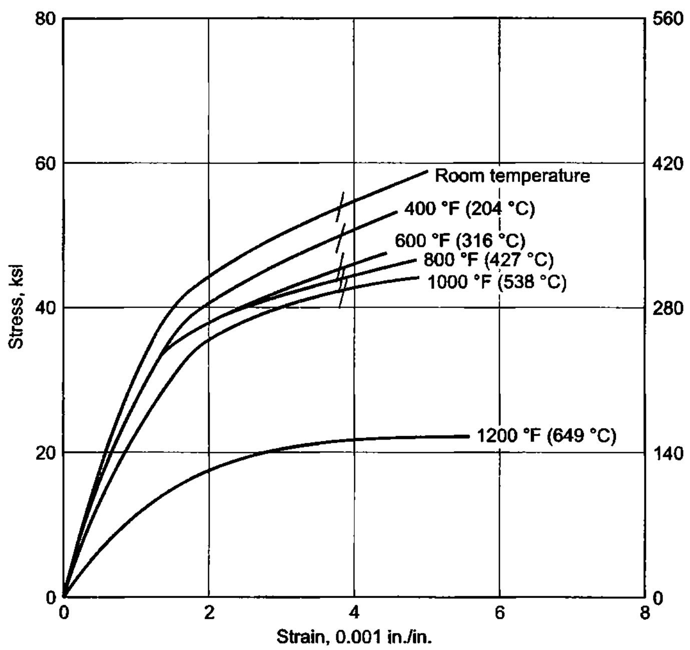
Source: K.A. Warren and R.P. Reed, Tensile and Impact Properties of Selected Materials from 20 to 300 °K, Monograph 63, National Bureau of Standards, 28 June 1963. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1218, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 28



TS.011 H-11 Mod chromium hot-work tool steel bar, effect of strain rate on tensile yield strength at room and elevated temperature

Bar diameter = 25.4 mm (1 in.). Heat treatment: 1010 °C (1850 °F), 1 h, air cooled, tempered twice 566 °C (1050 °F), 1 h, air cooled. Composition: Fe-0.4C-5Cr-1.3Mo-0.5V. UNS T20821

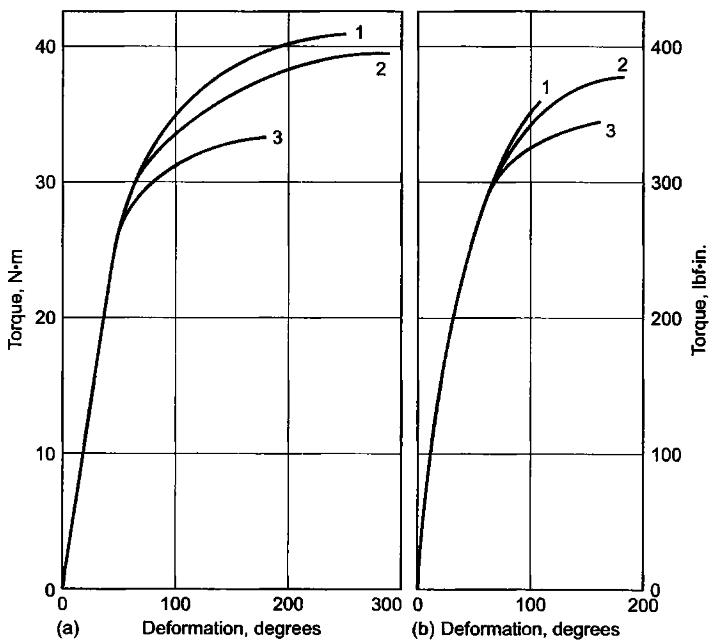
Source: D.P. Kendall, and T.E. Davidson, "The Effect of Strain Rate on Yielding of High Strength Steels," Report WVT 6618, Watervliet Arsenal, May 1966; D.P. Kendall, "The Effect of Strain Rate and Temperature on Yielding in Steels," Report WVT 7061, Watervliet Arsenal, Nov 1970. As published in *Aerospace Structural Metals Handbook*, Vol 1, Code 1218, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 33



TS.012 H-11 Mod chromium hot-work (annealed) tool steel sheet, compressive stress-strain curves at room and elevated temperatures

Sheet thickness = 1.626 mm (0.064 in.). Composition: Fe-0.4C-5Cr-1.3Mo-0.5V. UNS T20821

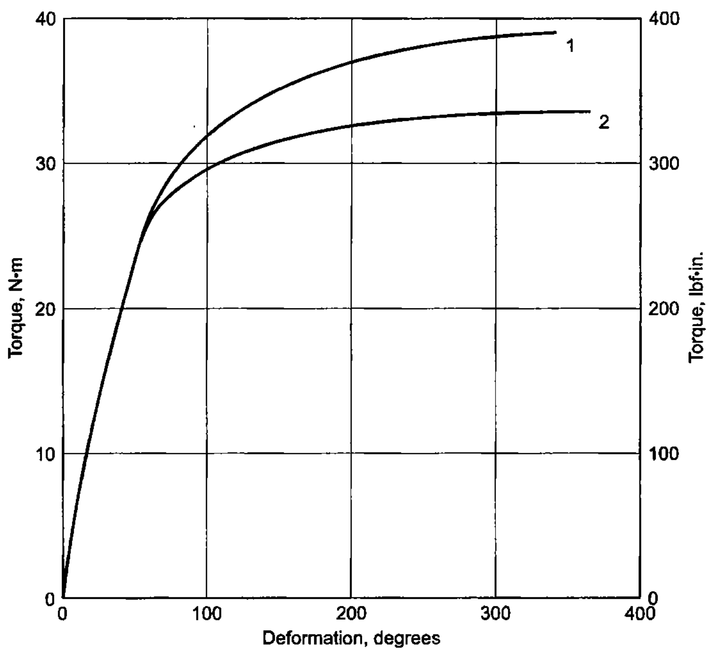
Source: R.G. Henning and A.W. Brisbane, "Mechanical Properties of AM 350, Potomac A, Potomac M, and Vasco Jet-1000 Steel Alloys in the Annealed Condition," ASD TDR -63-116, May 1963. As published in *Aerospace Structural Metals Handbook,* Vol 1, Code 1218, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 33



TS.013 L-type low-alloy special-purpose tool steel, torsional stress-strain curves with effect of tempering temperature

Specimens quenched in oil at 815 °C and then tempered: curve 1, 150 °C; curve 2, 175 °C; curve 3, 230 °C. (a) L-type with vanadium. (b) Without vanadium

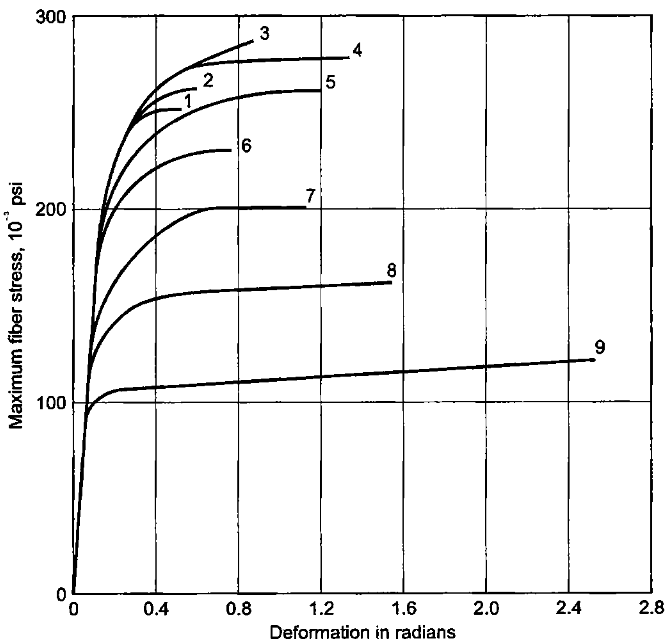
Source: Teledyne VASCO data. As published in G.A. Roberts, G. Krauss, and R.L. Kennedy, *Tool Steels,* 5th ed., ASM International, 1998, p 154



TS.014 L6 low-alloy special-purpose tool steel, torsional stress-strain curves with effect of tempering temperature

Specimens quenched in oil at 790 °C and then: curve 1, no tempering, 62.3 HRC; curve 2, tempered at 190 °C, 58.1 HRC. Composition: Fe-0.70C-0.55Mn-0.85Cr-1.40Ni-0.25Mo. UNS T61206

Source: Teledyne VASCO data. As published in G.A. Roberts, G. Krauss, and R.L. Kennedy, *Tool Steels,* 5th ed., ASM International, 1998, p 163



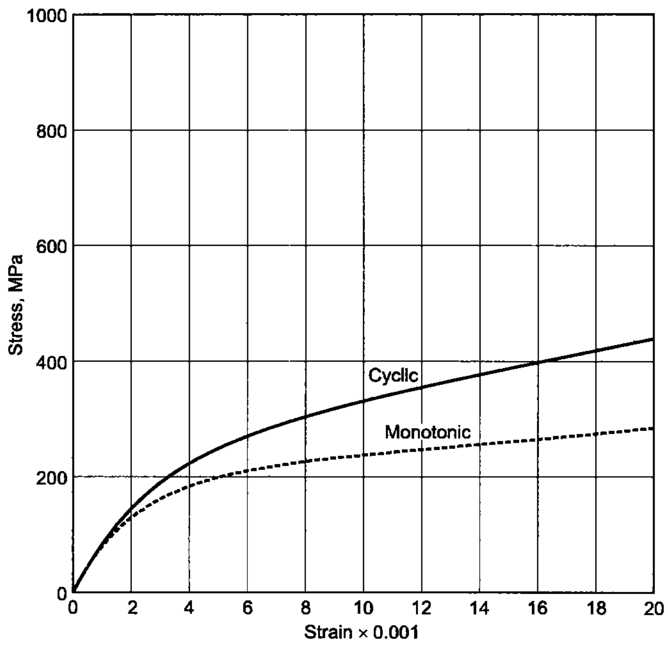
TS.015 1.1% carbon W-type water-hardening tool steel, torsional stress-strain curves with effect of tempering temperature

Brine quenched 788 °C (1450 °F) and tempered at: curve 1, as quenched; curve 2, 100 °C (212 °F); curve 3, 150 °C (300 °F); curve 4, 175 °C (350 °F); curve 5, 205 °C (400 °F); curve 6, 260 °C (500 °F); curve 7, 315 °C (600 °F), curve 8, 370 °C (700 °F), curve 9, 425 °C (800 °F). The toughness of the tool steel is measured in the torsion test as deformation in radians versus the stress in the extreme fibers. 0.4 radians is about 23°.

Source: G.A. Roberts, G. Krauss, and R.L. Kennedy, *Tool Steels,* 5th ed., ASM International, 1998, p 137

Nonferrous Metals

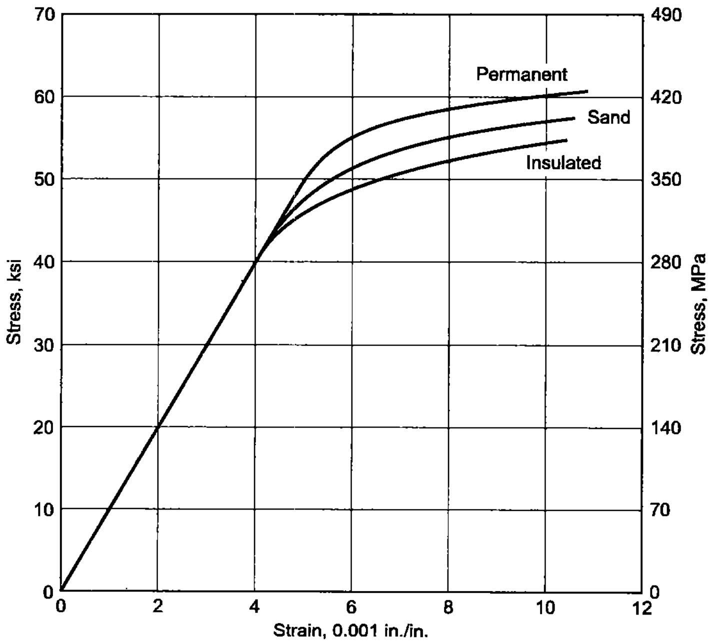
Cast Aluminum (CA)



CA.001 124EG-T5 aluminum permanent mold casting, tensile stress-strain curves, monotonic and cyclic

German casting material, Al-Si12-Cu-Ni-Mg with T5 temper. Tested at room temperature. Reference ASTM E 466 for cyclic force-controlled constant-amplitude fatigue test practices.

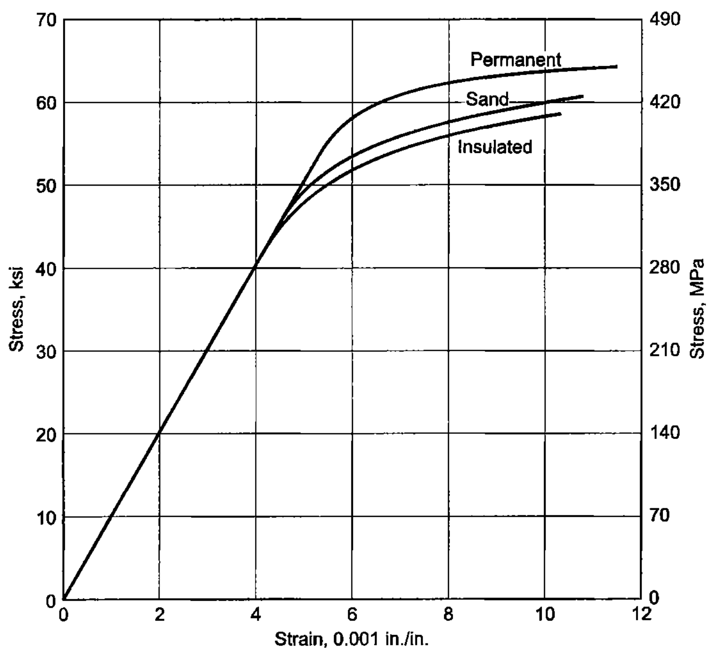
Source: John Deere Materials Data, Deere & Co., Moline, IL, p B13



CA.002 201.0-T6 aluminum casting, tensile stress-strain curves, various casting processes

Effect of casting process. Heat treatment: 2 h at 504–521 °C (940–970 °F), 14 h at 529 °C (985 °F), water quench, 24 h at room temperature, plus 20 h at 154 °C (310 °F), air cooled. Average mechanical properties for permanent mold castings: ultimate tensile strength, 450 MPa (65.2 ksi); tensile yield strength, 402 MPa (58.3 ksi). Average mechanical properties for sand castings: ultimate tensile strength, 394 MPa (57.1 ksi); tensile yield strength, 372 MPa (53.9 ksi). Average mechanical properties for insulated mold castings: ultimate tensile strength, 359 MPa (52.1 ksi); tensile yield strength, 349 MPa (50.6 ksi). UNS A02010

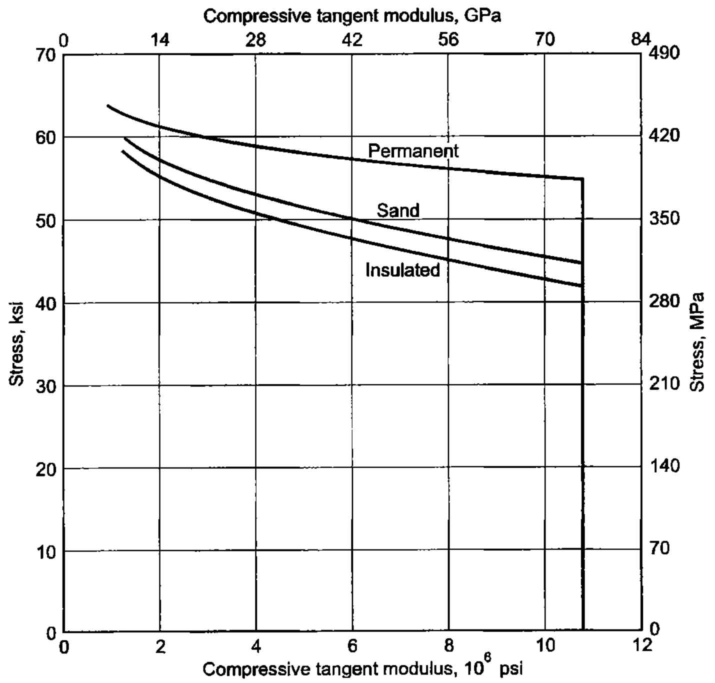
Source: "Mechanical Properties of Premium Aluminum Casting Alloys with Various Cooling Rates," Olin Corp., Jan 1973. As published in Cast Aluminum Section, *Structural Alloys Handbook,* Vol 3, CINDAS/ Purdue University, 1994, p 24, 67



CA.003 201.0-T6 aluminum casting, compressive stress-strain curves, various casting processes

Effect of casting process. Heat treatment, 2 h at 504–521 °C (940–970 °F), 14 h at 529 °C (985 °F), water quench, 24 h at room temperature, plus 20 h at 154 °C (310 °F), air cooled. Average compressive yield strength: permanent mold castings, 433 MPa (62.8 ksi); sand castings, 396 MPa (57.5 ksi); insulated mold castings, 382 MPa (55.4 ksi). UNS A02010

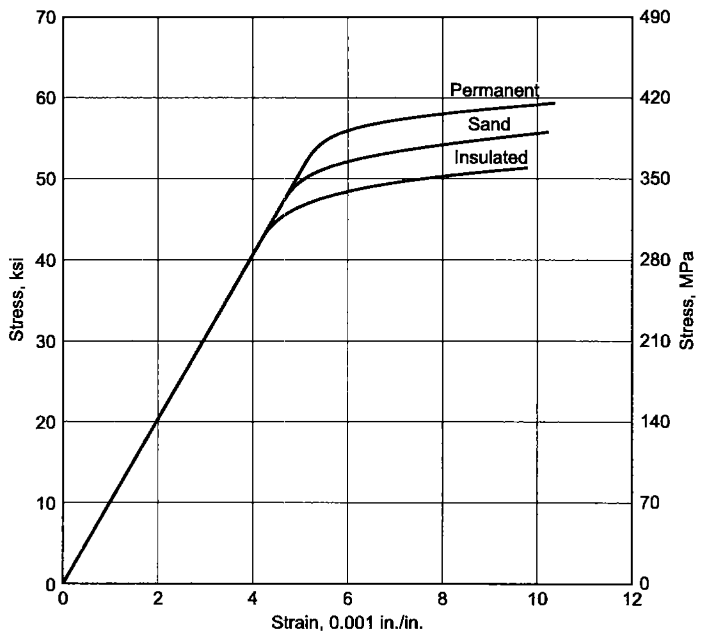
Source: "Mechanical Properties of Premium Aluminum Casting Alloys with Various Cooling Rates," Olin Corp., Jan 1973. As published in Cast Aluminum Section, *Structural Alloys Handbook*, Vol 3, CINDAS/ Purdue University, 1994, p 24, 67



CA.004 201.0-T6 aluminum casting, compressive tangent modulus curves, various casting processes

Effect of casting process. Heat treatment, 2 h at 504–521 °C (940–970 °F), 14 h at 529 °C (985 °F), water quench, 24 h at room temperature, plus 20 h at 154 °C (310 °F), air cooled. UNS A02010

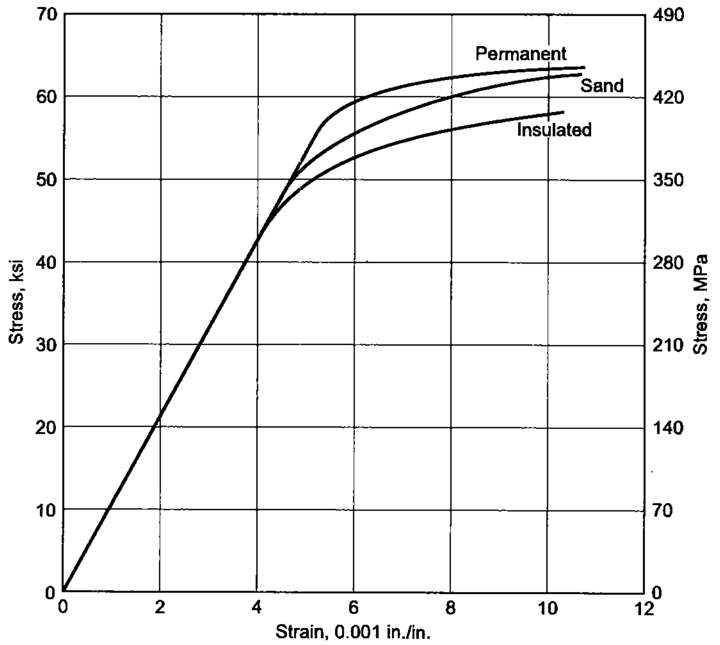
Source: "Mechanical Properties of Premium Aluminum Casting Alloys with Various Cooling Rates," Olin Corp., Jan 1973. As published in Cast Aluminum Section, *Structural Alloys Handbook*, Vol 3, CINDAS/ Purdue University, 1994, p 24, 68



CA.005 201.0-T7 aluminum casting, tensile stress-strain curves, various casting processes

Effect of casting process. Heat treatment, 2 h at 504–521 °C (940–970 °F), 14 h at 529 °C (985 °F), water quench, 24 h at room temperature, plus 5 h at 188 °C (370 °F), air cooled. Average mechanical properties for permanent mold castings: ultimate tensile strength, 439 MPa (63.7 ksi); tensile yield strength, 403 MPa (58.5 ksi). Average mechanical properties for sand castings: ultimate tensile strength, 385 MPa (55.8 ksi); tensile yield strength, 374 MPa (54.2 ksi). Average mechanical properties for insulated mold castings: ultimate tensile strength, 345 MPa (50.6 ksi); tensile yield strength, 344 MPa (49.9 ksi). UNS A02010

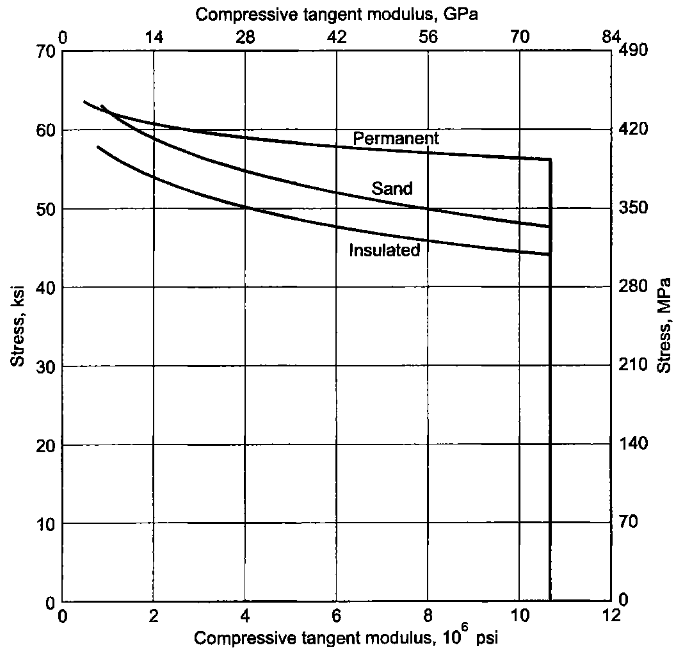
Source: "Mechanical Properties of Premium Aluminum Casting Alloys with Various Cooling Rates," Olin Corp., Jan 1973. As published in Cast Aluminum Section, *Structural Alloys Handbook*, Vol 3, CINDAS/Purdue University, 1994, p 24, 67



CA.006 201.0-T7 aluminum casting, compressive stress-strain curves, various casting processes

Effect of casting process. Heat treatment, 2 h at 504–521 °C (940–970 °F), 14 h at 529 °C (985 °F), water quench, 24 h at room temperature, plus 5 h at 188 °C (370 °F), air cooled. Average compressive yield strength: permanent mold castings, 429 MPa (62.2 ksi); sand castings, 407 MPa (59.1 ksi); insulated mold castings, 377 MPa (54.7 ksi). UNS A02010

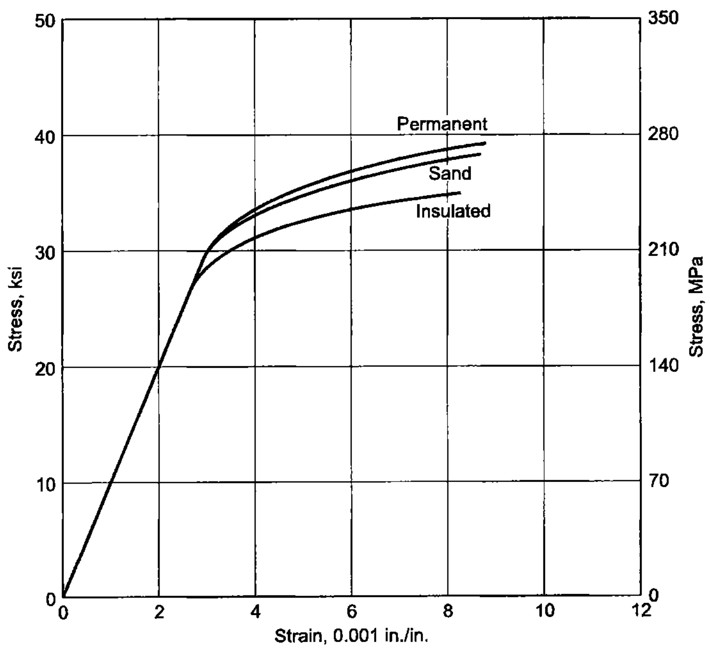
Source: "Mechanical Properties of Premium Aluminum Casting Alloys with Various Cooling Rates," Olin Corp., Jan 1973. As published in Cast Aluminum Section, *Structural Alloys Handbook*, Vol 3, CINDAS/Purdue University, 1994, p 24, 67



CA.007 201.0-T7 aluminum casting, compressive tangent modulus curves, various casting processes

Effect of casting process is illustrated. Heat treatment, 2 h at 504–521 °C (940–970 °F), 14 h at 529 °C (985 °F), water quench, 24 h at room temperature, plus 5 h at 188 °C (370 °F), air cooled. UNS A02010

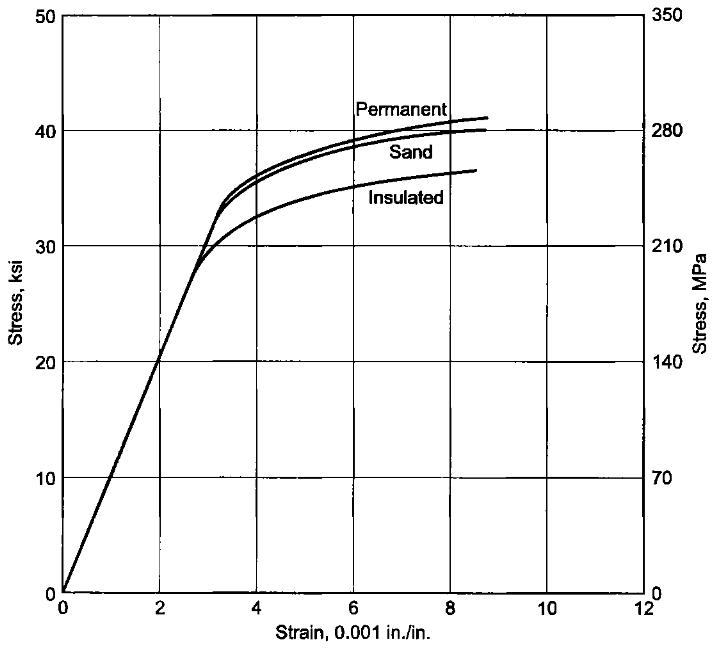
Source: "Mechanical Properties of Premium Aluminum Casting Alloys with Various Cooling Rates," Olin Corp., Jan 1973. As published in Cast Aluminum Section, *Structural Alloys Handbook*, Vol 3, CINDAS/ Purdue University, 1994, p 24, 68



CA.008 201.0-T43 aluminum casting, tensile stress-strain curves, various casting processes

Effect of casting process. Heat treatment, 2 h at 504–521 °C (940–970 °F), 14 h at 529 °C (985 °F), water quench, 24 h at room temperature, plus 0.5 h at 154 °C (310 °F), air cooled. Average mechanical properties for permanent mold castings: ultimate tensile strength, 407 MPa (59.0 ksi); tensile yield strength, 250 MPa (36.2 ksi). Average mechanical properties for sand castings: ultimate tensile strength, 356 MPa (51.7 ksi); tensile yield strength, 243 MPa (35.3 ksi). Average mechanical properties for insulated mold castings: ultimate tensile strength, 273 MPa (39.6 ksi); tensile yield strength, 225 MPa (32.6 ksi). UNS A02010

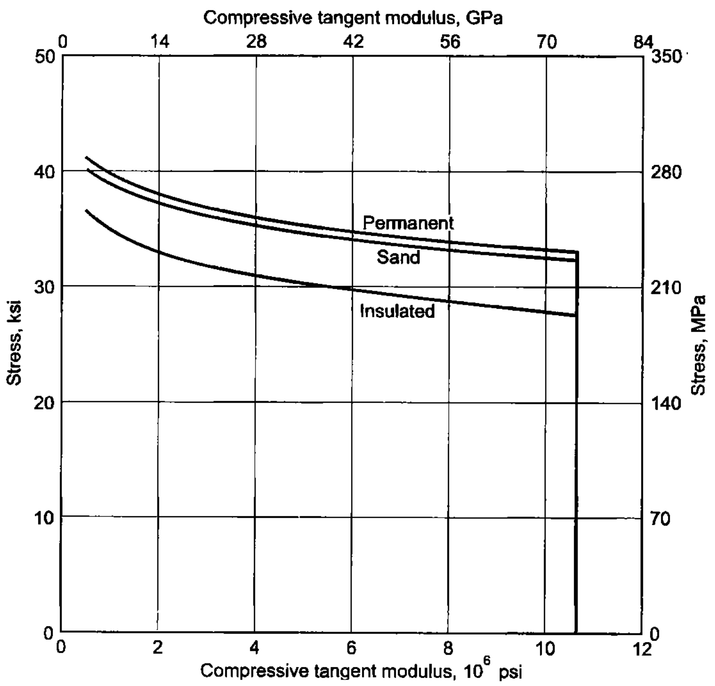
Source: "Mechanical Properties of Premium Aluminum Casting Alloys with Various Cooling Rates," Olin Corp., Jan 1973. As published in Cast Aluminum Section, *Structural Alloys Handbook*, Vol 3, CINDAS/ Purdue University, 1994, p 24, 67



CA.009 201.0-T43 aluminum casting, compressive stress-strain curves, various casting processes

Effect of casting process. Heat treatment, 2 h at 504–521 °C (940–970 °F), 14 h at 529 °C (985 °F), water quench, 24 h at room temperature, plus 0.5 h at 154 °C (310 °F), air cooled. Average compressive yield strength: permanent mold castings, 272 MPa (39.4 ksi); sand castings, 266 MPa (38.6 ksi); insulated mold castings, 238 MPa (34.5 ksi). UNS A02010

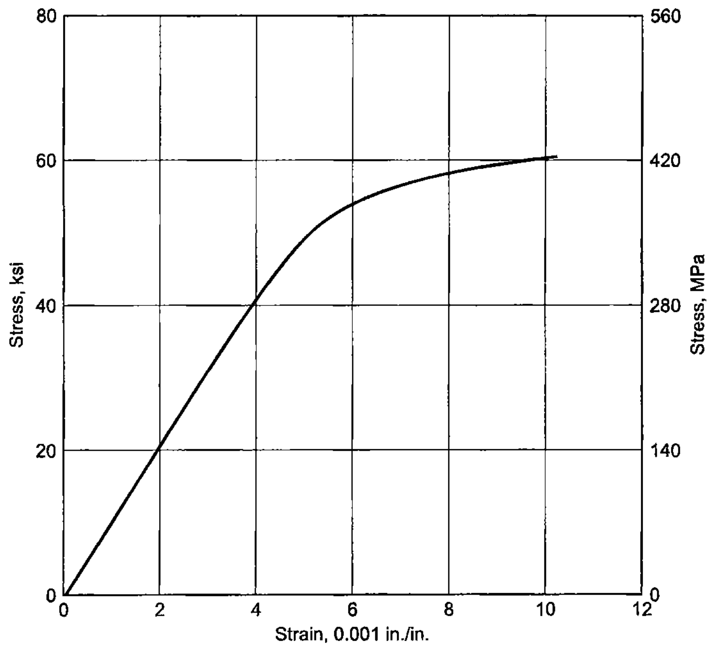
Source: "Mechanical Properties of Premium Aluminum Casting Alloys with Various Cooling Rates," Olin Corp., Jan 1973. As published in Cast Aluminum Section, *Structural Alloys Handbook,* Vol 3, CINDAS/ Purdue University, 1994, p 24, 67



CA.010 201.0-T43 aluminum casting, compressive tangent modulus curves, various casting processes

Effect of casting process is illustrated. Heat treatment, 2 h at 504–521 °C (940–970 °F), 14 h at 529 °C (985 °F), water quench, 24 h at room temperature, plus 0.5 h at 154 °C (310 °F), air cooled. UNS A02010

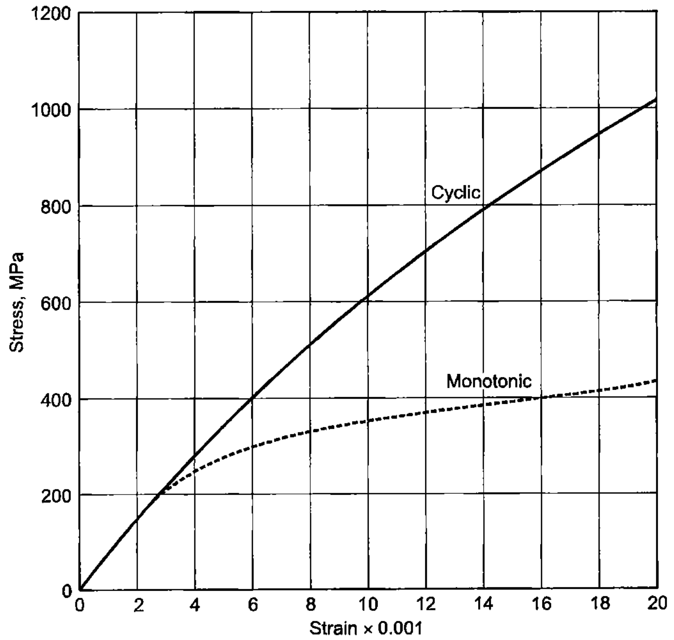
Source: "Mechanical Properties of Premium Aluminum Casting Alloys with Various Cooling Rates," Olin Corp., Jan 1973. As published in Cast Aluminum Section, *Structural Alloys Handbook,* Vol 3, CINDAS/ Purdue University, 1994, p 24, 68



CA.011 A201.0-T7 aluminum casting, typical tensile stress-strain curve

Designated area, at room temperature. Ramberg-Osgood parameter, n(tension) = 14. S basis design properties (originally presented in ksi) for strength class 1 and 2, designated area within casting: ultimate tensile strength, 414 MPa (60 ksi); tensile yield strength, 345 MPa (50 ksi); compressive yield strength, 352 MPa (51 ksi). UNS A12010

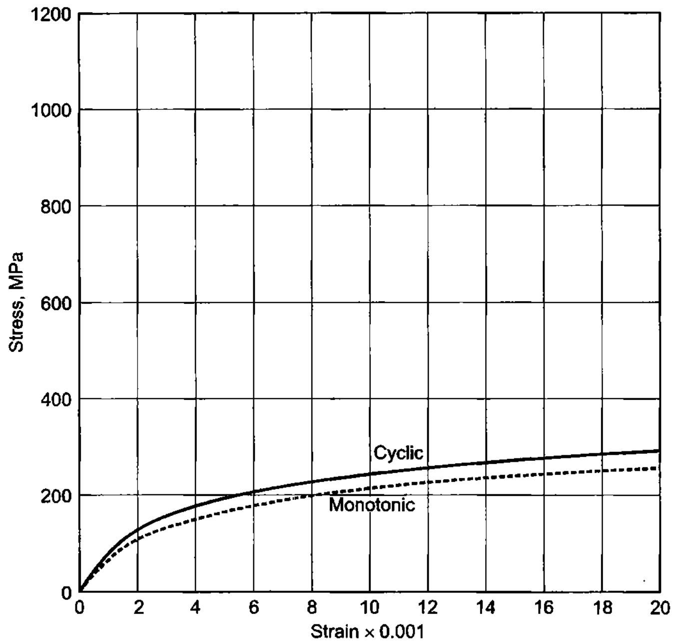
Source: *MIL-HDBK-5H*, Dec 1998, p 3-463, 3-465



CA.012 242.0-T5 aluminum permanent mold casting, tensile stress-strain curves, monotonic and cyclic

Al-Cu-Ni-Mg system. Tested at room temperature. Reference ASTM E 466 for cyclic force-controlled constant-amplitude fatigue test practices. UNS A02420

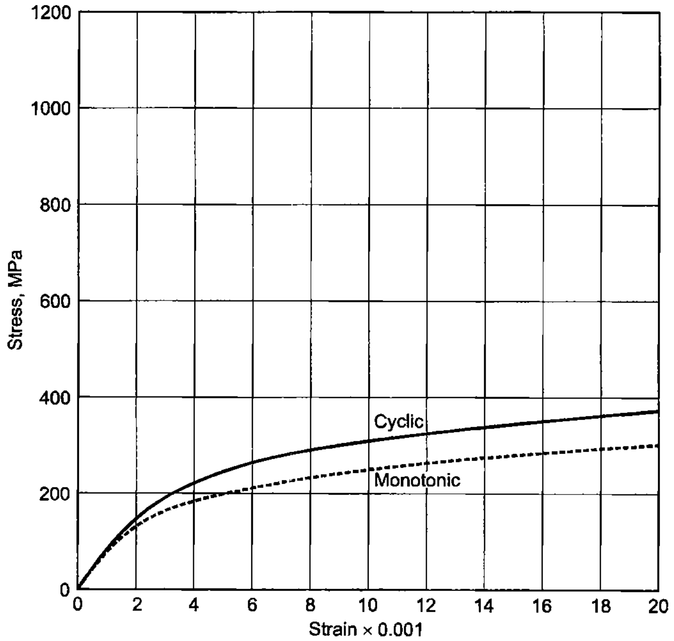
Source: John Deere Materials Data, Deere & Co., Moline, IL, p C13



CA.013 A332.0-T5 (PC) aluminum permanent mold casting, tensile stress-strain curves, monotonic and cyclic

Al-Si-Ni-Mg system. Tested at room temperature. Reference ASTM E 466 for cyclic force-controlled constant-amplitude fatigue test practices. UNS A13320 replaced by UNS A03360

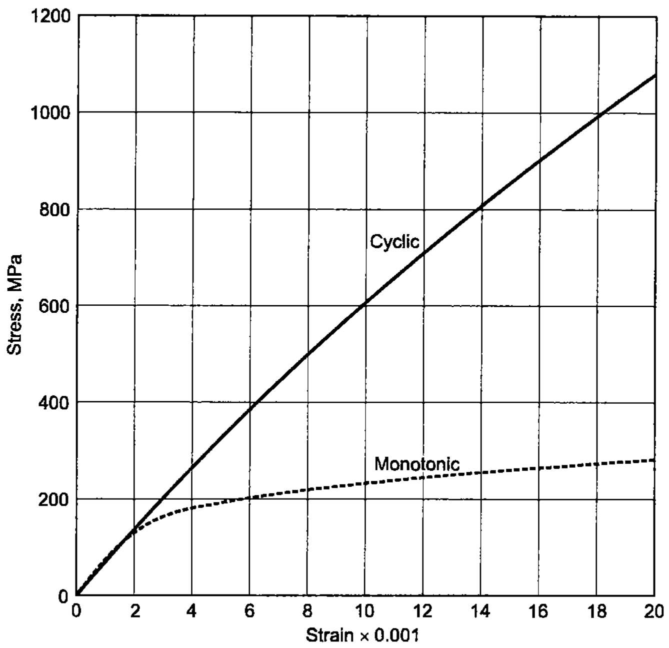
Source: John Deere Materials Data, Deere & Co., Moline, IL, p D14



CA.014 E332.0-T5 aluminum permanent mold casting, tensile stress-strain curves, monotonic and cyclic

Al-Si-Ni-Mg system. Tested at room temperature. Reference ASTM E 466 for cyclic force-controlled constant-amplitude fatigue test practices.

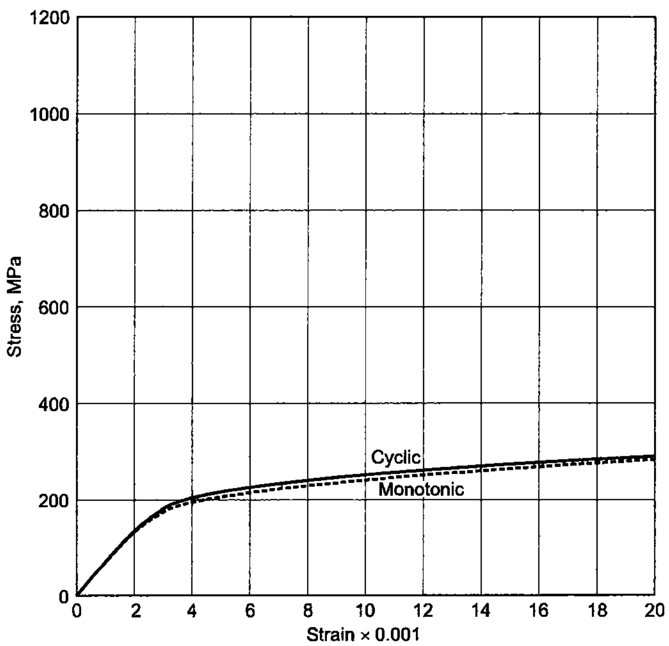
Source: John Deere Materials Data, Deere & Co., Moline, IL, p F13



CA.015 F332.0-T5 (SR) aluminum permanent mold casting, tensile stress-strain curves, monotonic and cyclic

Tested at room temperature. Reference ASTM E 466 for cyclic force-controlled constant-amplitude fatigue test practices. UNS A63320 replaced by UNS A03320

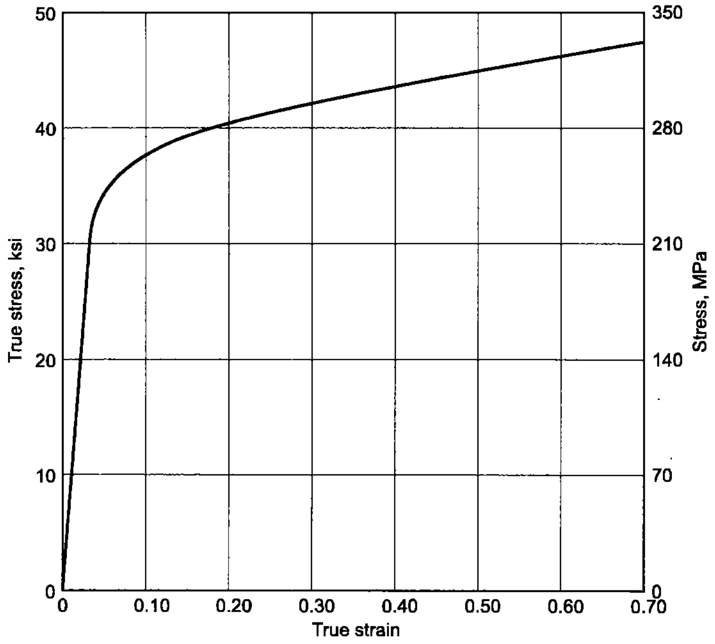
Source: John Deere Materials Data, Deere & Co., Moline, IL, p A14



CA.016 354.0-T5 aluminum permanent mold casting, tensile stress-strain curves, monotonic and cyclic

354.0-T5 casting material, Al-Si-Cu-Mg system. Tested at room temperature. Reference ASTM E 466 for cyclic force-controlled constant-amplitude fatigue test practices. UNS A03540

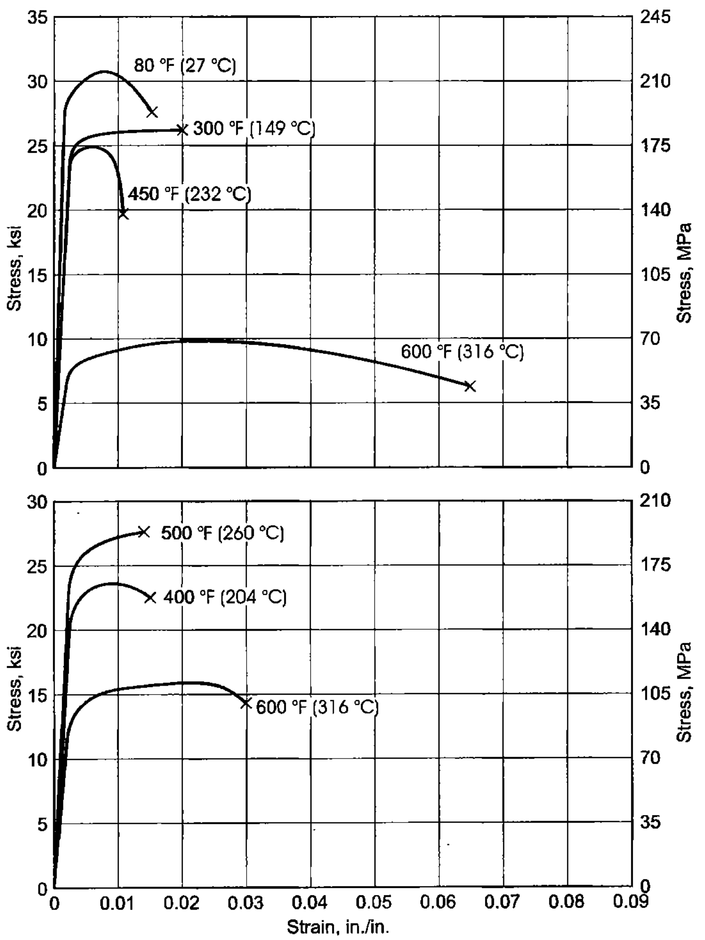
Source: John Deere Materials Data, courtesy of Deere & Co., Moline, IL, p E12



CA.017 C355.0-T61 aluminum casting, tensile uniaxial true stress-strain curve

Specimen size: 6.25 mm (0.250 in.) diam, 31.75 mm (1.25 in.) gage length. UNS A33550

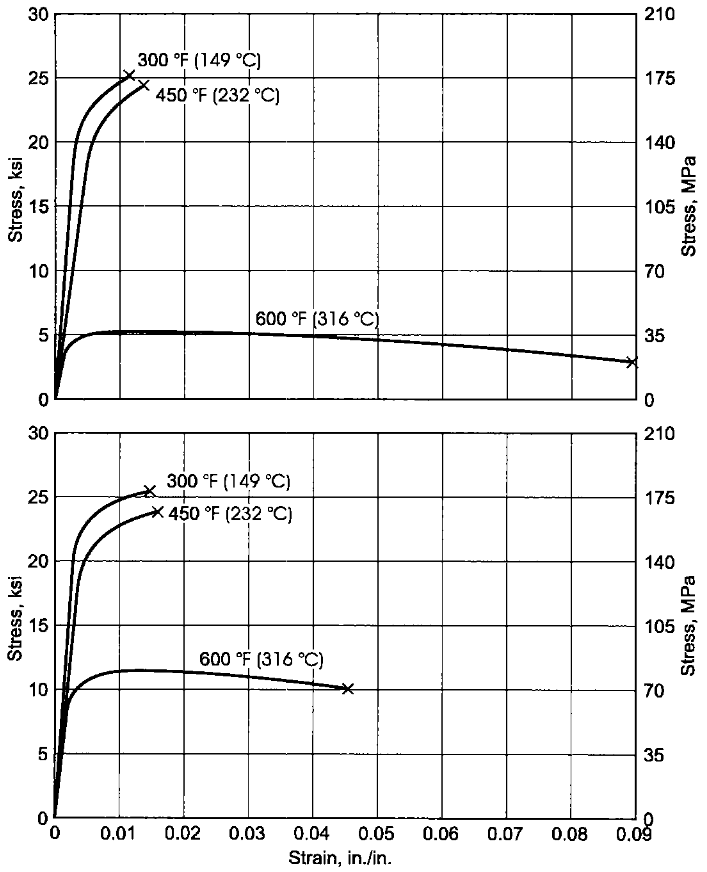
Source: J. Mattavi, "Low Cycle Fatigue Behavior Under Biaxial Strain Distribution," TP-67-16-T, Hamilton Standard, Sept 1967. As published in Cast Aluminum Section, *Structural Alloys Handbook,* Vol 3, CINDAS/Purdue University, 1994, p 70



CA.018 356.0-T6 aluminum casting, tensile stress strain curves at several temperatures

Effect of strain rate and temperature. Strain rate is 1.0 s^{-1}. Hold times at given temperatures: 1800 s (top); 10 s (bottom). Material was solution heat treated at 540 °C (1000 °F), water quenched, and aged at 154 °C (310 °F) for 3 h. UNS A03560

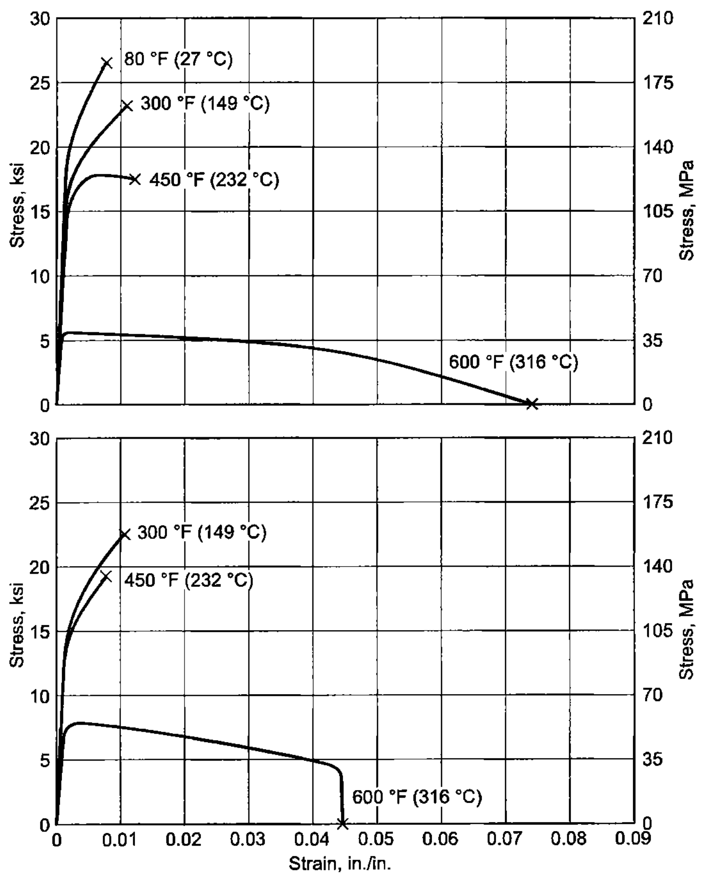
Source: H.E. Dedman, E.J. Wheelan, and E.J. Kattus, "Tensile Properties of Aircraft-Structural Metals at Various Rates of Loading after Rapid Heating," WADC TR-58-440, Southern Research Institute, Part 1, Nov 1958. As published in Cast Aluminum Section, *Structural Alloys Handbook,* Vol 2, CINDAS/Purdue University, 1994, p 71



CA.019 356.0-T6 aluminum casting, tensile stress strain curves at several temperatures

Effect of strain rate and temperature. Strain rate is 0.01 s^{-1}. Hold times at given temperatures: 1800 s (top); 10 s (bottom). Material was solution heat treated at 540 °C (1000 °F), water quenched, and aged at 154 °C (310 °F) for 3 h. UNS A03560

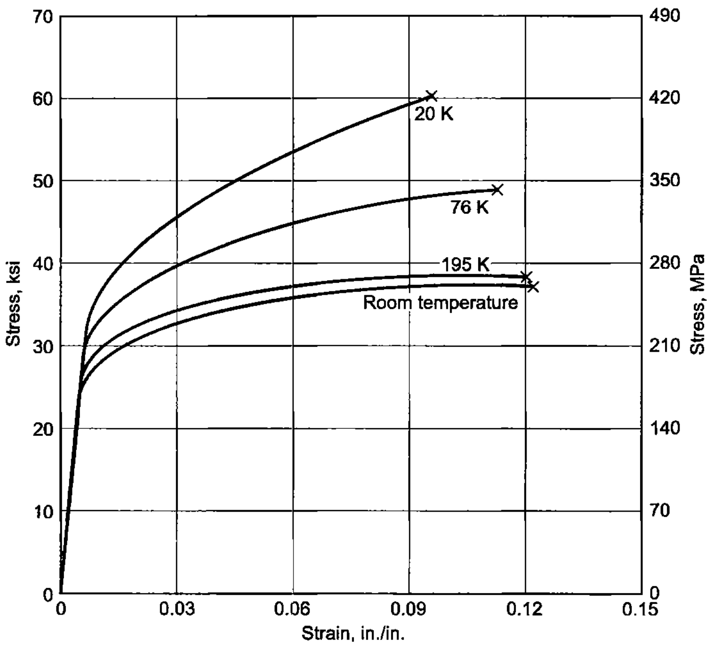
Source: H.E. Dedman, E.J. Wheelan, and E.J. Kattus, "Tensile Properties of Aircraft-Structural Metals at Various Rates of Loading after Rapid Heating," WADC TR-58-440, Southern Research Institute, Part 1, Nov 1958. As published in Cast Aluminum Section, *Structural Alloys Handbook,* Vol 2, CINDAS/Purdue University, 1994, p 71



CA.020 356.0-T6 aluminum casting, tensile stress-strain curves at several temperatures

Effect of strain rate and temperature. Strain rate is 0.00005 s^{-1}. Hold times at given temperatures: 1800 s (top); 10 s (bottom). Material was solution heat treated at 540 °C (1000 °F), water quenched, and aged at 154 °C (310 °F) for 3 h. UNS A03560

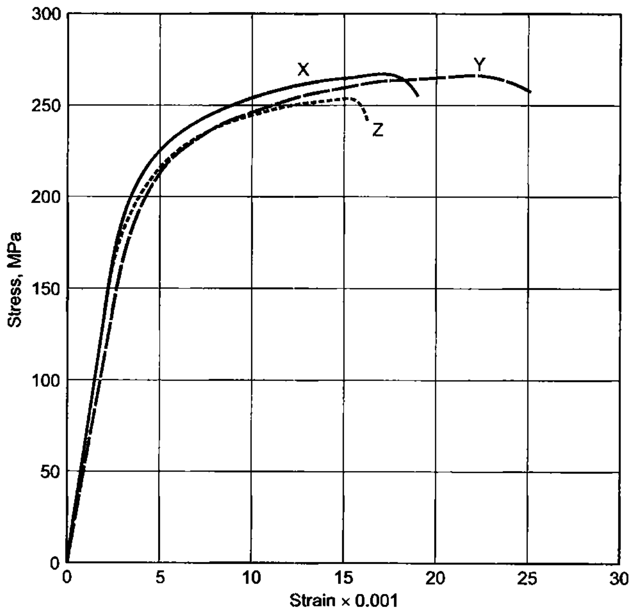
Source: H.E. Dedman, E.J. Wheelan, and E.J. Kattus, "Tensile Properties of Aircraft-Structural Metals at Various Rates of Loading after Rapid Heating," WADC TR-58-440, Southern Research Institute, Part 1, Nov 1958. As published in Cast Aluminum Section, *Structural Alloys Handbook*, Vol 2, CINDAS/Purdue University, 1994, p 71



CA.021 356.0-T6 aluminum casting, tensile stress-strain curves at low temperature

Chill cast aluminum. Hardness, 41 HRB. UNS A03560

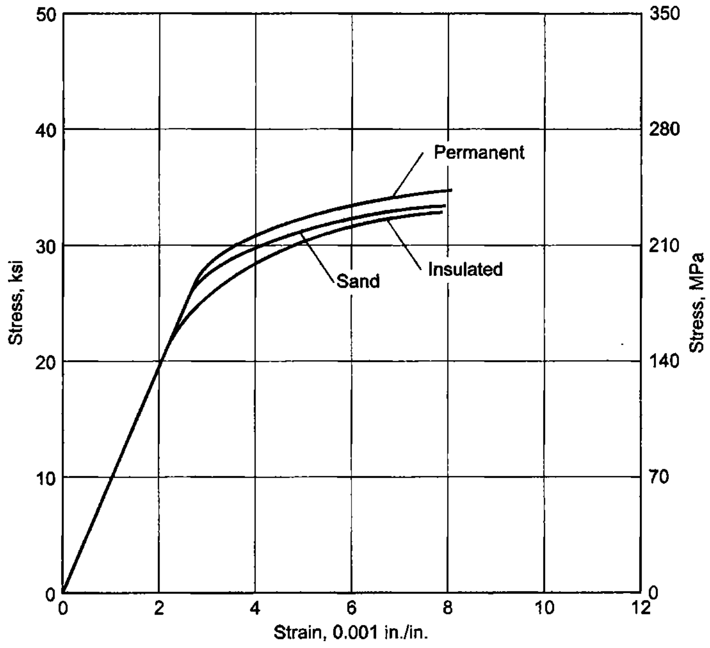
Source: K.A. Warren and R.P. Reed, *Tensile and Impact Properties of Selected Materials from 20 to 300 K*, Monograph 63, National Bureau of Standards, June 1963. As published in *Structural Alloys Handbook*, Vol 3, CINDAS/Purdue University, 1994, p 70



CA.022 A356-T6 aluminum cast cylinder, monotonic tensile stress-strain curve

Near-net-shape casting formed by pouring molten alloy, 704 °C (1300 °F) into investment molds at room temperature (X), 538 °C (1000 °F) (Y), and 982 °C (1800 °F) (Z). Three different cooling rates create different microstructures. Curves are results from one laboratory. Property values are averages from seven labs as part of a round-robin test program. Young's modulus, GPa (psi × 10^6), X, 70 (10.1), Y, 70 (10.1), Z, 71 (10.3); yield strength 0.2% MPa (ksi), X, 229 (33.3), Y, 224 (32.5), Z, 217 (31.5); ultimate strength MPa (ksi), X, 283 (41.1), Y, 266 (38.6), Z, 252 (36.6); strain hardening exponent (n), X, 0.083, Y, 0.087, Z, 0.091; strain hardening coefficient K, MPa (ksi), X, 388 (56.4), Y, 397 (57.6), Z, 382 (55.4). UNS A13560

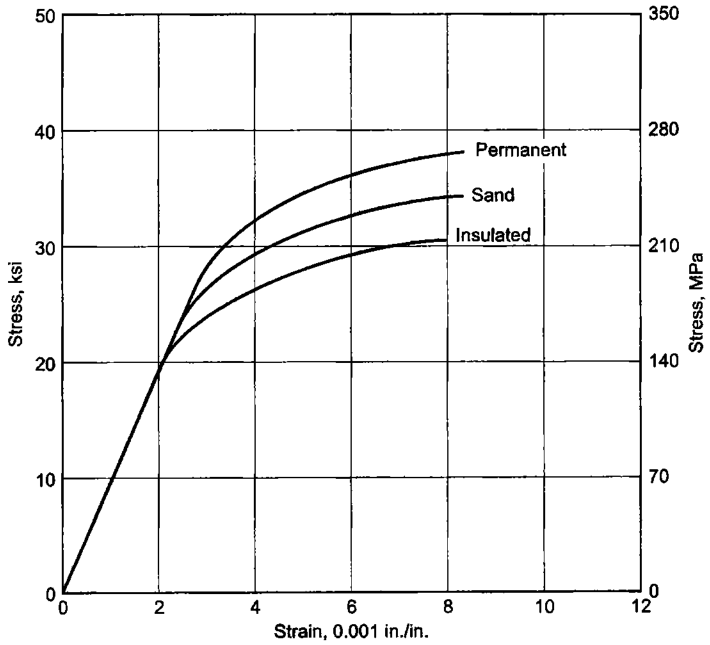
Source: *Fatigue and Fracture Toughness of A356-T6 Cast Aluminum Alloy*, R.I. Stephens, Ed., SP-760, Society of Automotive Engineers, 1988.



CA.023 A356.0-T6 aluminum casting, tensile stress-strain curves, various casting processes

Effect of molding process. Heat treatment, 12 h at 538 °C (1000 °F), water quench, 12–24 h delay at room temperature, 3 h at 154 °C (310 °F), and air cooled. Average mechanical properties for permanent mold castings: ultimate tensile strength, 299 MPa (43.4 ksi); tensile yield strength, 215 MPa (31.2 ksi). Average mechanical properties for sand castings: ultimate tensile strength, 253 MPa (36.7 ksi); tensile yield strength, 223 MPa (32.3 ksi). Average mechanical properties for insulated mold castings: ultimate tensile strength, 219 MPa (31.7 ksi); tensile yield strength, 205 MPa (29.8 ksi). UNS A13560

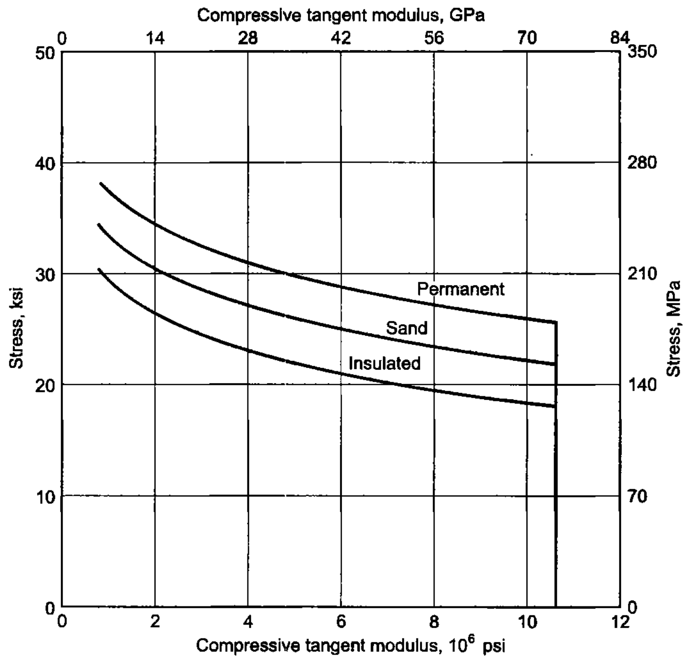
Source: "Mechanical Properties of Premium Aluminum Casting Alloys with Various Cooling Rates," Olin Corp., Jan 1973. As published in Cast Aluminum Section, *Structural Alloys Handbook*, Vol 3, CINDAS/Purdue University, 1994, p 24, 66



CA.024 A356.0-T6 aluminum casting, compressive stress-strain curves, various casting processes

Effect of molding process. Heat treatment, 12 h at 538 °C (1000 °F), water quench, 12–24 h delay at room temperature, 3 h at 154 °C (310 °F), and air cooled. Average compressive yield strength: permanent mold castings, 219 MPa (31.7 ksi); sand castings, 245 MPa (35.6 ksi); insulated mold castings, 192 MPa (27.9 ksi). UNS A13560

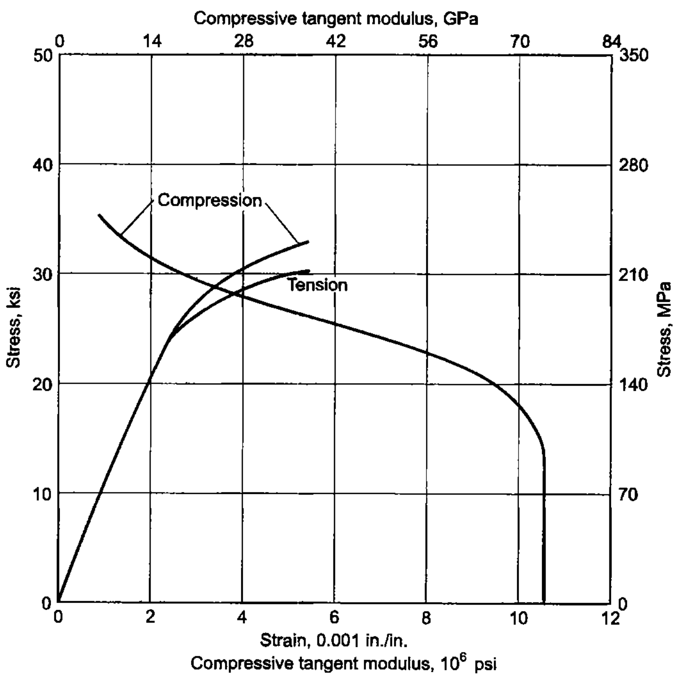
Source: "Mechanical Properties of Premium Aluminum Casting Alloys with Various Cooling Rates," Olin Corp., Jan 1973. As published in Cast Aluminum Section, *Structural Alloys Handbook*, Vol 3, CINDAS/Purdue University, 1994, p 24, 66



CA.025 A356.0-T6 aluminum casting, compressive tangent modulus curves, various casting processes

Effect of molding process. Heat treatment, 12 h at 538 °C (1000 °F), water quench, 12–24 h delay at room temperature, 3 h at 154 °C (310 °F), and air cooled. UNS A13560

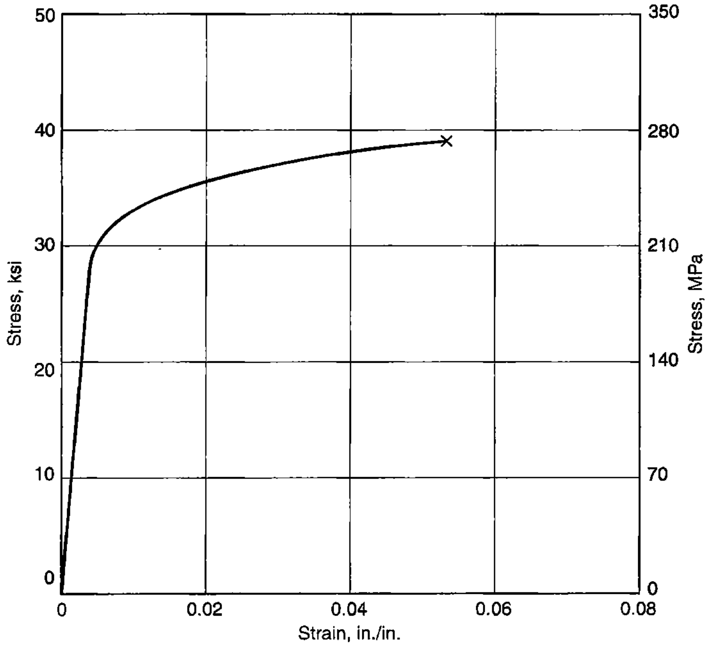
Source: "Mechanical Properties of Premium Aluminum Casting Alloys with Various Cooling Rates," Olin Corp., Jan 1973. As published in Cast Aluminum Section, *Structural Alloys Handbook*, Vol 3, CINDAS/ Purdue University, 1994, p 68



CA.026 A356.0-T6P aluminum casting, typical tensile and compressive stress-strain and tangent modulus curves

Tested at room temperature. Ramberg-Osgood parameters, n(tension) = 10, n(compression) = 9.2. In the temper designation, T6P, P indicates a difference in the standard procedure or difference in the minimum tensile requirements as compared to the Aluminum Association's limits. S basis values for A356.0-T6P per AMS 4218: Ultimate tensile strength, 220 MPa (32 ksi); tensile and compressive yield strength, 152 MPa (22 ksi). UNS A13560

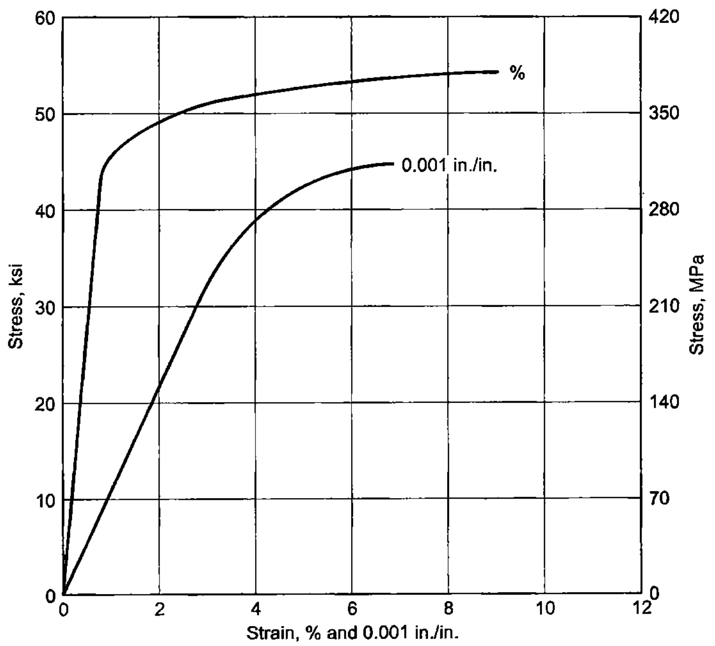
Source: *MIL-HDBK-5H*, Dec 1998, p 3-482, 3-483



CA.027 A356.0-T6P aluminum casting, full range tensile stress-strain curve

Tested at room temperature. X indicates fracture. In the temper designation T6P, P indicates a difference in the standard procedure or difference in the minimum tensile requirements as compared to the Aluminum Association's limits. S basis values for A356.0-T6P per AMS 4218: ultimate tensile strength, 220 MPa (32 ksi); tensile and compressive yield strength, 152 MPa (22 ksi). UNS A13560

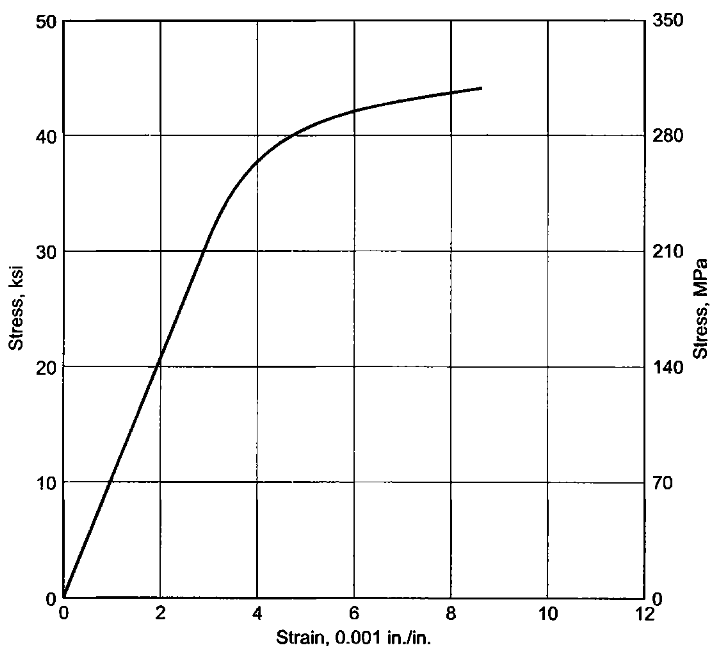
Source: *MIL-HDBK-5H,* Dec 1998, p 3-482, 3-483



CA.028 A357.0-T6 aluminum cast plate, tensile stress-strain curves

Sand cast plate thickness: 6.35 mm (0.25 in.). The full range strain is given in % (top curve) and the expanded range strain is in 0.001 in./in. (bottom curve). Composition: Al-7.0Si-0.6Mg-0.1Te-Be. UNS A13570

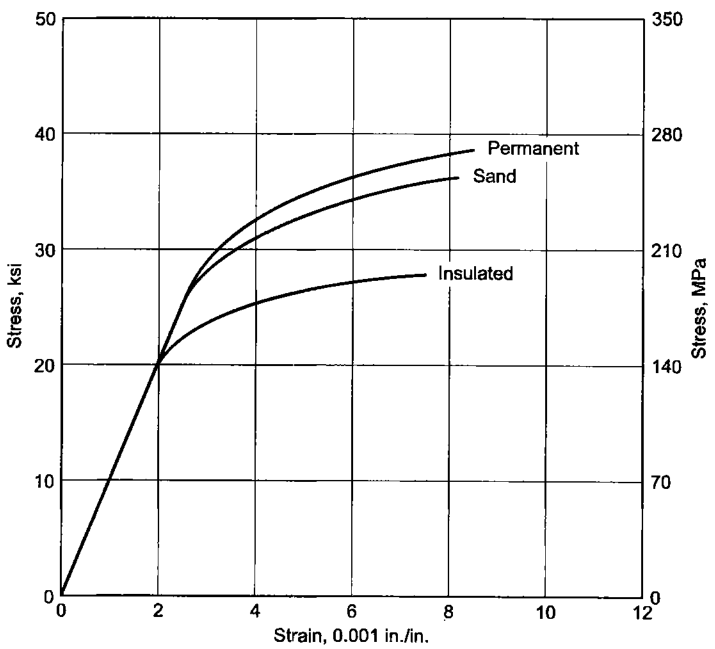
Source: "Development: Premium Alloy Castings of Alloy A357.0-T6," Alcoa, Pittsburgh, PA, 1971. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 3109, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 24



CA.029 A357.0-T6 aluminum casting, typical tensile stress-strain curve

Class 2 alloy casting, designated area, at room temperature. Ramberg-Osgood parameter, n(tension) = 16. S basis design properties (originally presented in ksi) for strength class 2, designated area within casting: ultimate tensile strength, 345 MPa (50 ksi); tensile and compressive yield strength, 276 MPa (40 ksi). UNS A13570

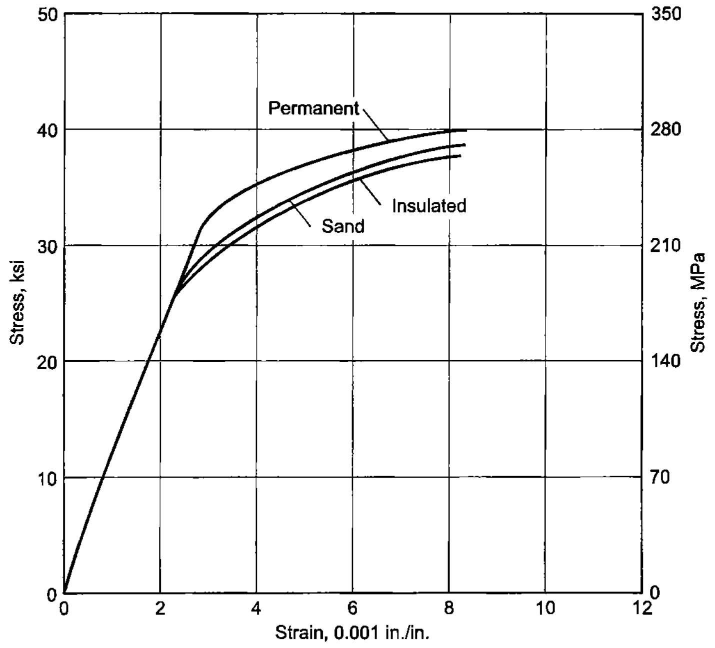
Source: *MIL-HDBK-5H,* Dec 1998, p 3-485, 3-486



CA.030 A357.0-T6 aluminum casting, tensile stress-strain curves, various casting processes

Effect of molding process. Heat treatment, 12 h at 538 °C (1000 °F), water quench, 12–24 h delay at room temperature, 5 h at 177 °C (350 °F), and air cooled. Average mechanical properties for permanent mold castings: ultimate tensile strength, 316 MPa (45.8 ksi); tensile yield strength, 243 MPa (35.2 ksi). Average mechanical properties for sand castings: ultimate tensile strength, 268 MPa (38.9 ksi); tensile yield strength, 229 MPa (33.2 ksi). Average mechanical properties for insulated mold castings: ultimate tensile strength, 179 MPa (26.0 ksi); tensile yield strength, 179 MPa (26.0 ksi). UNS A13570

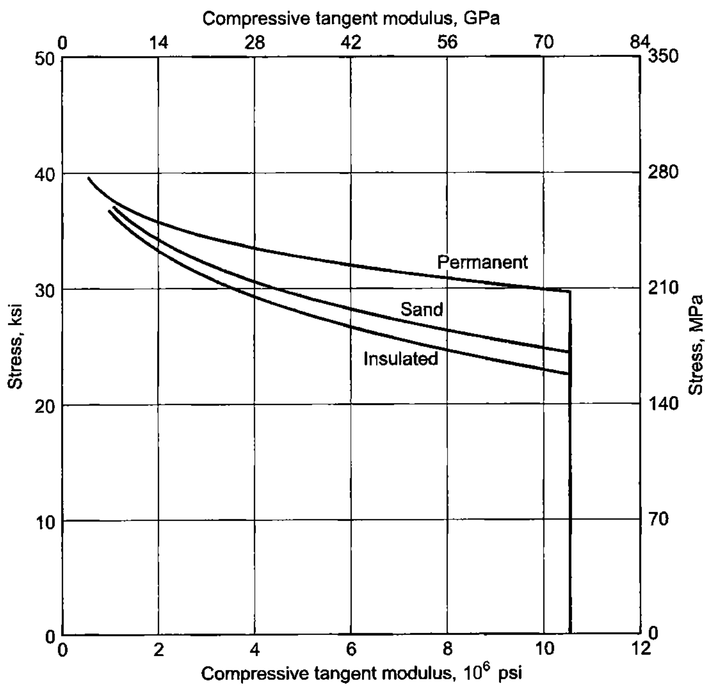
Source: "Mechanical Properties of Premium Aluminum Casting Alloys with Various Cooling Rates," Olin Corp., Jan 1973. As published in Cast Aluminum Section, *Structural Alloys Handbook,* Vol 3, CINDAS/ Purdue University, 1994, p 24, 66



CA.031 A357.0-T6 aluminum casting, compressive stress-strain curves, various casting processes

Effect of molding process. Heat treatment, 12 h at 538 °C (1000 °F), water quench, 12–24 h delay at room temperature, 5 h at 177 °C (350 °F), and air cooled. Average compressive yield strength: permanent mold castings, 256 MPa (37.2 ksi); sand castings, 240 MPa (34.8 ksi); insulated mold castings, 232 MPa (33.7 ksi). UNS A13570

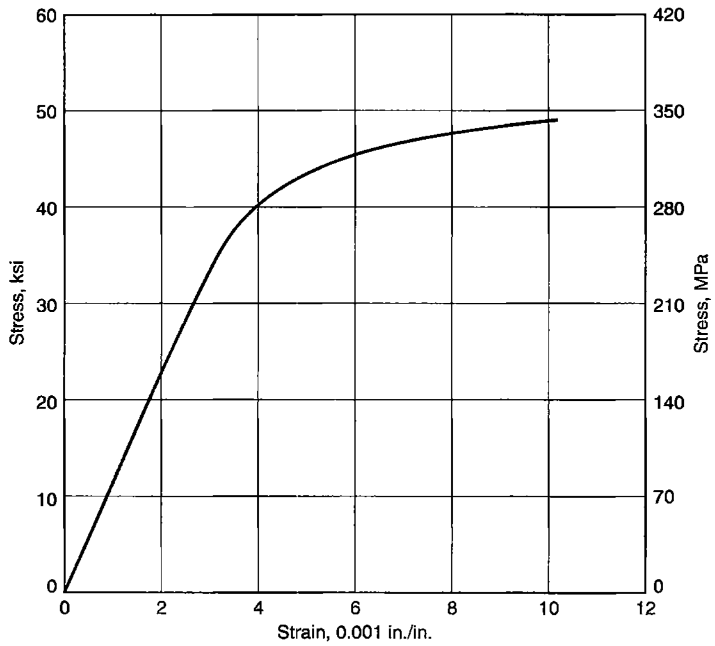
Source: "Mechanical Properties of Premium Aluminum Casting Alloys with Various Cooling Rates," Olin Corp., Jan 1973. As published in Cast Aluminum Section, *Structural Alloys Handbook,* Vol 3, CINDAS/Purdue University, 1994, p 24, 66



CA.032 A357.0-T6 aluminum casting, compressive tangent modulus curves, various casting processes

Effect of molding process. Heat treatment, 12 h at 538 °C (1000 °F), water quench, 12–24 h delay at room temperature, 5 h at 177 °C (350 °F), and air cooled. UNS A13570

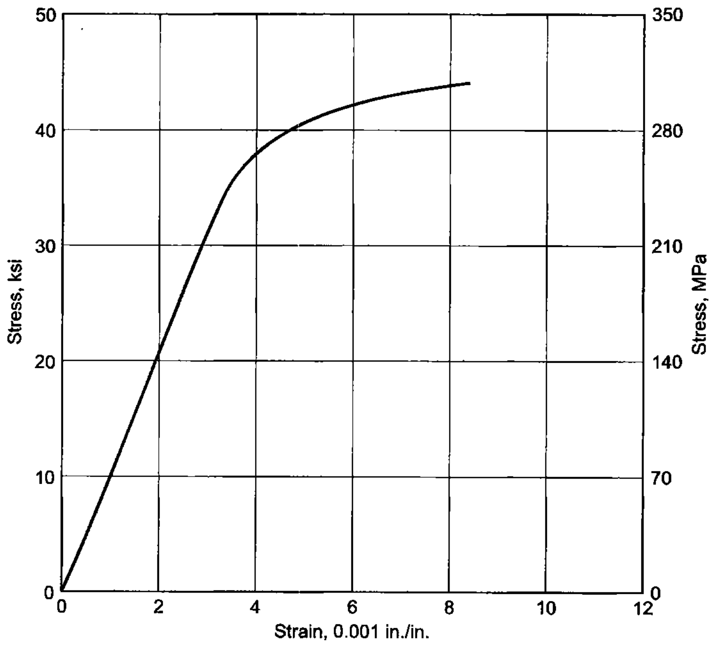
Source: "Mechanical Properties of Premium Aluminum Casting Alloys with Various Cooling Rates," Olin Corp., Jan 1973. As published in Cast Aluminum Section, *Structural Alloys Handbook,* Vol 3, CINDAS/ Purdue University, 1994, p 24, 68



CA.033 A357.0-T6 aluminum cast plate, compressive stress-strain curve

Sand cast plate thickness: 6.35 mm (0.25 in.). Composition: Al-7.0Si-0.6Mg-0.1Te-Be. UNS A13570

Source: "Development: Premium Alloy Castings of Alloy A357.0-T6," Alcoa, Pittsburgh, PA, 1971. As published in *Aerospace Structural Metals Handbook*, Vol 5, Code 3109, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 29

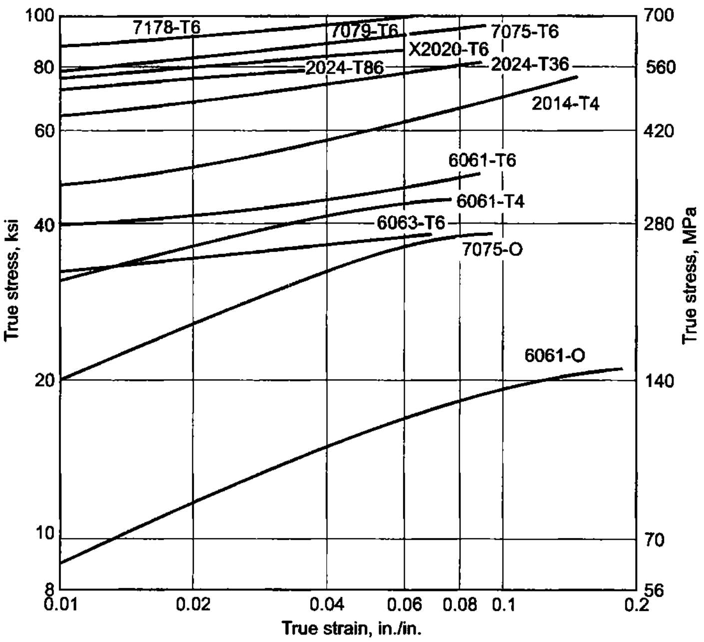


CA.034 D357.0-T6 aluminum casting, typical tensile stress-strain curve

Designated area, at room temperature. Ramberg-Osgood parameter, n(tension) = 16. B basis design properties (originally presented in ksi) for designated area within casting: ultimate tensile strength, 338 MPa (49 ksi); tensile and compressive yield strength, 285 MPa (41 ksi). UNS A43570

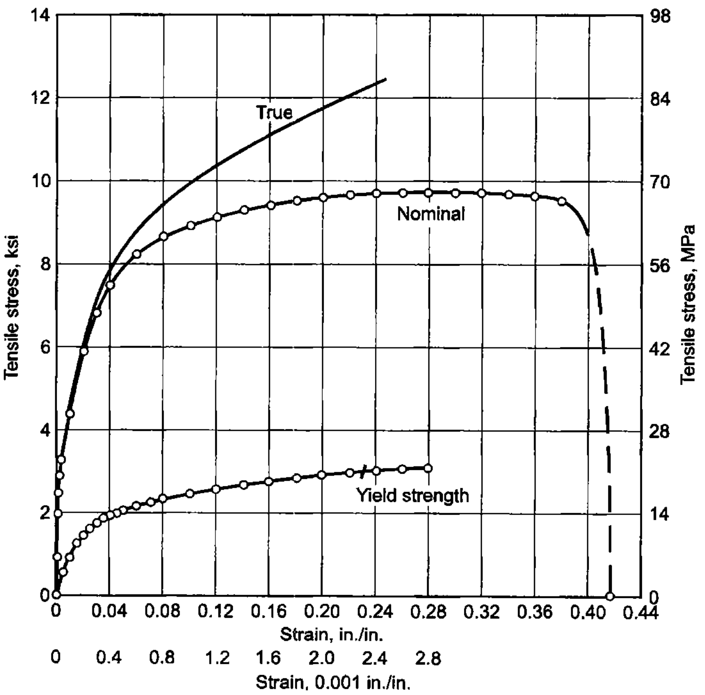
Source: MIL-HDBK-5H, Dec 1998, p 3-488, 3-489

Wrought Aluminum (WA)



WA.001 Heat-treatable aluminum alloys, true stress-strain curves

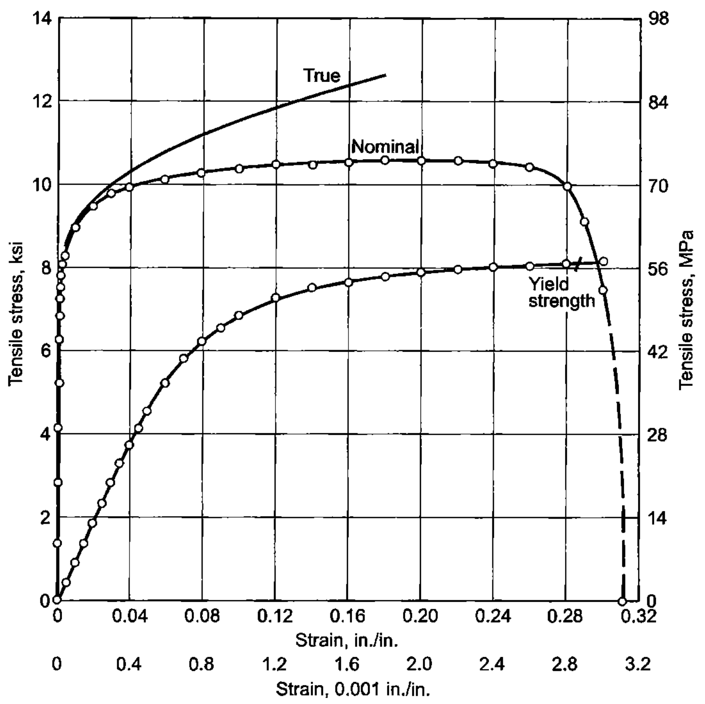
X2020-T6, 2014-T4, 2024-T36, 2024-T86, 6061-O, 6061-T4, 6061-T6, 6063-T6, 7075-O, 7075-T6, 7079-T6, 7178-T6



WA.002 1060-O aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 67.2 MPa (9.75 ksi). True tensile strength, 86.2 MPa (12.5 ksi). Nominal yield strength (0.2% offset), 21 MPa (3.0 ksi). Elongation (in 50.8 mm, or 2 in.), 42.7%. Reduction of area, 91%. True strain at maximum load, 24.8%. A log-log plot of the stress-strain curve would yield a slope (n) of 0.22 in the area of uniform plastic deformation.
UNS A91060

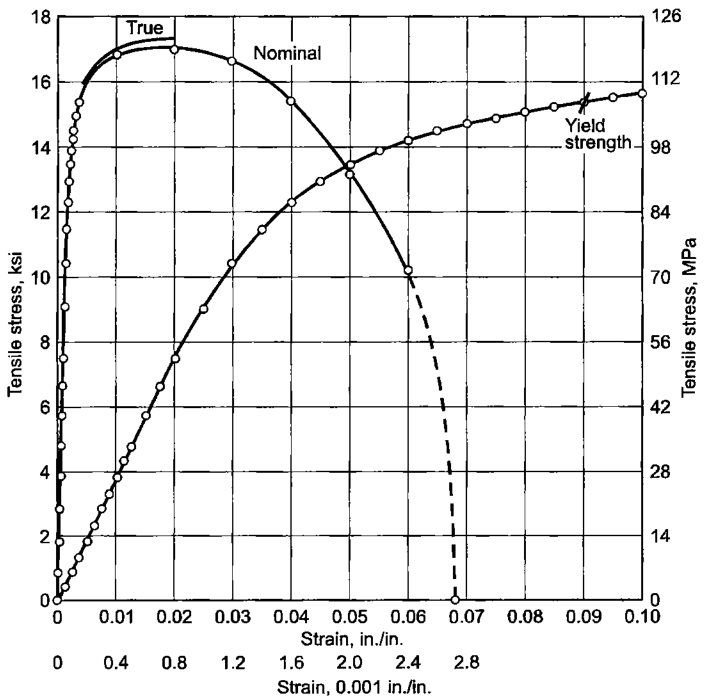
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, Oct 1951



WA.003 1060-H12 aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 73.1 MPa (10.6 ksi). True tensile strength, 87.6 MPa (12.7 ksi). Nominal yield strength (0.2% offset), 57 MPa (8.2 ksi). Elongation (in 50.8 mm, or 2 in.), 31.1%. Reduction of area, 90%. True strain at maximum load, 18.0%. A log-log plot of the stress-strain curve would yield a slope (n) of 0.14 in the area of uniform plastic deformation. UNS A91060

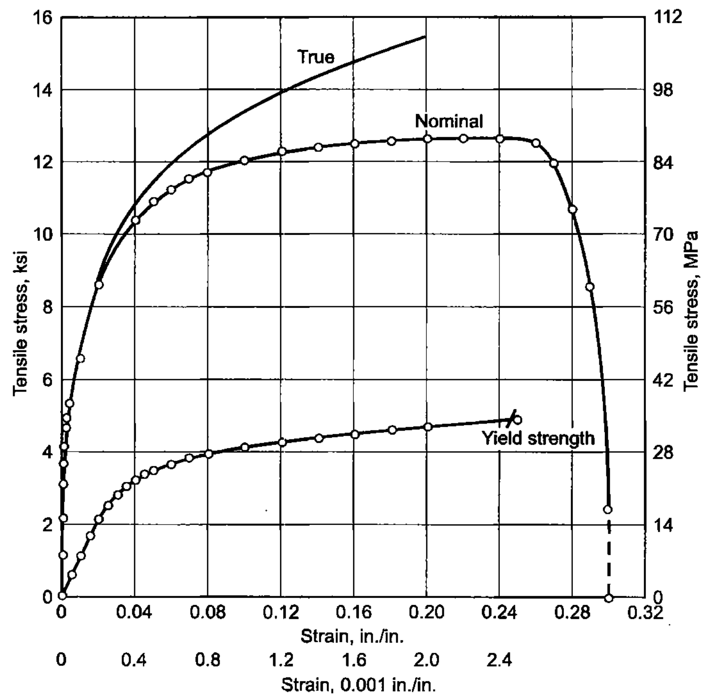
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, July 1954



WA.004 1060-H18 aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 119 MPa (17.2 ksi). True tensile strength, 121 MPa (17.5 ksi). Nominal yield strength (0.2% offset), 108 MPa (15.6 ksi). Elongation (in 50.8 mm, or 2 in.), 6.7%. Reduction of area, 79%. True strain at maximum load, 2.0%. A log-log plot of the stress-strain curve would yield a slope (n) of 0.02 in the area of uniform plastic deformation. UNS A91060

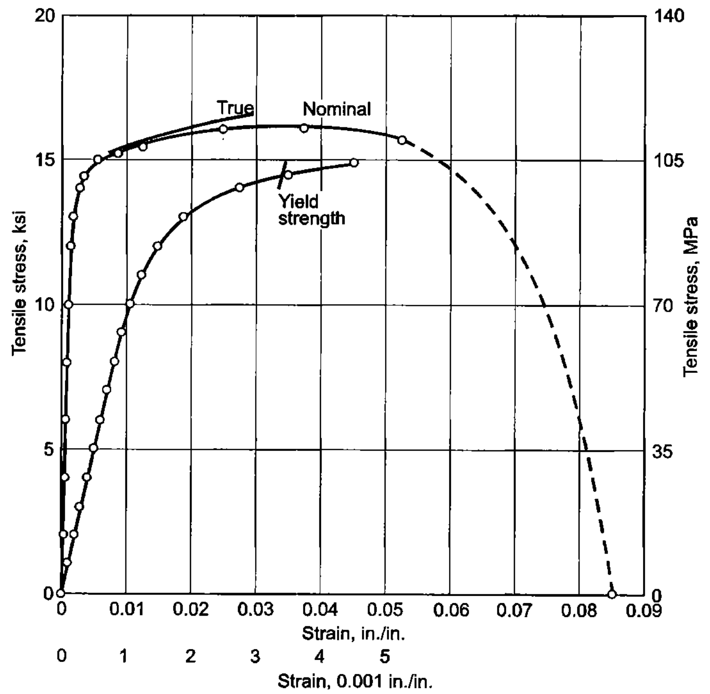
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, July 1954



WA.005 1100-O aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 84.8 MPa (12.3 ksi). True tensile strength, 103 MPa (15.0 ksi). Nominal yield strength (0.2% offset), 33 MPa (4.8 ksi). Elongation (in 50.8 mm, or 2 in.), 30.0%. Reduction of area, 88%. True strain at maximum load, 20.0%. A log-log plot of the stress-strain curve would yield a slope (n) of 0.22 in the area of uniform plastic deformation.
UNS A91100

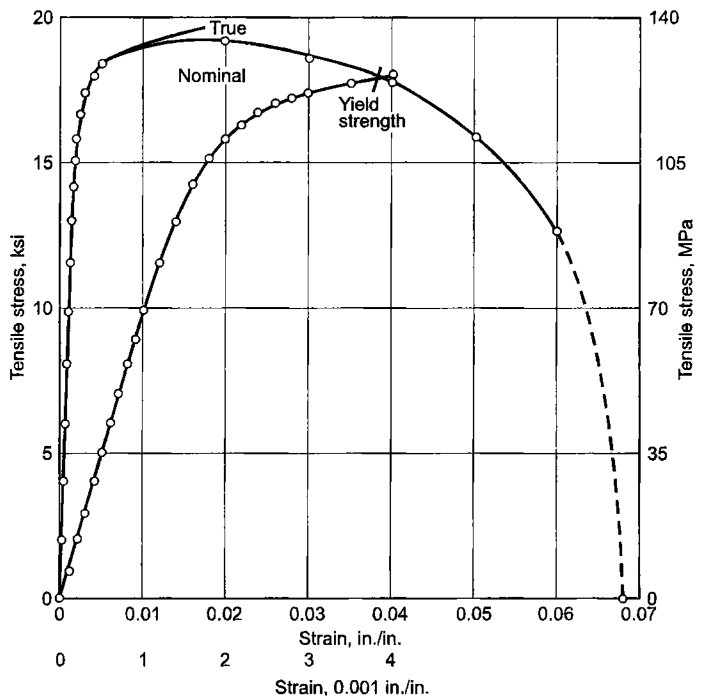
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, July 1954



WA.006 1100-H12 aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 111 MPa (16.1 ksi). True tensile strength, 108 MPa (15.7 ksi). Nominal yield strength (0.2% offset), 99.3 MPa (14.4 ksi). Elongation (in 50.8 mm, or 2 in.), 8.5%. Reduction of area, 76%. True strain at maximum load, 3.4%. A log-log plot of the stress-strain curve would yield a slope (n) of 0.05 in the area of uniform plastic deformation.
UNS A91100

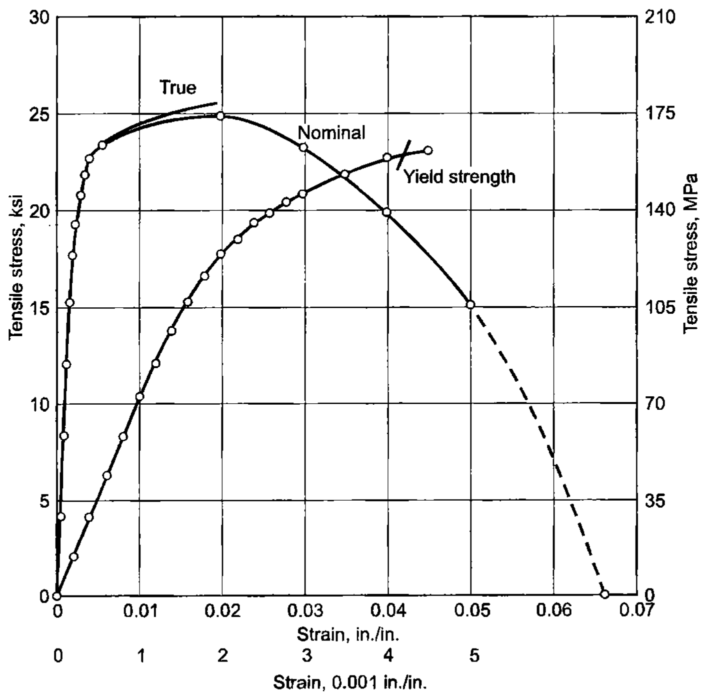
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, July 1954



WA.007 1100-H16 aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 132 MPa (19.2 ksi). True tensile strength, 135 MPa (19.6 ksi). Nominal yield strength (0.2% offset), 122.7 MPa (17.8 ksi). Elongation (in 50.8 mm, or 2 in.), 6.8%. Reduction of area, 79%. True strain at maximum load, 1.7%. A log-log plot of the stress-strain curve would yield a slope (*n*) of 0.02 in the area of uniform plastic deformation. UNS A91100

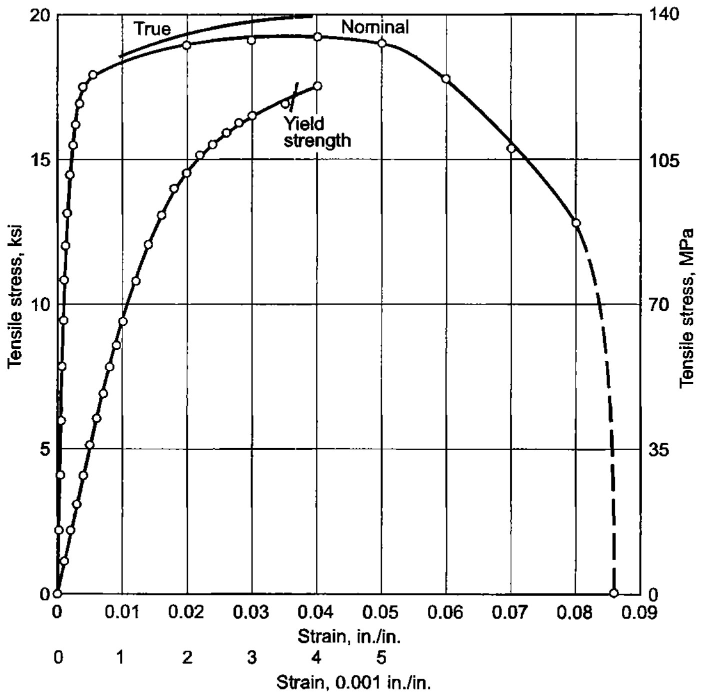
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, July 1954



WA.008 1100-H18 aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 171 MPa (24.8 ksi). True tensile strength, 175 MPa (25.4 ksi). Nominal yield strength (0.2% offset), 157 MPa (22.8 ksi). Elongation (in 50.8 mm, or 2 in.), 6.6%. Reduction of area, 72%. True strain at maximum load, 2.0%. A log-log plot of the stress-strain curve would yield a slope (*n*) of 0.06 in the area of uniform plastic deformation.
UNS A91100

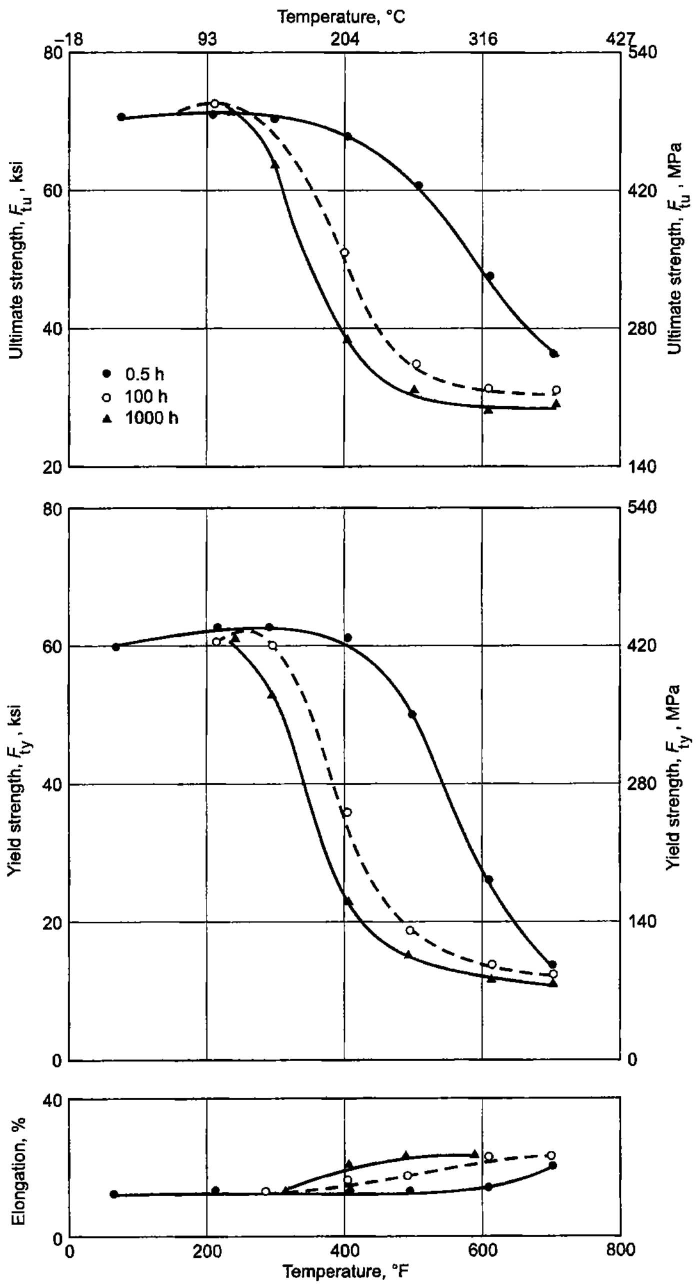
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, July 1954



WA.009 1100-H26 aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 125 MPa (18.2 ksi). True tensile strength, 138 MPa (20.0 ksi). Nominal yield strength (0.2% offset), 119 MPa (17.2 ksi). Elongation (in 50.8 mm, or 2 in.), 8.6%. Reduction of area, 78%. True strain at maximum load, 3.9%. A log-log plot of the stress-strain curve would yield a slope (n) of 0.06 in the area of uniform plastic deformation.
UNS A91100

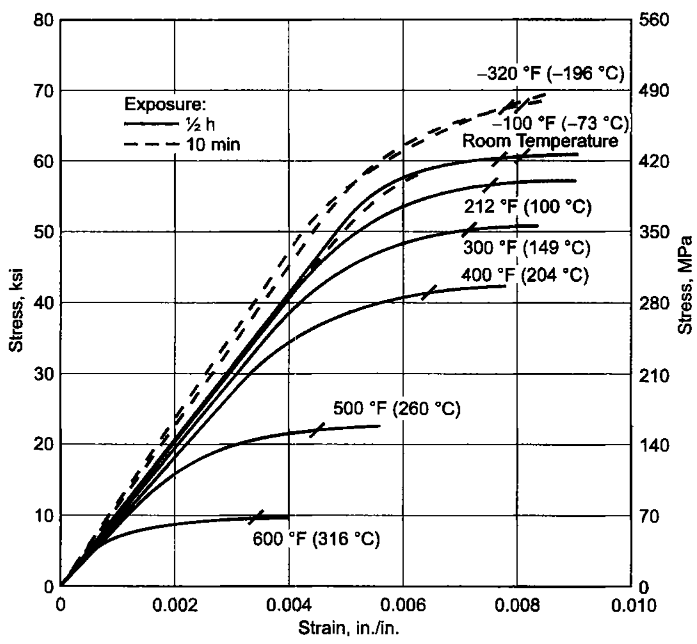
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, July 1954



WA.010 2014-T6 aluminum alloy, clad 2014-T6, room-temperature tensile properties

Effect of exposure to elevated temperature. Composition: Al-4.5Cu-1Mn-1Si-0.5Mg. UNS A92014

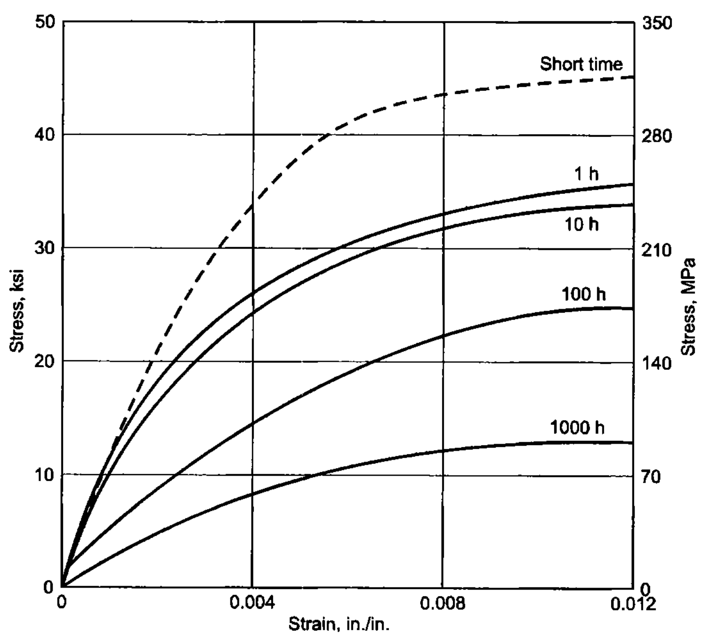
Source: Metallic Materials & Elements for Flight Vehicle Structures, *MIL-HDBK-5,* Dept. of Defense, FSC 1500, Aug 1962. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3201, CINDAS/ Purdue University, 1995, p 19



WA.011 2014-T6 aluminum alloy, clad 2014-T6, bar, tensile stress-strain curves

Tested at various temperatures. Bar diameter: 19.05 mm (0.75 in.). Composition: Al-4.5Cu-1Mn-1Si-0.5Mg. UNS A92014

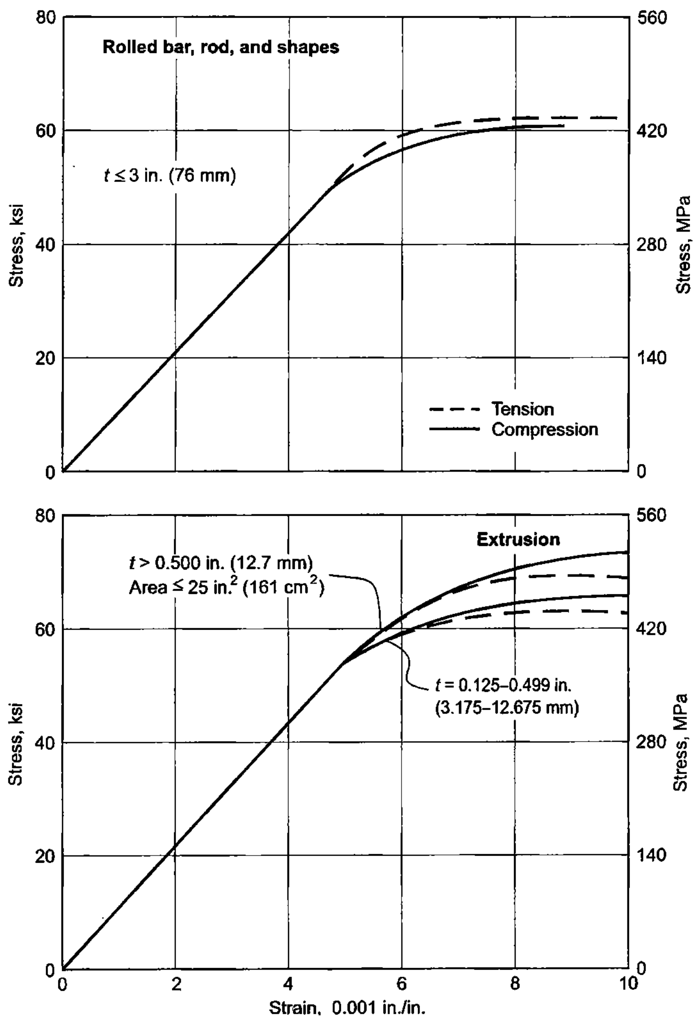
Source: "Phase II—Cryogenic Properties of 2014-T6 and A-286," Bell Aerosystems Co., BLR61-35(M) Rev. A, 29 June 1962. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3201, CINDAS/Purdue University, 1995, p 19



WA.012 2014-T6 aluminum alloy, clad 2014-T6, isochronous tensile stress-strain curves

Tested at 205 °C (400 °F). Composition: Al-4.5Cu-1Mn-1Si-0.5Mg. UNS A92014

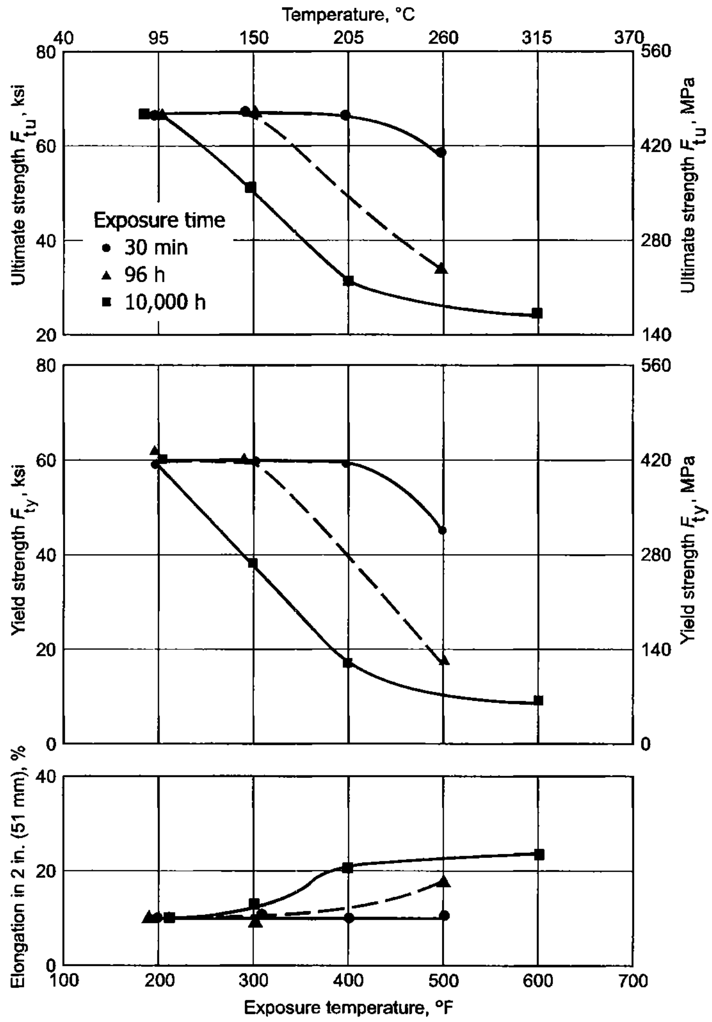
Source: F.M. Howell and G.W. Stickley, "Isochronous Stress-Strain Curves for Several Heat-Treated Wrought Aluminum Alloys at 300 and 400 F," Alcoa Research Laboratories, 29 April 1958. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3201, CINDAS/Purdue University, 1995, p 25



WA.013 2014-T6 aluminum alloy, clad 2014-T6, rolled bar, rod, and extrusions, tensile and compressive stress-strain curves

t, thickness. Composition: Al-4.5Cu-1Mn-1Si-0.5Mg. UNS A92014

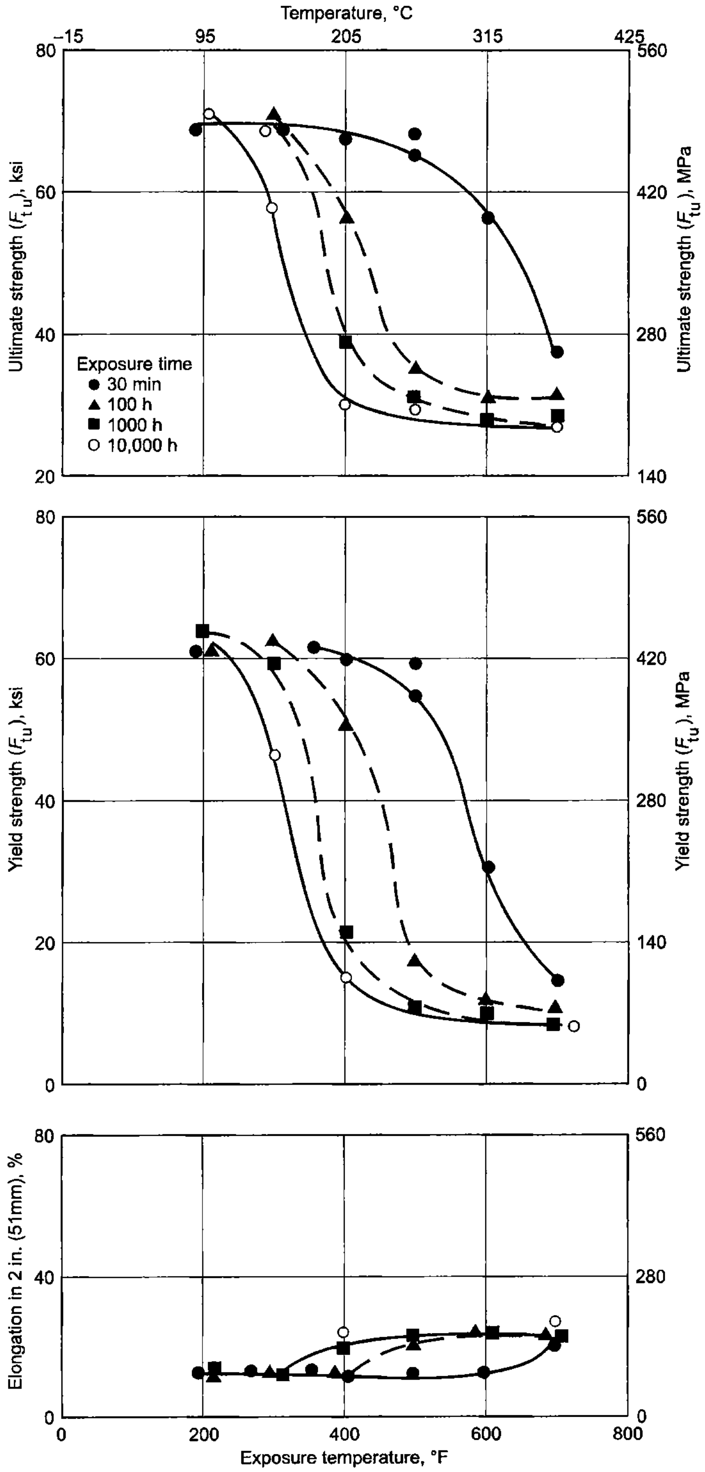
Source: Metallic Materials & Elements for Flight Vehicle Structures, *MIL-HDBK-5*, Dept of Defense, FSC 1500, Aug 1962. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3201, CINDAS/ Purdue University, 1995, p 18



WA.014 2014-T6 aluminum alloy, clad 2014-T6, rolled and drawn rod, effect of exposure to elevated temperature on tensile properties

Tested at room temperature. Composition: Al-4.5Cu-1Mn-1Si-0.5Mg. UNS A92014

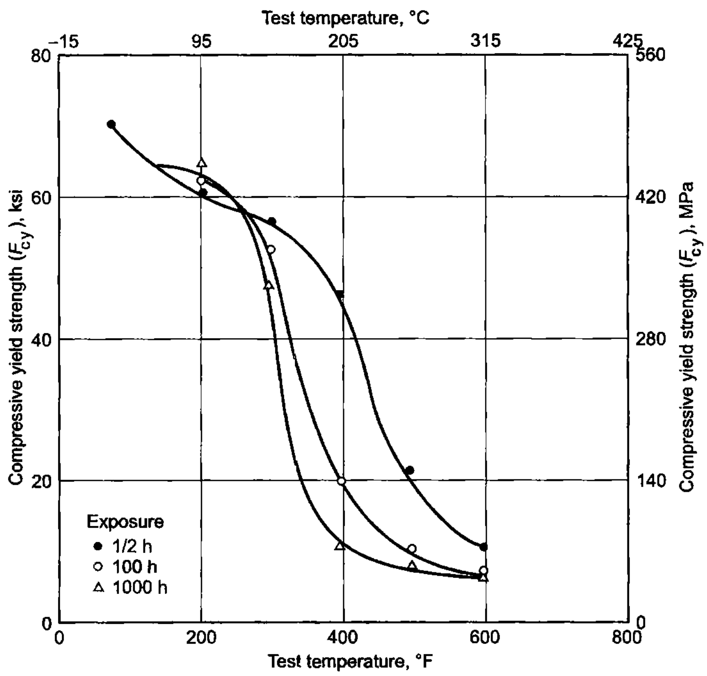
Source: *Report on the Elevated Temperature Properties of Aluminum and Magnesium Alloy,* STP 291, ASTM, Oct 1960. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3201, CINDAS/ Purdue University, 1995, p 22



WA.015 2014-T6 aluminum alloy, clad 2014-T6, forged rod, effect of exposure to elevated temperature on tensile properties

Tested at room temperature. Composition: Al-4.5Cu-1Mn-1Si-0.5Mg. UNS A92014

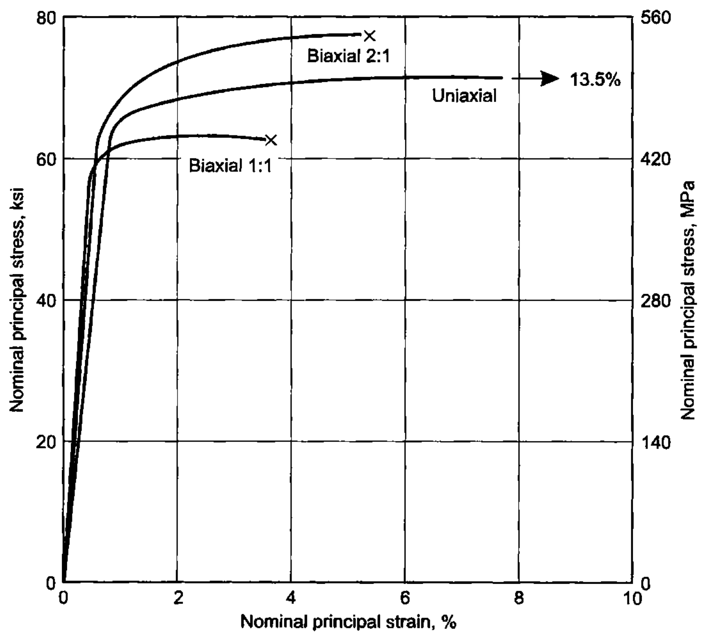
Source: *Report on the Elevated Temperature Properties of Aluminum and Magnesium Alloy,* STP 291, ASTM, Oct 1960. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3201, CINDAS/Purdue University, 1995, p 22



WA.016 2014-T6 aluminum alloy, clad 2014-T6, sheet, effect of exposure and test temperature on compressive yield strength

Thickness: 1.626 mm (0.064 in.). Composition: Al-4.5Cu-1Mn-1Si-0.5Mg. UNS A92014

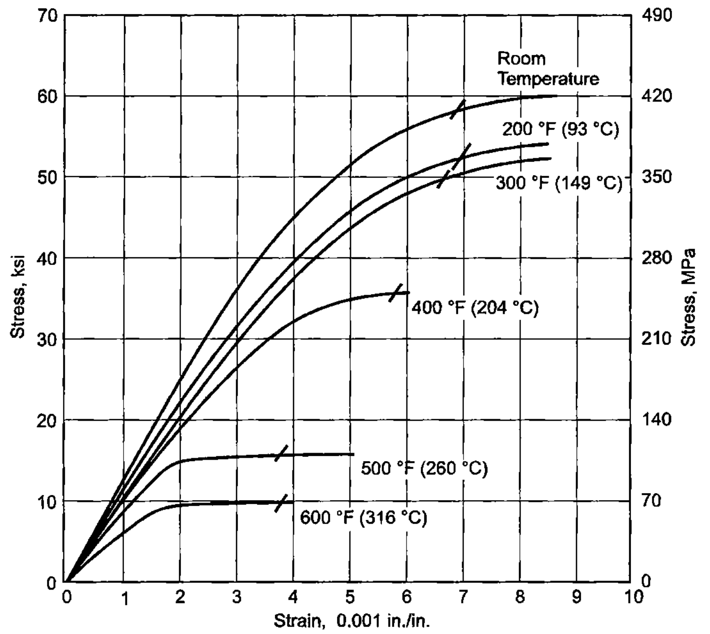
Source: D.E. Miller, "Determining Physical Properties of Ferrous and Non-Ferrous Structural Sheet Materials at Elevated Temperatures," AFTR 6517, Pt 3, Dec 1953. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3201, CINDAS/Purdue University, 1995, p 22



WA.017 2014-T6 aluminum alloy, clad 2014-T6, sheet, uniaxial and biaxial stress-strain curves

Test direction: longitudinal. Typical for sheet thickness 3.18 mm (0.125 in.). Composition: Al-4.5Cu-1Mn-1Si-0.5Mg. UNS A92014

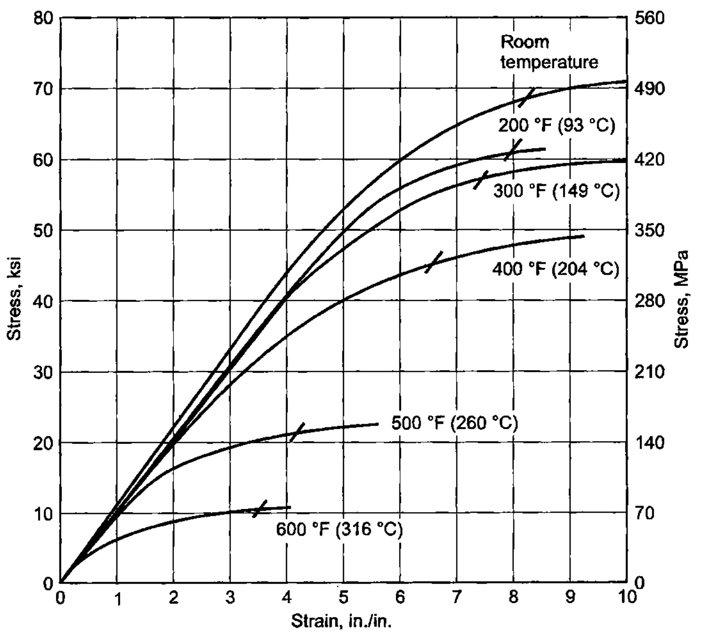
Source: E.L. Terry and S.W. McClaren, "Biaxial Stress and Strain Data on High Strength Alloys for Design of Pressurized Components," ASD-TDR-62-401, Chance-Vought Corp., 1962. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3201, CINDAS/Purdue University, 1995, p 18



WA.018 2014-T6 aluminum alloy, clad 2014-T6, sheet, tensile stress-strain curves

Tested at room and elevated temperatures. Sheet thickness: 1.626 mm (0.064 in.). Composition: Al-4.5Cu-1Mn-1Si-0.5Mg. UNS A92014

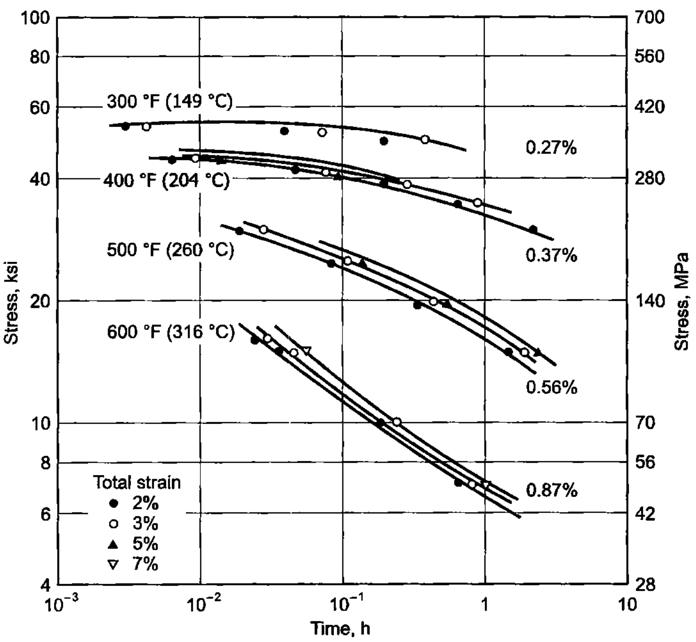
Source: D.E. Miller, "Determining Physical Properties of Ferrous and Non-Ferrous Structural Sheet Materials at Elevated Temperatures," AFTR 6517, Pt 3, Dec 1953. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3201, CINDAS/Purdue University, 1995, p 19



WA.019 2014-T6 aluminum alloy, clad 2014-T6, sheet, compressive stress-strain curves

Tested at room and elevated temperatures (1/2 hour at temperature). Sheet thickness: 1.626 mm (0.064 in.). Composition: Al-4.5Cu-1Mn-1Si-0.5Mg. UNS A92014

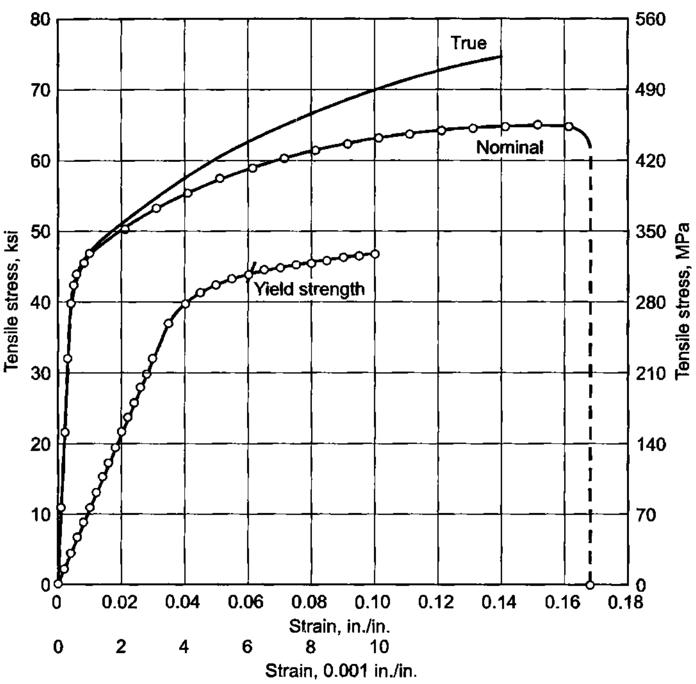
Source: D.E. Miller, "Determining Physical Properties of Ferrous and Non-Ferrous Structural Sheet Materials at Elevated Temperatures," AFTR 6517, Pt 3, Dec 1953. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3201, CINDAS/Purdue University, 1995, p 22



WA.020 2014-T6 aluminum alloy, clad 2014-T6, sheet, short-time total strain curves

Tested at 150–315 °C (300–600 °F). Thermal expansion included. Sheet thickness: 1.016 mm (0.040 in.). Composition: Al-4.5Cu-1Mn-1Si-0.5Mg. UNS A92014

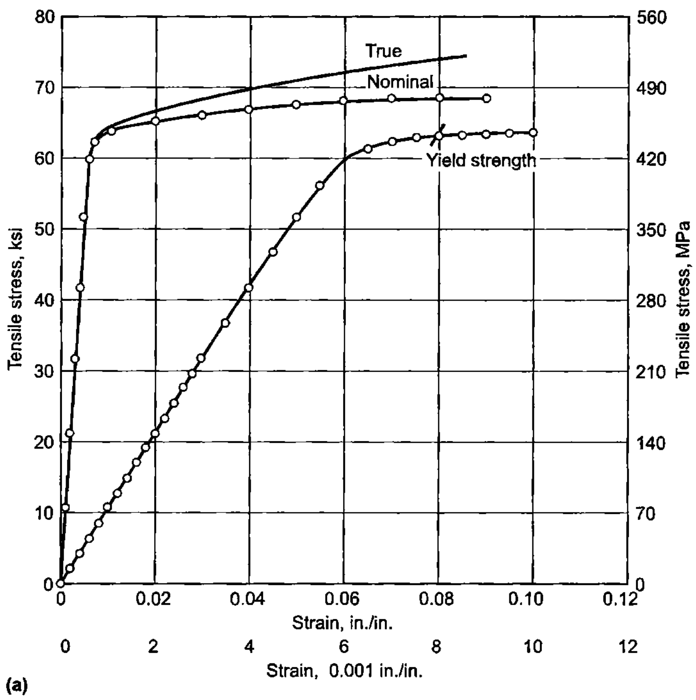
J.A. Van Echo, W.F. Wirth, and W.F. Simmons, "Short-Time Creep Properties of Structural Sheet Materials for Aircraft & Missiles," AFTR 6731, Pt III, May 1955. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3201, CINDAS/Purdue University, 1995, p 25



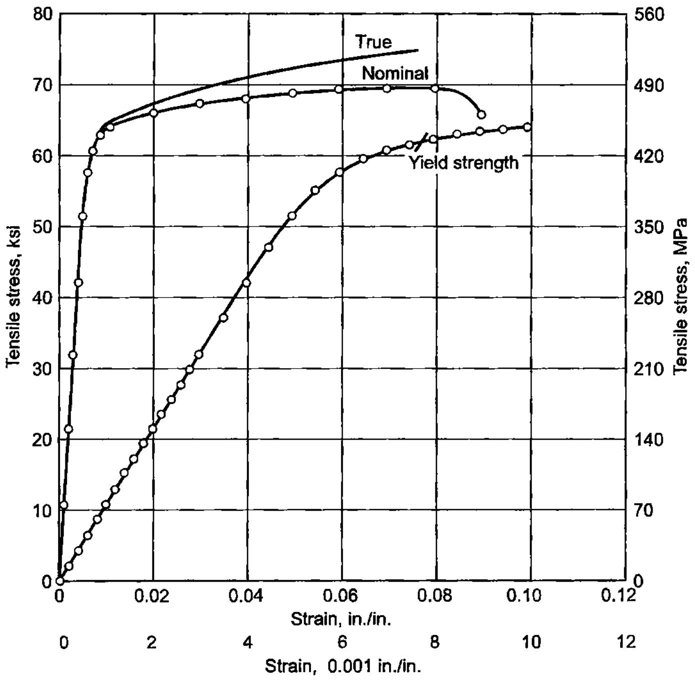
WA.021 2014-T4 aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test specimen diam, 19.05 mm (0.75 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 448 MPa (65.0 ksi). True tensile strength, 517 MPa (75.0 ksi). Nominal yield strength (0.2% offset), 302 MPa (43.8 ksi). Elongation (in 50.8 mm, or 2 in.), 16.8%. Reduction of area, 32%. True strain at maximum load, 14.1%. A log-log plot of the stress-strain curve would yield a slope (n) of 0.21 in the area of uniform plastic deformation. UNS A92014

Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, June 1953



(a)

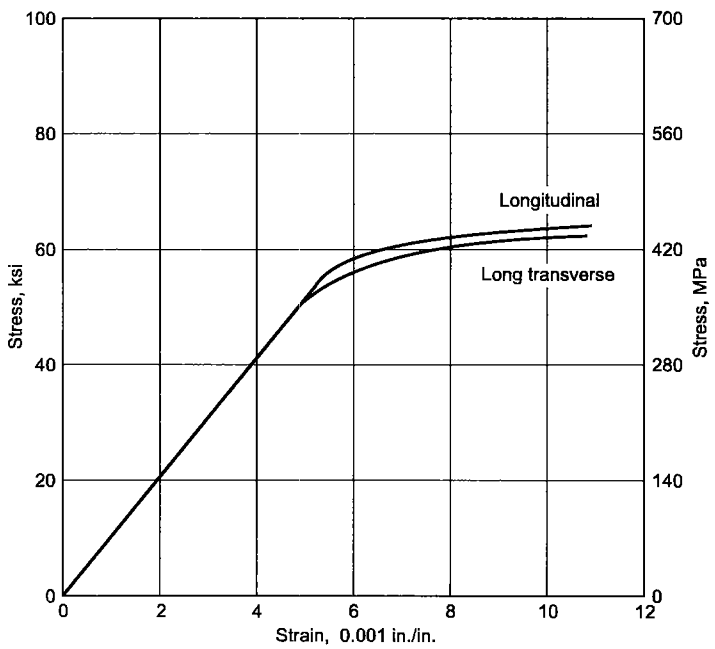


(b)

WA.022 2014-T6 aluminum alloy plate, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test direction: (a) longitudinal; (b) transverse. Test specimen thickness, 15.9 mm (5/8 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 473 MPa (68.6 ksi). True tensile strength, 514 MPa (74.6 ksi). Nominal yield strength (0.2% offset), 436 MPa (63.2 ksi). Elongation (in 50.8 mm, or 2 in.), 9.0%. Reduction of area, 23%. True strain at maximum load, 8.6%. A log-log plot of the stress-strain curve would yield a slope (n) of 0.08 in the area of uniform plastic deformation. UNS A92014

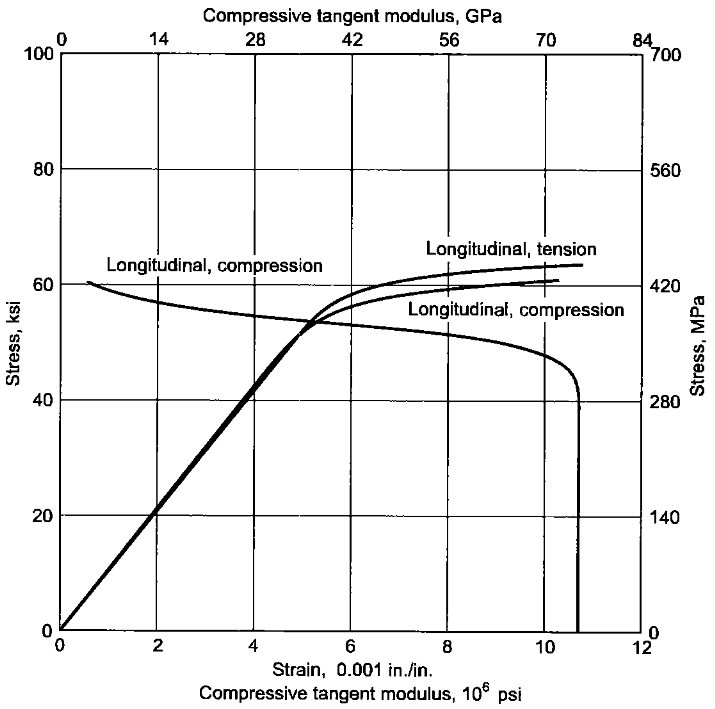
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, July 1954



WA.023 2014-T6 aluminum alloy, clad 2014-T6, sheet, tensile stress-strain curves

Tested at room temperature. Typical for sheet thickness 1.016–6.325 mm (0.040–0.249 in.). Ramberg-Osgood parameter: *n*(longitudinal, tension) = 27; *n*(long transverse, tension) = 20. UNS A92014

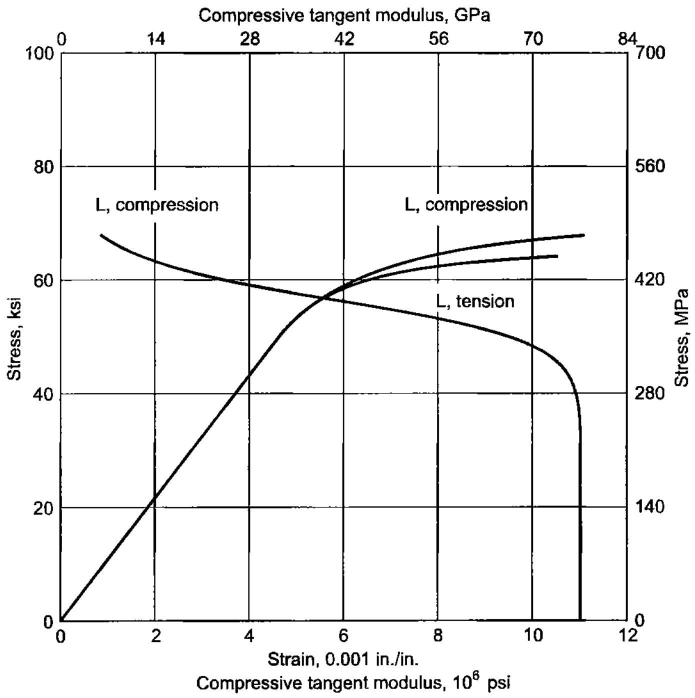
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.024 2014-T6 aluminum alloy rolled bar, rod, and shapes, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal. Typical for thickness ≤76.20 mm (≤3.000 in.). Ramberg-Osgood parameter: *n*(L, tension) = 31; *n*(L, compression) = 25. UNS A92014

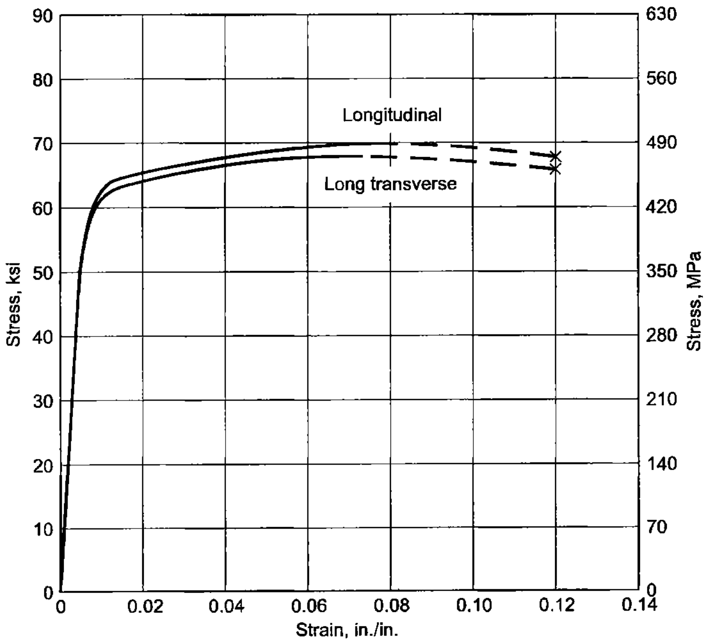
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.025 2014-T6 aluminum alloy extrusion, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal. Typical for extrusion thickness 3.175–12.675 mm (0.125–0.499 in.). Ramberg-Osgood parameter: n(L, tension) = 23; n(L, compression) = 15. UNS A92014

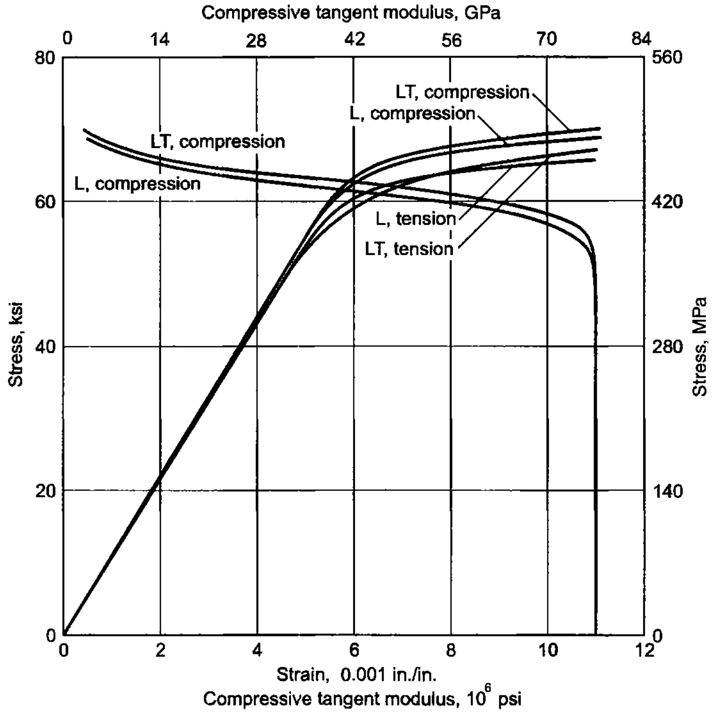
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.026 2014-T6 aluminum alloy forging, tensile stress-strain curves (full range)

Tested at room temperature. Typical. UNS A92014

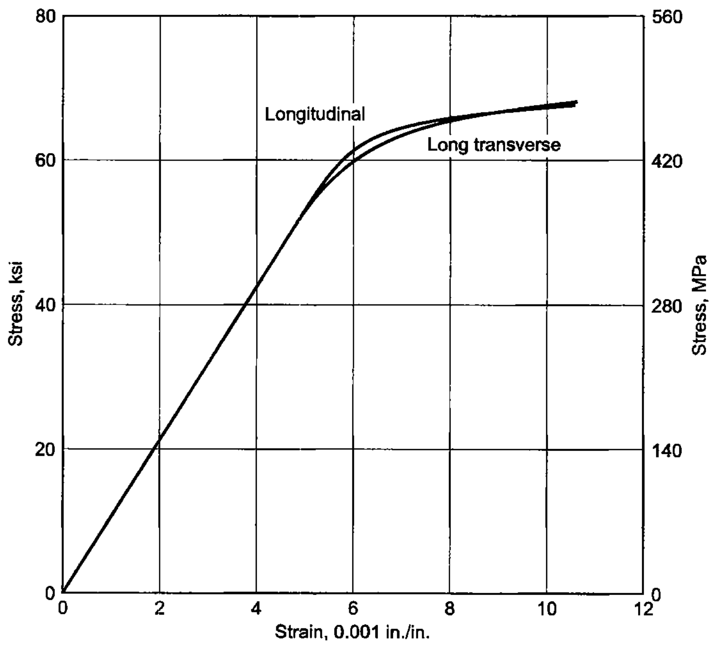
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.027 2014-T62 aluminum alloy extrusion, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for extrusion thickness ≤12.675 mm (≤0.499 in.). Ramberg-Osgood parameter: n(L, tension) =29; n(LT, tension) = 17; n(L, compression) = 29; n(LT, compression) = 32. UNS A92014

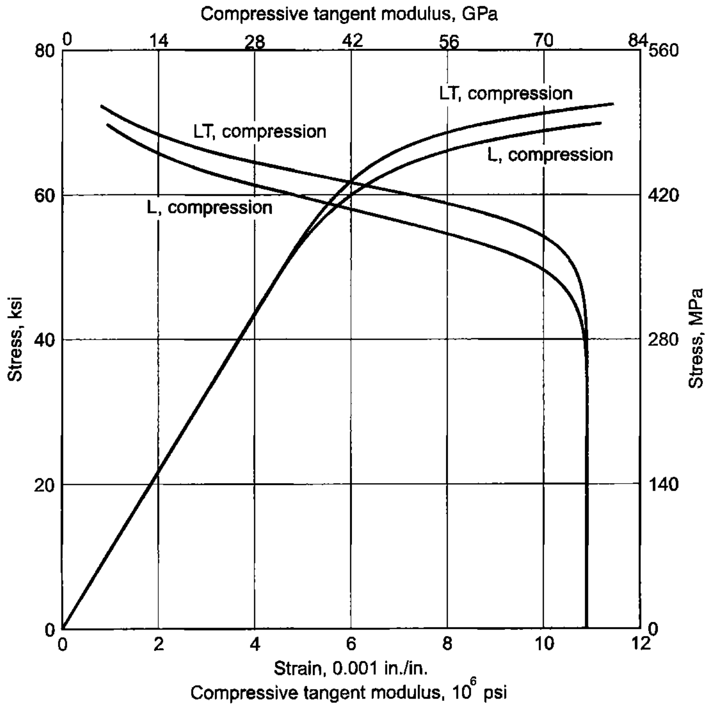
Source: *MIL-HDBK-5H*, 1 Dec 1998



WA.028 2014-T651 aluminum alloy plate, tensile stress-strain curves

Tested at room temperature. Typical for plate thickness 6.35–50.80 mm (0.250–2.000 in.). Ramberg-Osgood parameter: n(longitudinal, tension) = 30; n(long transverse, tension) = 19. UNS A92014

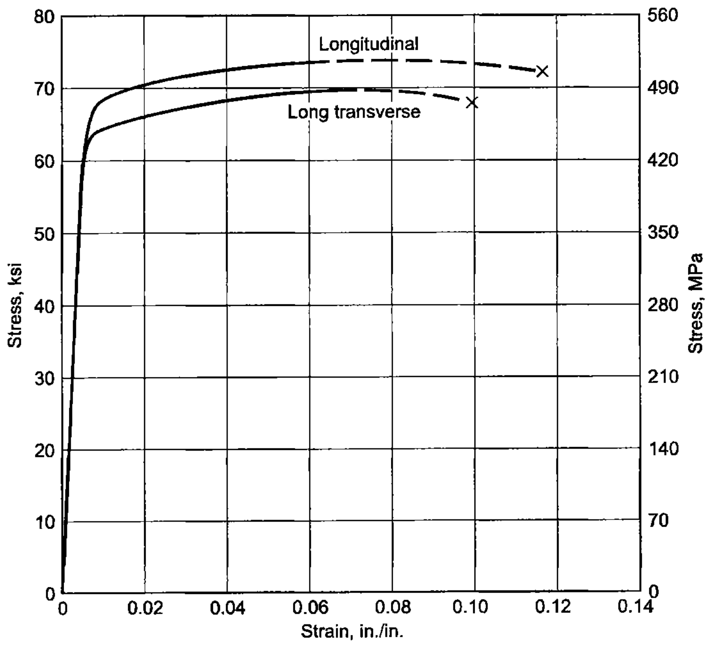
Source: MIL-HDBK-5H, 1 Dec 1998



WA.029 2014-T651 aluminum alloy plate, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for plate thickness 6.35–50.80 mm (0.250–2.000 in.). Ramberg-Osgood parameter: n(L, compression) = 15; n(LT, compression) = 18.
UNS A92014

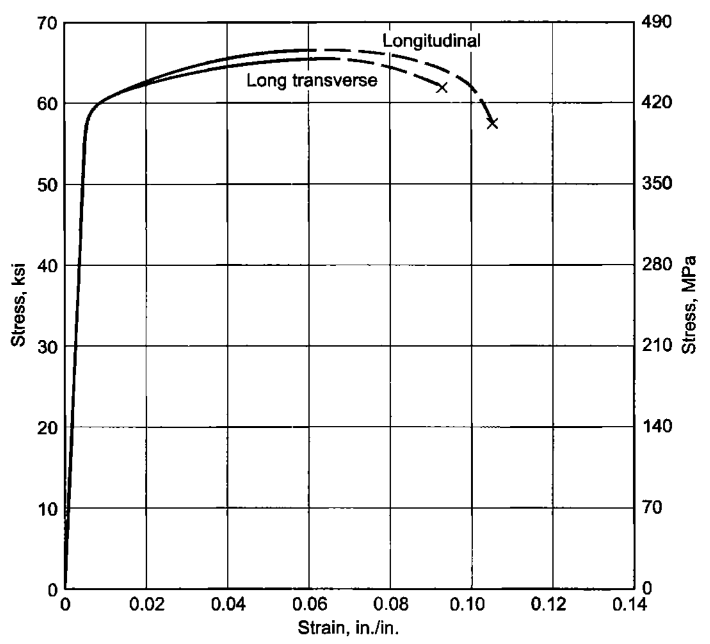
Source: *MIL-HDBK-5H*, 1 Dec 1998



WA.030 2014-T651X aluminum alloy extrusion, tensile stress-strain curve (full range)

Tested at room temperature. Typical for extrusion thickness 12.70–19.025 mm (0.500–0.749 in.). UNS A92014

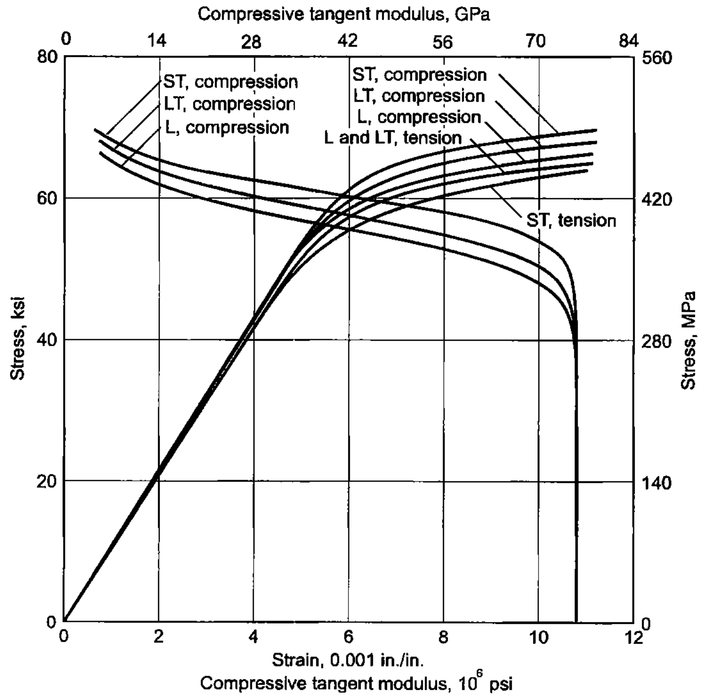
Source: *MIL-HDBK-5H*, 1 Dec 1998



WA.031 2014-T652 aluminum alloy forging, tensile stress-strain curves (full range)

Tested at room temperature. Typical. UNS A92014

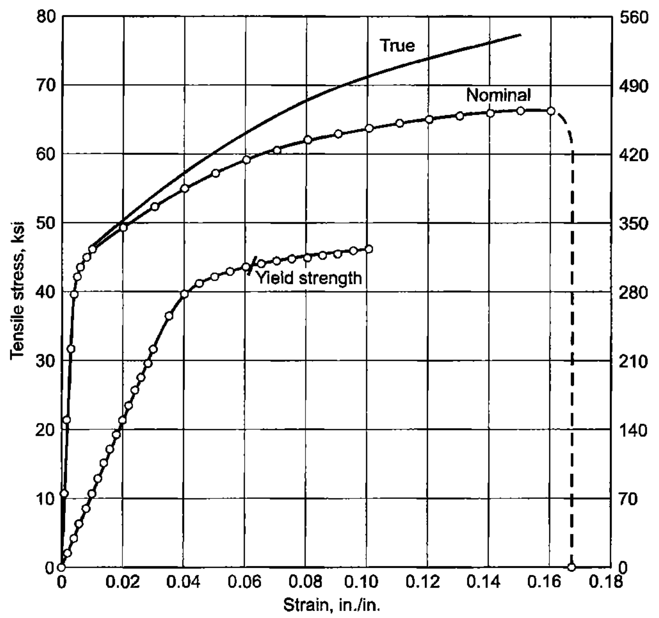
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.032 2014-T652 aluminum alloy hand forging, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse; ST, short transverse. Typical for forging thickness 50.825–76.20 mm (2.001–3.000 in.). Ramberg-Osgood parameter: *n*(L, tension) = 18; *n*(LT, tension) = 18; *n*(ST, tension) = 13; *n*(L, compression) = 17; *n*(LT, compression) = 18; *n*(ST, compression) = 22. UNS A92014

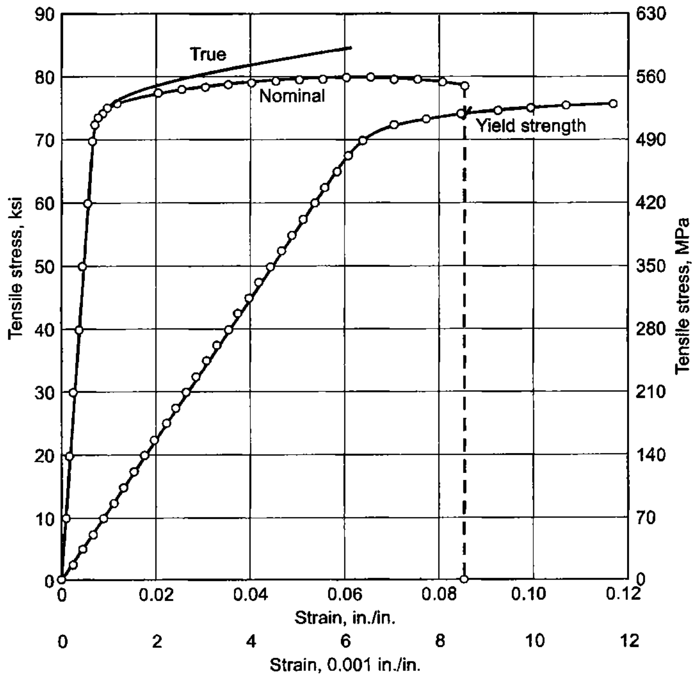
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.033 2017-T4 aluminum alloy rolled and drawn rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 459 MPa (66.5 ksi). True tensile strength, 514 MPa (74.5 ksi). Nominal yield strength (0.2% offset), 302 MPa (43.8 ksi). Elongation (in 50.8 mm, or 2 in.), 16.7%. Reduction of area, 38%. True strain at maximum load, 14.8%. UNS A92017

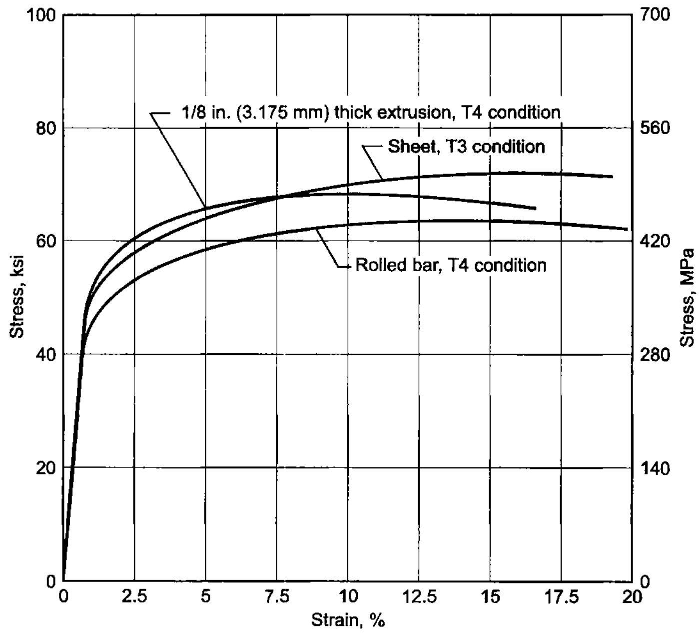
Alcoa, Aluminum Research Laboratory, New Kensington, PA



WA.034 X2020-T6 aluminum alloy extruded bar, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. Test specimen diam, 12.7 mm (0.500 in.). Gage length: 50.8 mm (2 in.). Nominal tensile strength, 552 MPa (80.0 ksi). True tensile strength, 586 MPa (85.0 ksi). Nominal yield strength (0.2% offset), 514 MPa (74.5 ksi). Elongation (in 50.8 mm, or 2 in.), 8.5%. Reduction of area, 16%. True strain at maximum load, 6.0%. A log-log plot of the stress-strain curve would yield a slope (n) of 0.06 in the area of uniform plastic deformation.

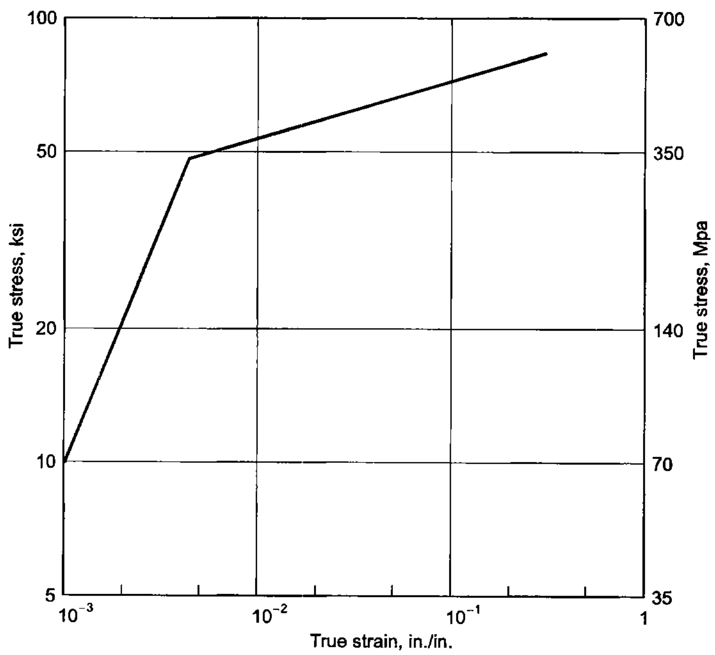
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA



WA.035 2024-T3 and 2024-T4 aluminum alloy, clad 2024, rolled bar, extrusion, and sheet, complete tensile stress-strain curves

Test direction: longitudinal. Composition: Al-4.5Cu-1.5Mg-0.6Mn. UNS A92024

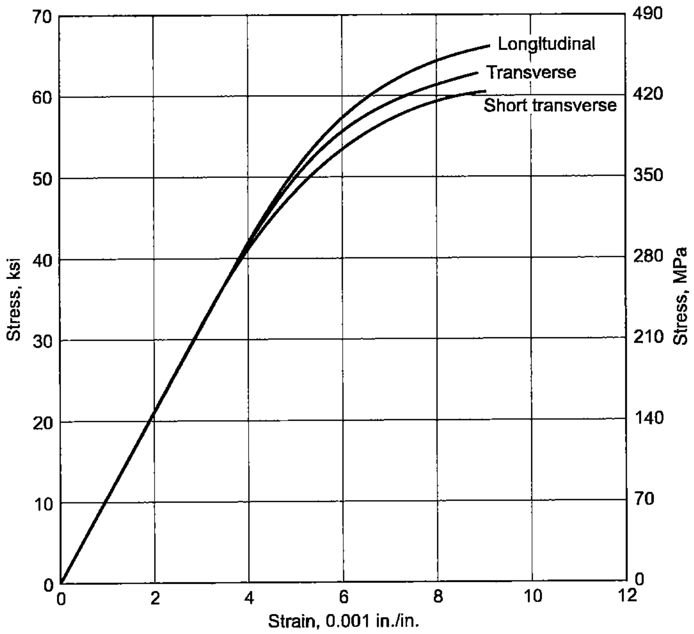
Source: A.J. McEvily, Jr., W. Illig, and H.F. Hardrath, "Static Strength of Aluminum-Alloy Specimens Containing Fatigue Cracks," NACA TN3816, Oct 1956. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3203, CINDAS/Purdue University, 1995, p 15



WA.036 2024-T3 aluminum alloy, true-stress, true-strain curves

Composition: Al-4.5Cu-1.5Mg-0.6Mn. UNS A92024

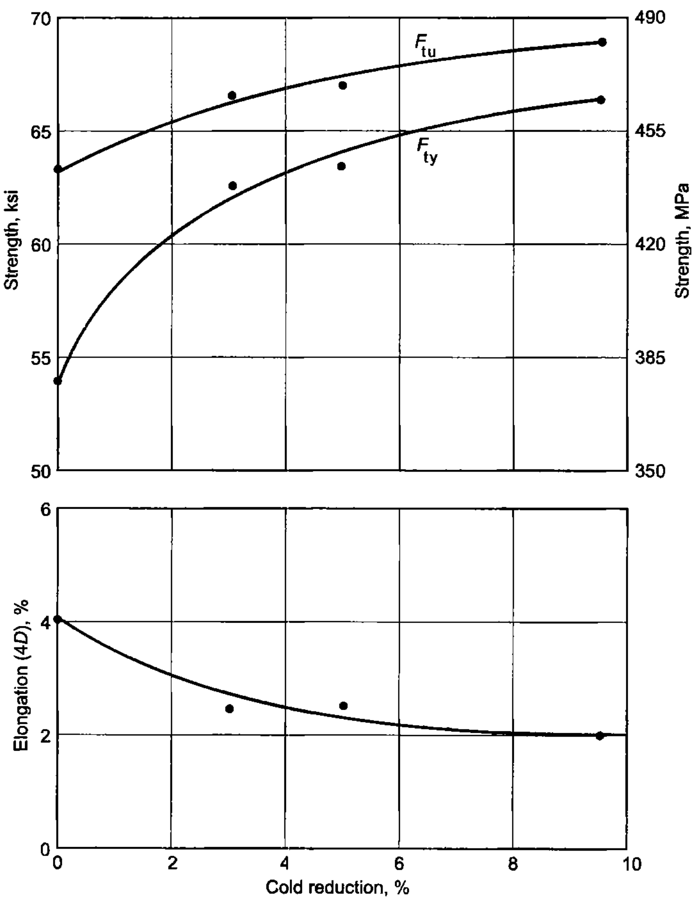
Source: G.W. Brown and R. Ikegami, The Fatigue of Aluminum Alloys Subjected to Random Loading, *Exp. Mech.,* Vol 10, Aug 1970, p 321–327. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3203, CINDAS/Purdue University, 1995, p 16



WA.037 2024-T852 aluminum alloy hand forgings, tensile stress-strain curves

Composition: Al-4.5Cu-1.5Mg-0.6Mn. UNS A92024

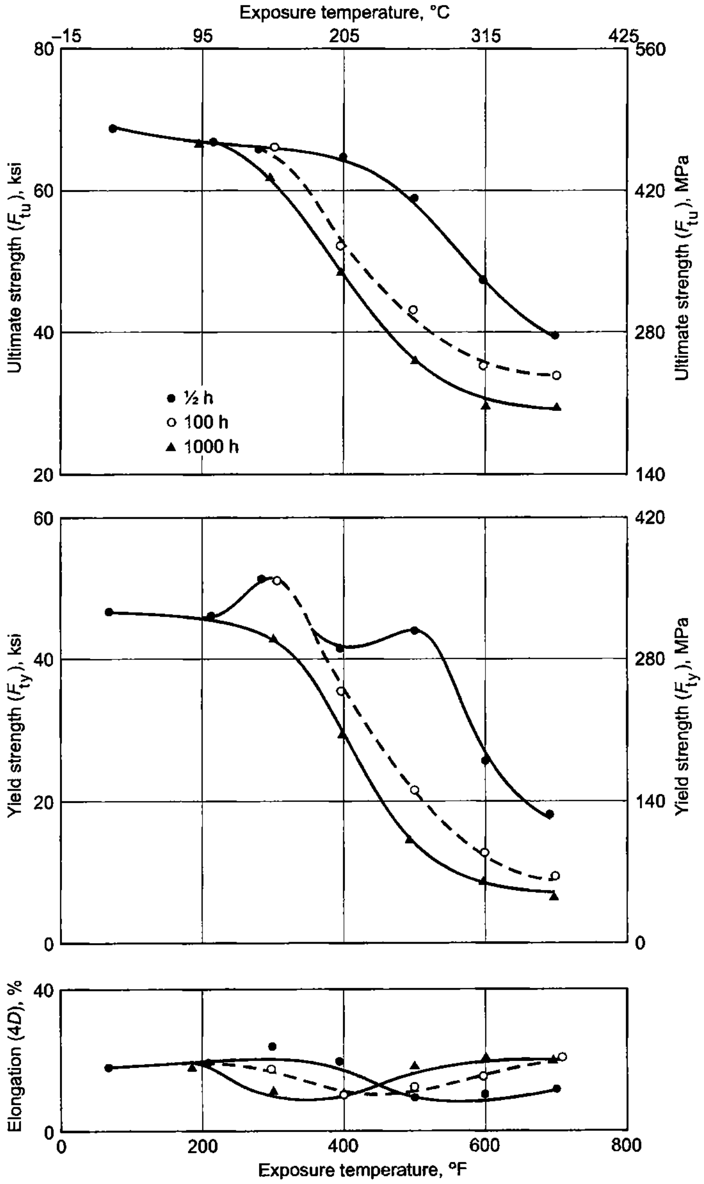
Source: D.J. Brownhill et al., "Mechanical Properties, Including Fracture Toughness and Fatigue, Corrosion Characteristics and Fatigue-Crack Propagation Rates of Stress-Relieved Aluminum Hand Forgings," AFML-TR-70-10, Alcoa Research Laboratories, Feb 1970. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3203, CINDAS/ Purdue University, 1995, p 16



WA.038 2024-T6 and 2024-T852 aluminum alloy forgings, effects of heat treatment on tensile properties

Test direction: short transverse. Composition: Al-4.5Cu-1.5Mg-0.6Mn. UNS A92024

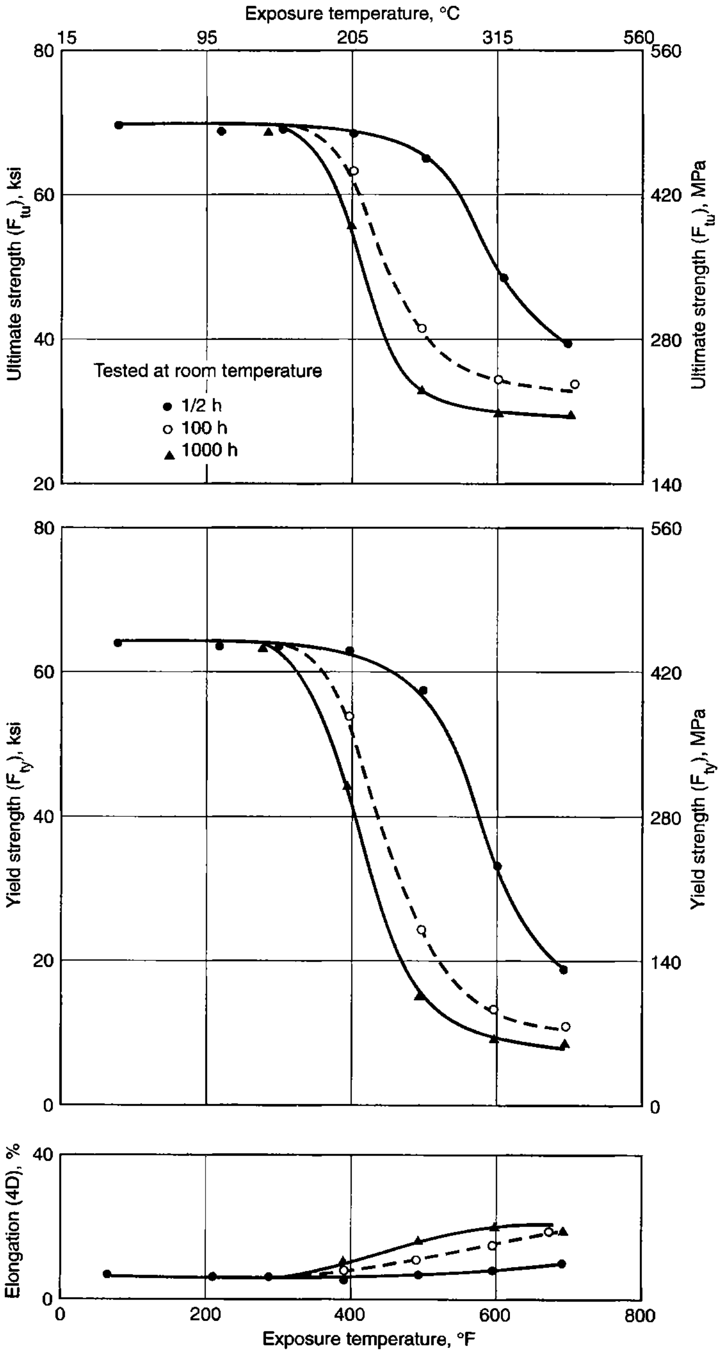
Source: J.H. Hull and S.J. Erwin, How Deformation Affects the Mechanical Properties of Aluminum Forgings, *Met. Eng. Quart.*, Vol 12, Nov 1972, p 1–6. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3203, CINDAS/Purdue University, 1995, p 16



WA.039 2024-T4 aluminum alloy, effects of exposure to elevated temperature on tensile properties

Tested at room temperature. Composition: Al-4.5Cu-1.6Mg-0.6Mn. UNS A92024

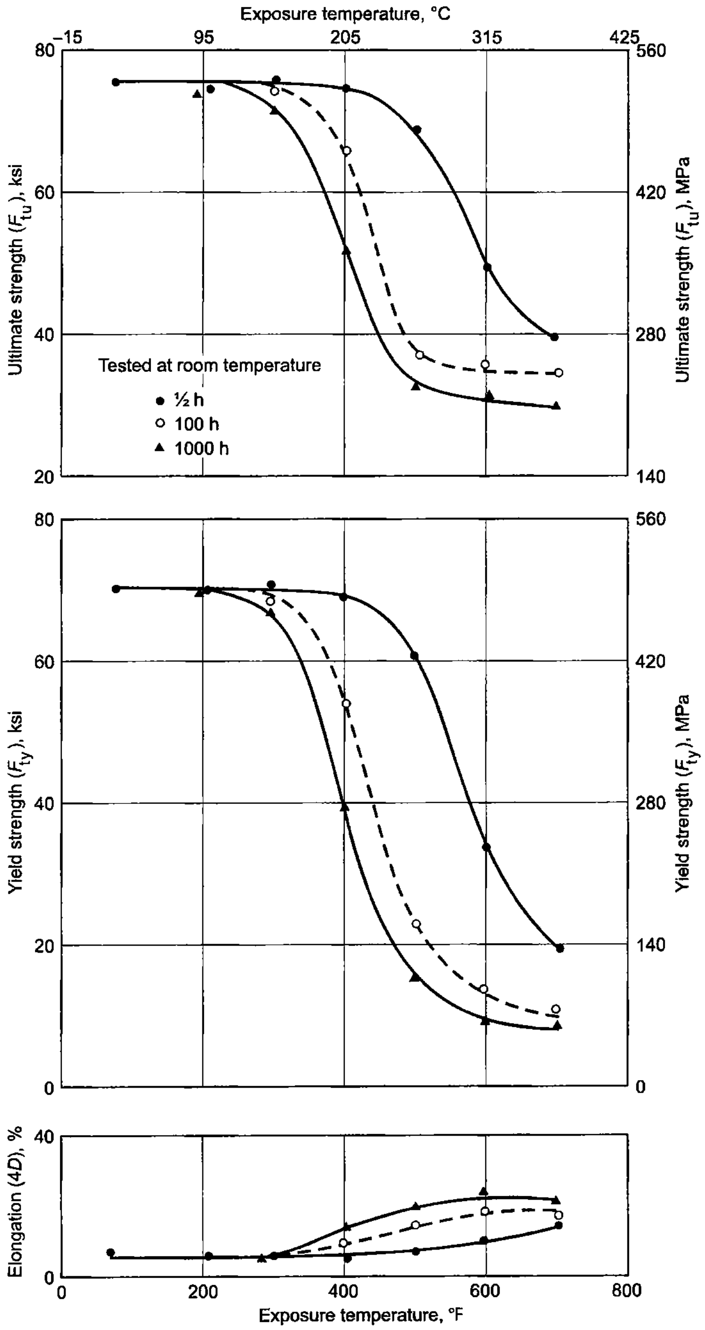
Source: "2024-T4 Products," Alcoa Research Laboratory Data Sheet, Sept 1957. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3203, CINDAS/Purdue University, 1995, p 16



WA.040 2024-T81 aluminum alloy, effects of exposure to elevated temperature on tensile properties

Tested at room temperature. Composition: Al-4.5Cu-1.5Mg-0.6Mn. UNS A92024

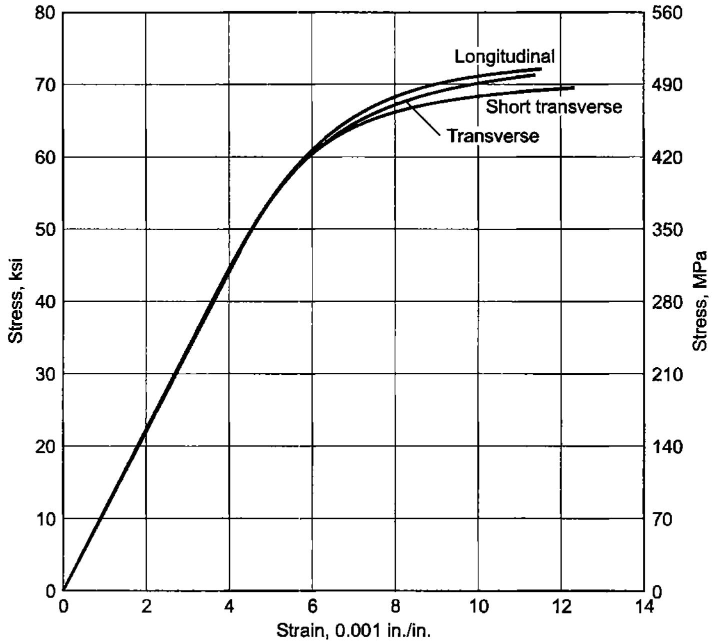
Source: "2024-T81," Alcoa Research Laboratory Data Sheet, July 1957. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3203, CINDAS/Purdue University, 1995, p 17



WA.041 2024-T86 aluminum alloy, effects of exposure to elevated temperature on tensile properties

Tested at room temperature. Composition: Al-4.5Cu-1.5Mg-0.6Mn. UNS A92024

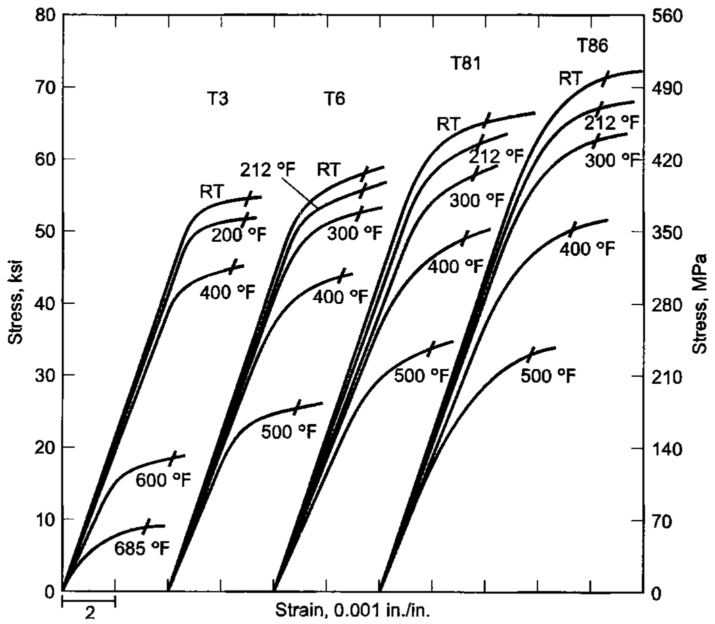
Source: "2024-T86," Alcoa Research Laboratory Data Sheet, July 1957. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3203, CINDAS/Purdue University, 1995, p 17



WA.042 2024-T852 aluminum alloy hand forgings, compressive stress-strain curves

Composition: Al-4.5Cu-1.5Mg-0.6Mn. UNS A92024

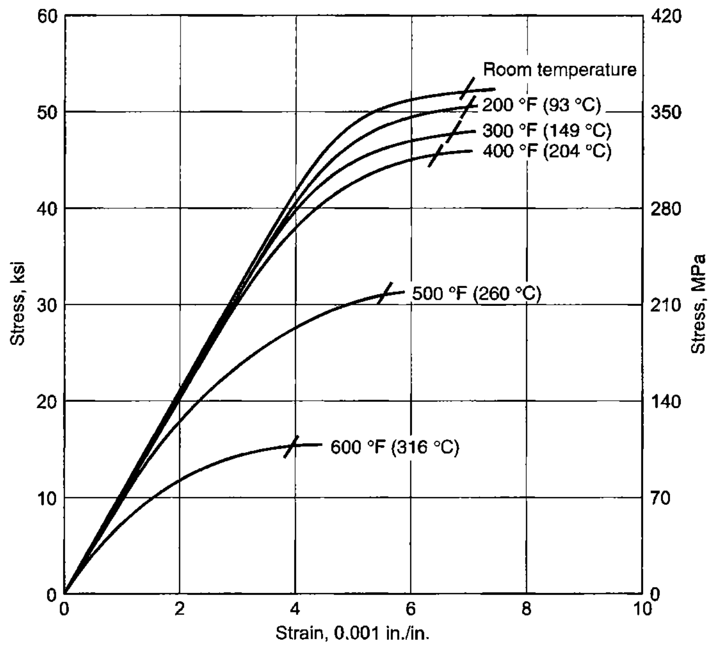
Source: D.J. Brownhill et al., "Mechanical Properties, Including Fracture Toughness and Fatigue, Corrosion Characteristics and Fatigue-Crack Propagation Rates of Stress-Relieved Aluminum Hand Forgings," AFML-TR-70-10, Alcoa Research Laboratories, Feb 1970. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3203, CINDAS/ Purdue University, 1995, p 17



WA.043 2024-T3, 2024-T6, 2024-T81, and 2024-T86 aluminum alloy sheet and plate, tensile stress-strain curves

Tested at various temperatures; 30 min exposure. RT, room temperature; 93 °C (200 °F); 100 °C (212 °F); 150 °C (300 °F); 205 °C (400 °F); 260 °C (500 °F); 315 °C (600 °F); 363 °C (685 °F). Composition: Al-4.5Cu-1.5Mg-0.6Mn. UNS A92024

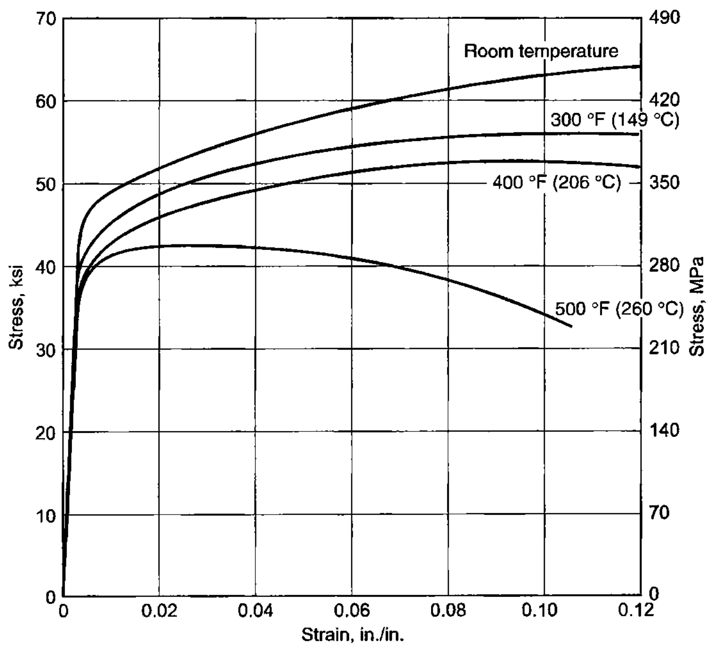
Source: "Tensile Stress-Strain Curves for 2024," Alcoa Research Laboratories Data Sheets, Oct and May 1957. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3203, CINDAS/ Purdue University, 1995, p 18



WA.044 2024-T4 aluminum alloy bar and extrusions, tensile stress-strain curves

Tested at various temperatures. Extrusion dimensions: 6.35 × 38.1 mm (0.25 × 1.5 in.). Composition: Al-4.5Cu-1.5Mg-0.6Mn. UNS A92024

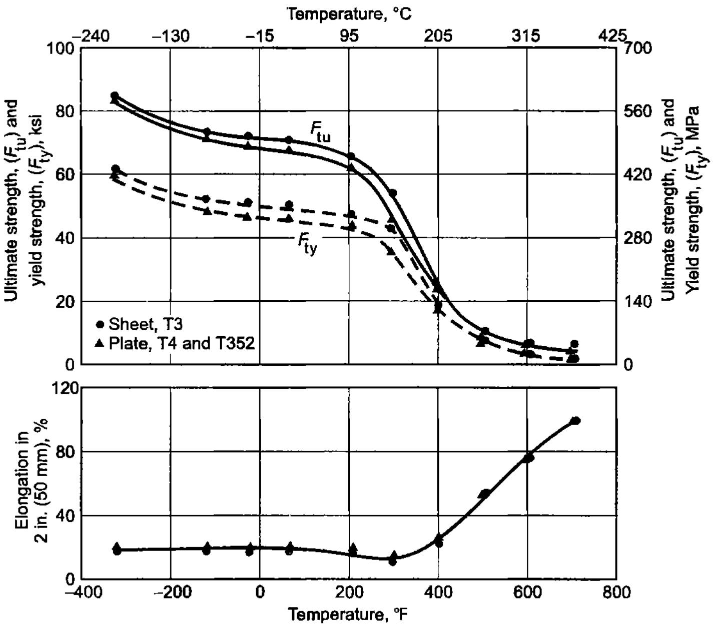
Source: S.A. Gordon, R. Simon, and W.P. Achbach, "Materials-Property-Design Criteria for Metals," WADC TR 55-150, Pt 4, Oct 1956. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3203, CINDAS/Purdue University, 1995, p 19



WA.045 2024-T4 aluminum alloy sheet, complete tensile stress-strain curves

Tested at various temperatures. Test direction: transverse. Thickness: 1.626 mm (0.064 in.). Composition: Al-4.5Cu-1.5Mg-0.6Mn. UNS A92024

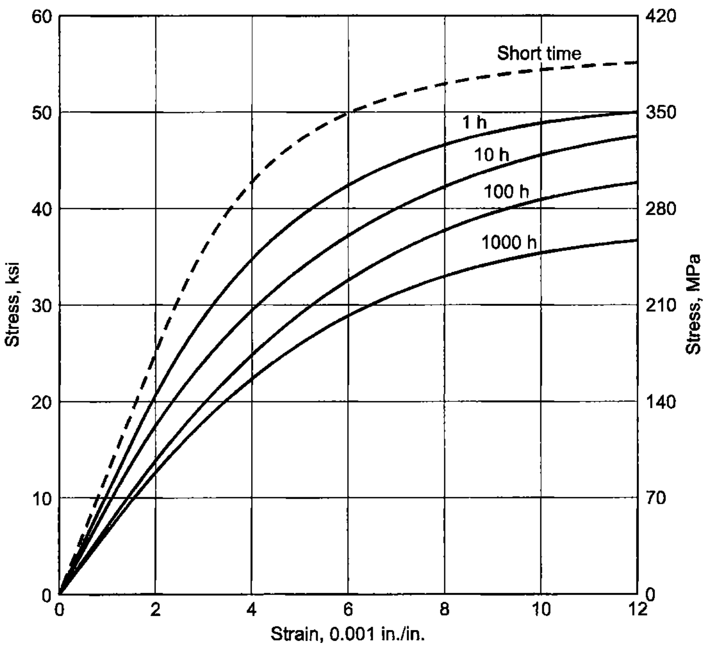
Source: "Correlation of Information Available on the Fabrication of Aluminum Alloys, Section IV," Case Institute Final Report to Nat. Def. Res. Comm., 15 Sept 1944. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3203, CINDAS/Purdue University, 1995, p 19

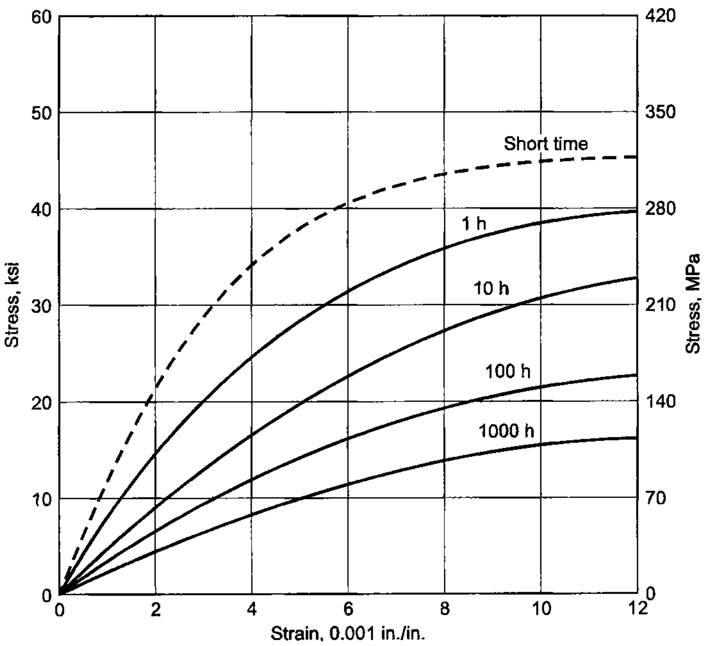


WA.046 2024-T3, 2024-T4, and 2024-T351 aluminum alloy sheet and plate, effects of temperature on tensile properties

Tested at −195 to 370 °C (−320 to 700 °F) after 10,000 h exposure. Composition: Al-4.5Cu-1.5Mg-1Mn. UNS A92024

Source: "Aluminum Standards and Data," The Aluminum Association, 6th ed., March 1979. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3203, CINDAS/Purdue University, 1995, p 19

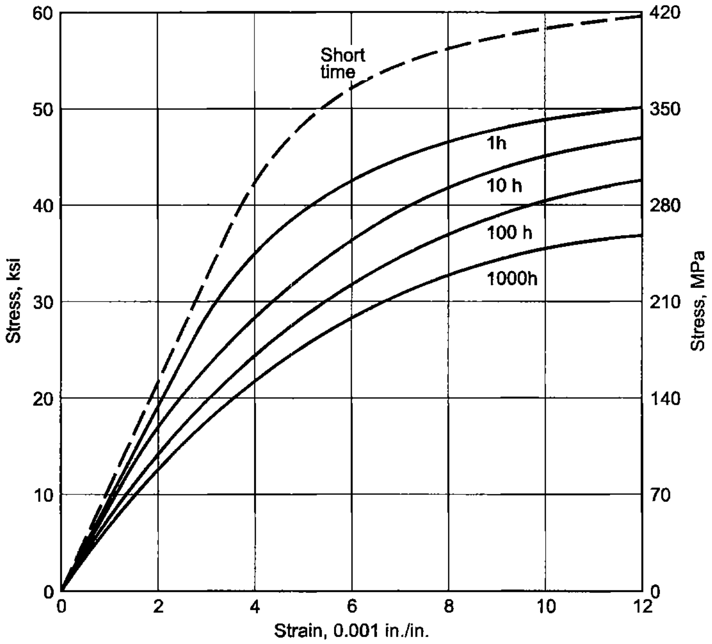


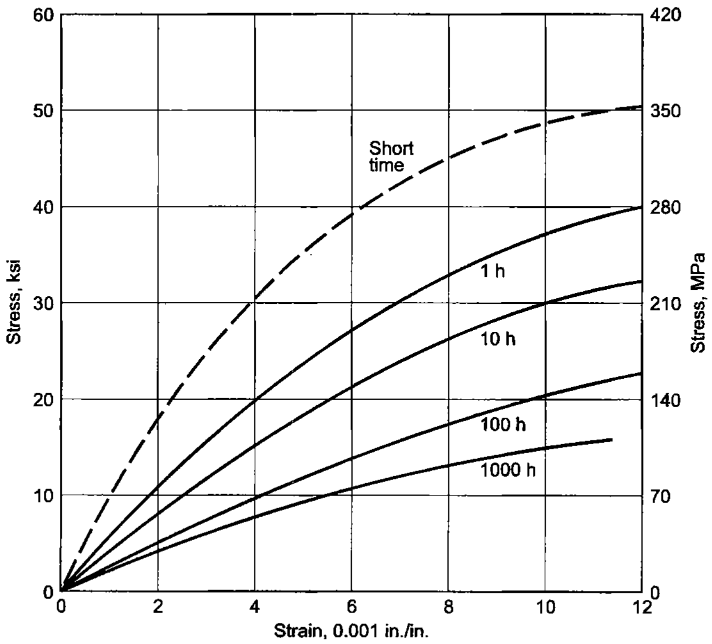


WA.047 2024-T6 aluminum alloy, isochronous stress-strain curves in tension

Tested at 150 °C (300 °F) (top) and 205 °C (400 °F) (bottom). Composition: Al-4.5Cu-1.5Mg-1Mn. UNS A92024

Source: "Isochronous Stress-Strain Curves for Several Heat-Treated Wrought Aluminum Alloys at 300 and 400 F," Alcoa Research Laboratories, 29 April 1958. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3203, CINDAS/Purdue University, 1995, p 24

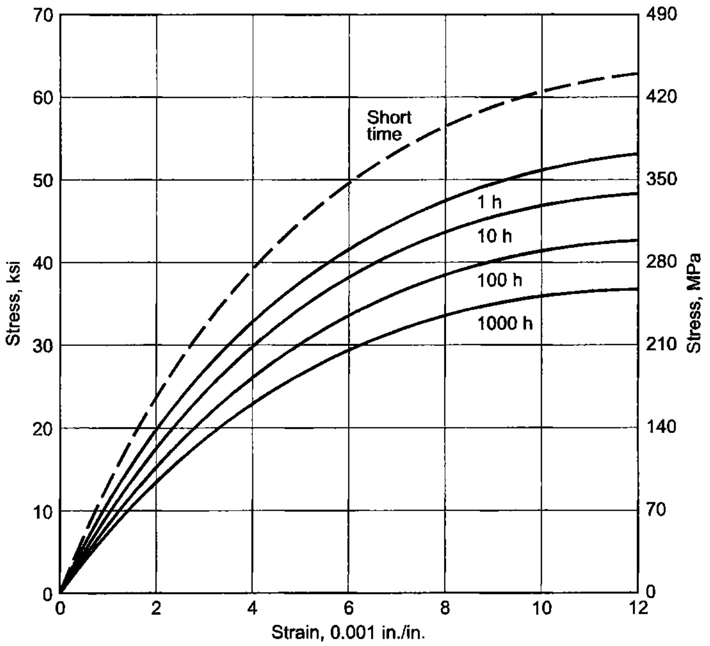


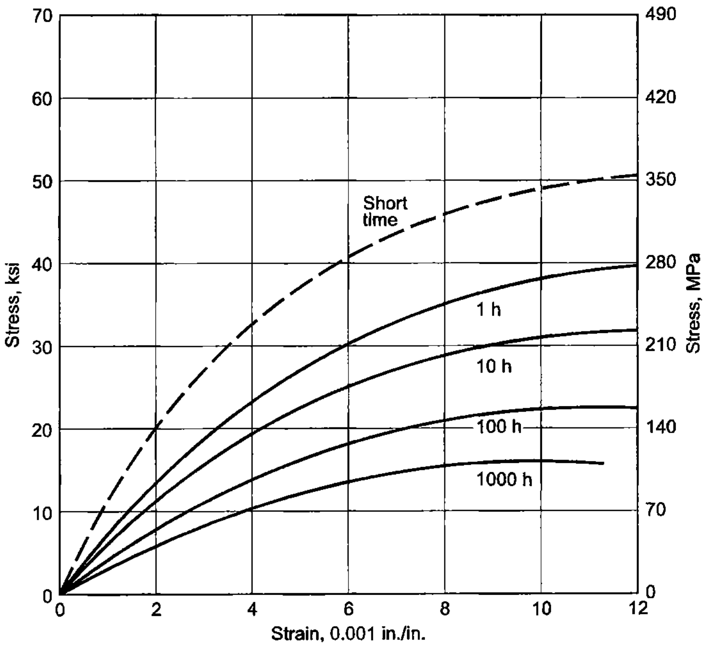


WA.048 2024-T81 aluminum alloy, isochronous stress-strain curves in tension

Tested at 150 °C (300 °F) (top) and 205 °C (400 °F) (bottom). Composition: Al-4.5Cu-1.5Mg-1Mn. UNS A92024

Source: "Isochronous Stress-Strain Curves for Several Heat-Treated Wrought Aluminum Alloys at 300 and 400 F," Alcoa Research Laboratories, 29 April 1958. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3203, CINDAS/Purdue University, 1995, p 25

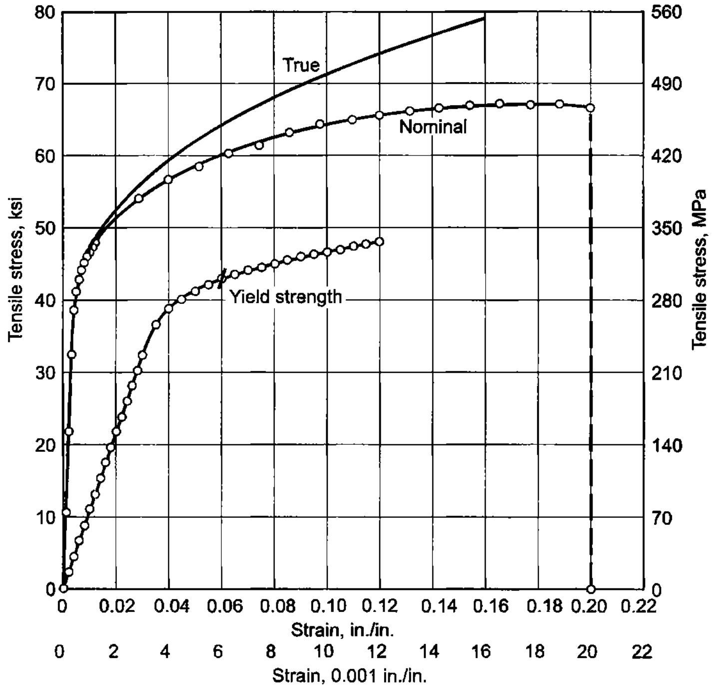




WA.049 2024-T86 aluminum alloy, isochronous stress-strain curves in tension

Tested at 150 °C (300 °F) (top) and 205 °C (400 °F) (bottom). Composition: Al-4.5Cu-1.5Mg-1Mn. UNS A92024

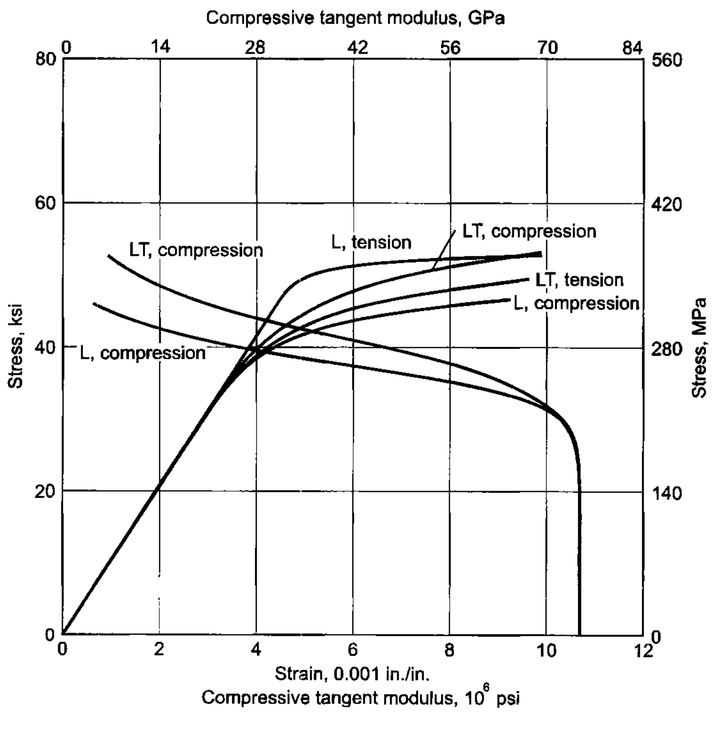
Source: "Isochronous Stress-Strain Curves for Several Heat-Treated Wrought Aluminum Alloys at 300 and 400 F," Alcoa Research Laboratories, 29 April 1958. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3203, CINDAS/Purdue University, 1995, p 25



WA.050 2024-T3, aluminum alloy plate, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test specimen thickness, 12.7 mm (0.5 in.). Gage length: 44.45 mm (1.75 in.). Nominal tensile strength, 464 MPa (67.3 ksi). True tensile strength, 546 MPa (79.2 ksi). Nominal yield strength (0.2% offset), 314 MPa (45.5 ksi). Elongation (in 50.8 mm, or 2 in.), 20.0%. Reduction of area, 27%. True strain at maximum load, 16.3%. A log-log plot of the stress-strain curve would yield a slope (n) of 0.21 in the area of uniform plastic deformation. UNS A92024

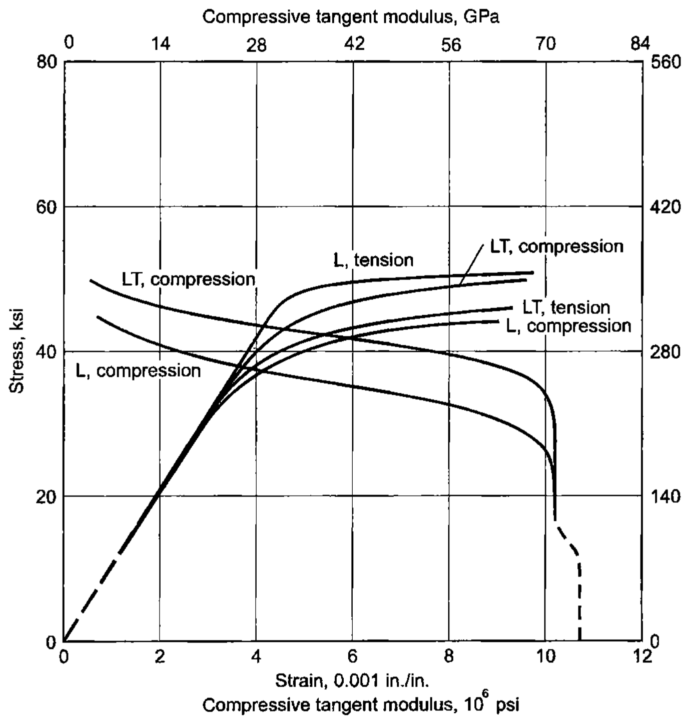
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, Aug 1954



WA.051 2024-T3 aluminum alloy sheet, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for sheet thickness ≤6.325 mm (≤0.249 in.). Ramberg-Osgood parameter: n(L, tension) = 50; n(LT, tension) = 12; n(L, compression) = 15; n(LT, compression) = 11. UNS A92024

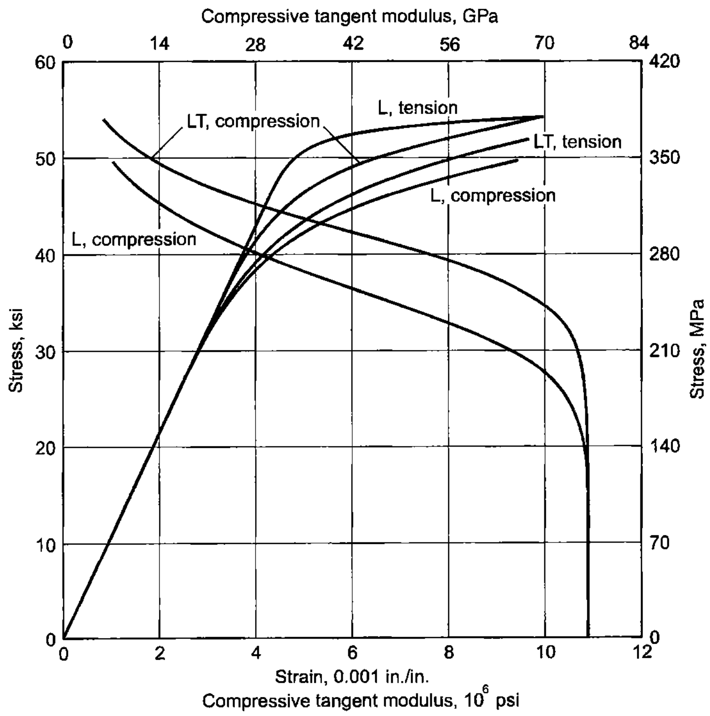
Source: *MIL-HDBK-5H*, 1 Dec 1998



WA.052 2024-T3 aluminum alloy sheet, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for sheet thickness 1.60–6.325 mm (0.063–0.249 in.). Ramberg-Osgood parameter: *n*(L, tension) = 50; *n*(LT, tension) = 15; *n*(L, compression) = 13; *n*(LT, compression) = 19.
UNS A92024

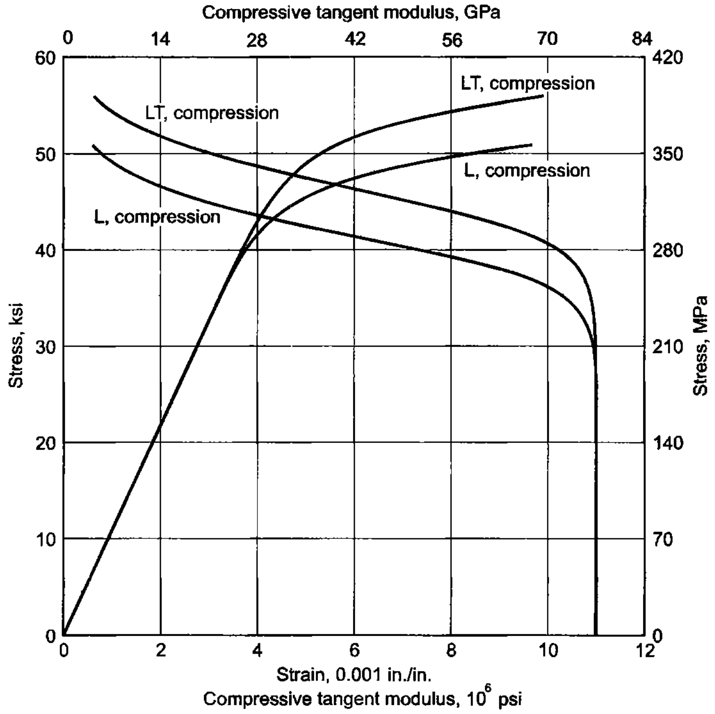
Source: *MIL-HDBK-5H*, 1 Dec 1998



WA.053 2024-T351 aluminum alloy, clad 2024-T351, plate, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for plate thickness 12.70–50.80 mm (0.500–2.000 in.). Ramberg-Osgood parameter: *n*(L, tension) = 42; *n*(LT, tension) = 9.0; *n*(L, compression) = 9.0; *n*(LT, compression) = 12.
UNS A92024

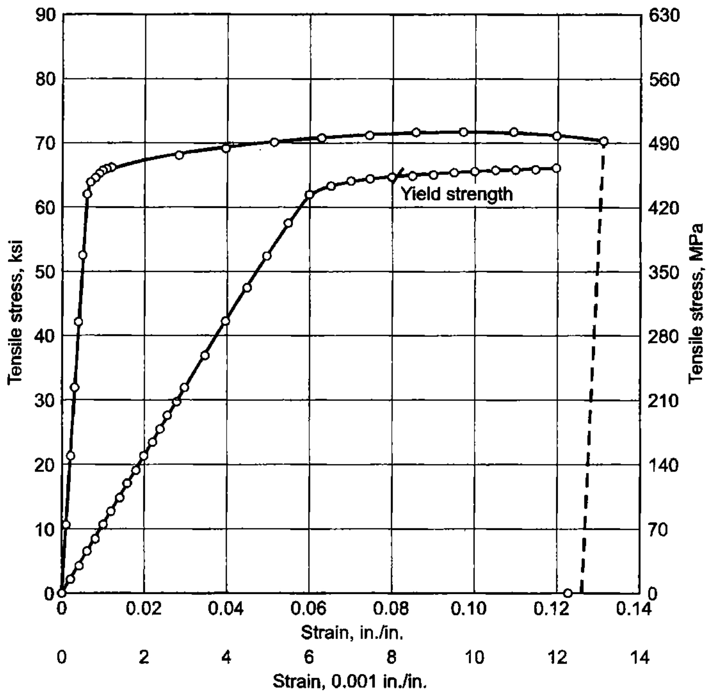
Source: *MIL-HDBK-5H*, 1 Dec 1998

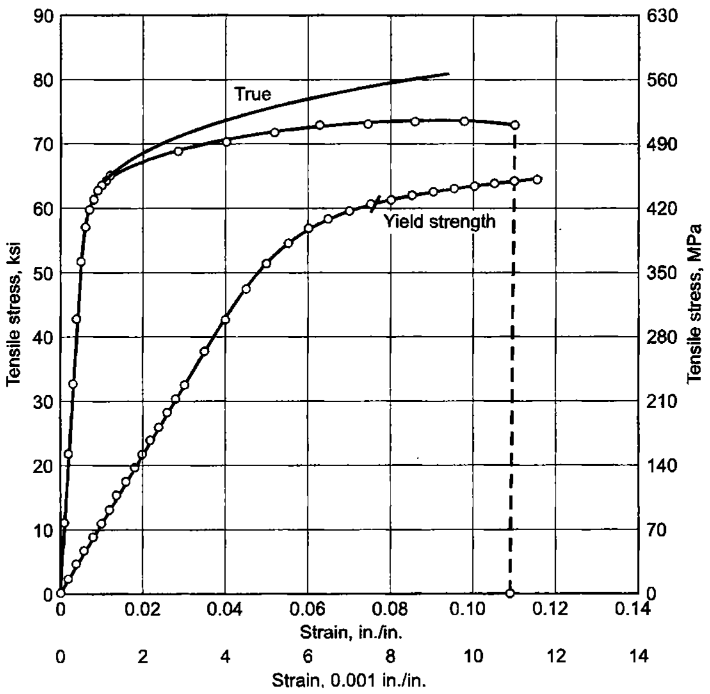


WA.054 2024-T351X aluminum alloy extrusion, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for extrusion thickness 6.35–19.02 mm (0.250–0.749 in.). Ramberg-Osgood parameter: n(L, compression) = 16; n(LT, compression) = 17. UNS A92024

Source: *MIL-HDBK-5H,* 1 Dec 1998

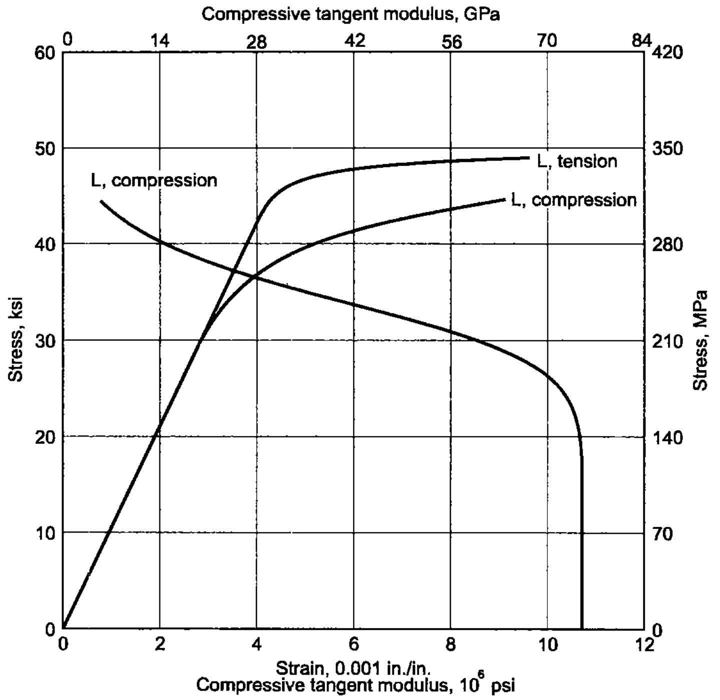




WA.055 2024-T36 aluminum alloy extruded plate, tensile stress-strain curves

Upper curve test direction, longitudinal; lower curve test direction, transverse. The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test specimen thickness, 12.7 mm (0.5 in.). Gage length: 44.45 mm (1.75 in.). Nominal longitudinal values: Tensile strength, 496 MPa (72.0 ksi). True tensile strength, 546 MPa (79.2 ksi). Nominal yield strength (0.2% offset), 450 MPa (65.2 ksi). Elongation (in 50.8 mm, or 2 in.), 13.2%. Reduction of area, 20%. True strain at maximum load, 9.2%. A log-log plot of the stress-strain curve would yield a slope (n) of 0.10 in the area of uniform plastic deformation. UNS A92024

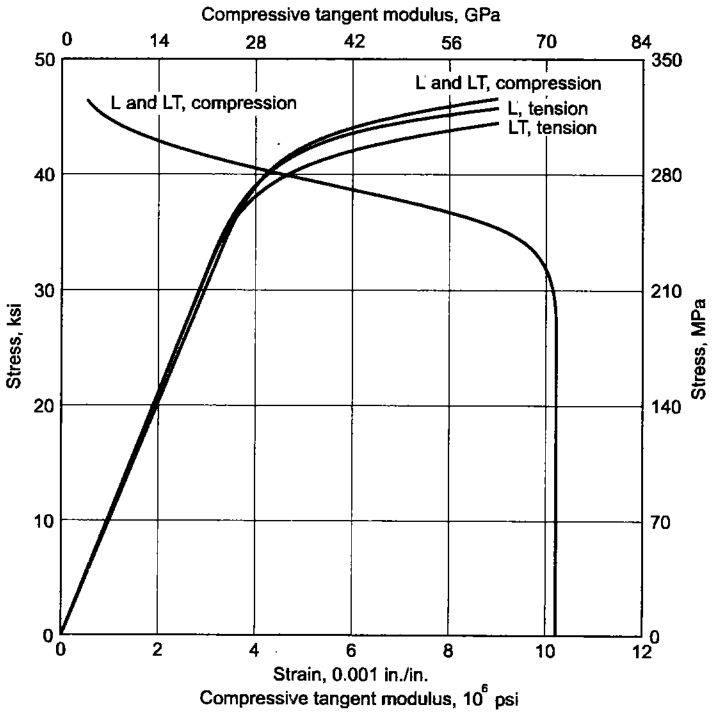
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA



WA.056 2024-T4 aluminum alloy rolled bar, rod, and shapes, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal. Typical for thickness ≤139.70 mm (≤5.500 in.). Ramberg-Osgood parameter: *n*(L, tension) = 50; *n*(L, compression) = 10. UNS A92024

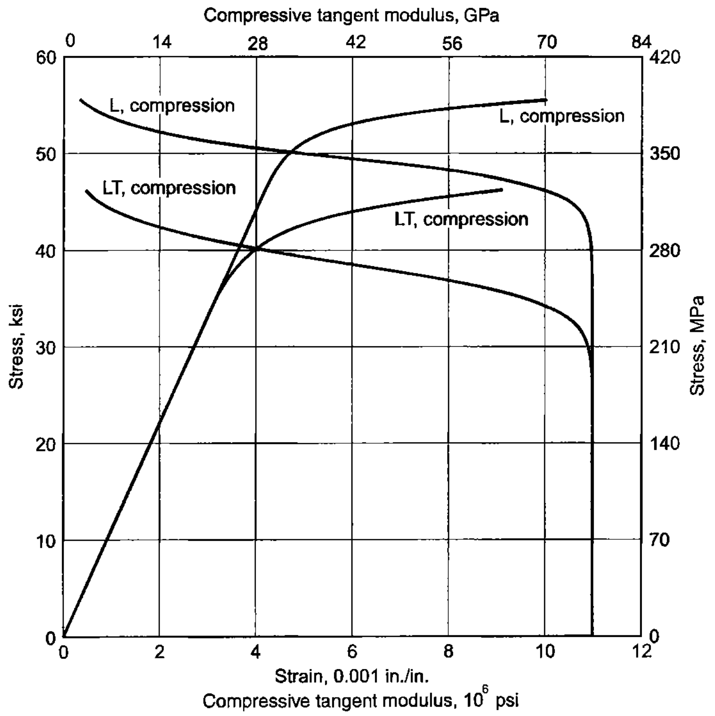
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.057 2024-T42 aluminum alloy, clad 2024-T42, plate, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for plate thickness 12.70–25.40 mm (0.500–1.000 in.). Ramberg-Osgood parameter: *n*(L, tension) = 17; *n*(LT, tension) = 16; *n*(L, compression) = 19; *n*(LT, compression) = 19.
UNS A92024

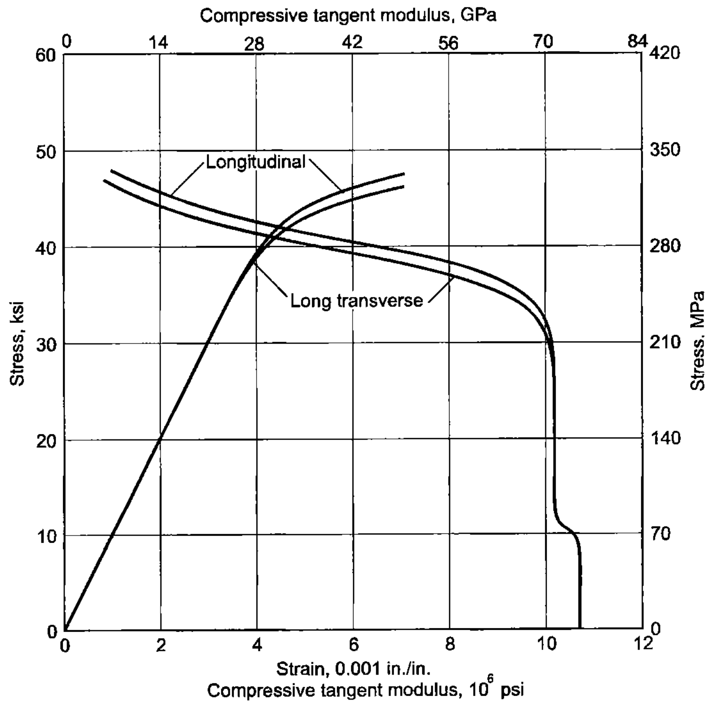
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.058 2024-T42 aluminum alloy extrusion, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for extrusion thickness ≥38.10 mm (≥1.500 in.). Ramberg-Osgood parameter: n(L, compression) = 32; n(LT, compression) = 19. UNS A92024

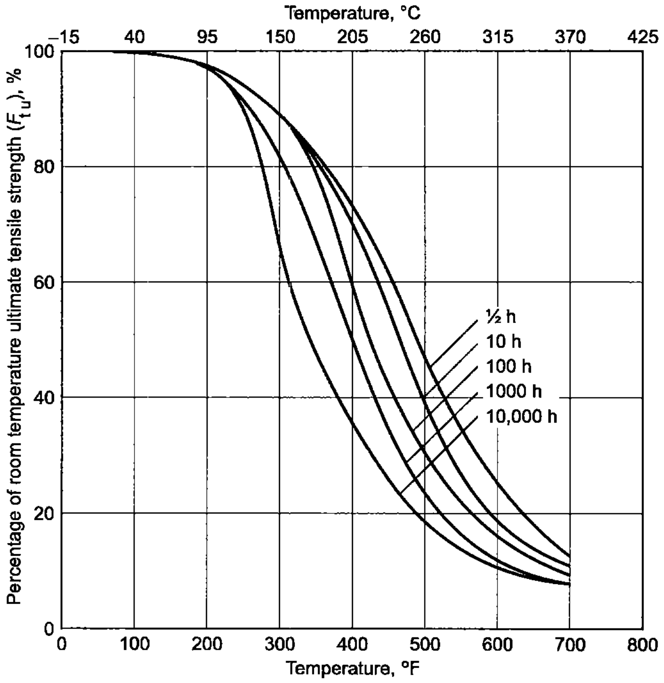
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.059 2024-T42 aluminum alloy, clad 2024-T42, sheet, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for sheet thickness 1.829–6.325 mm (0.072–0.249 in.). Ramberg-Osgood parameter: n(longitudinal, compression) = 17; n(long transverse, compression) = 17. Tensile yield strength: longitudinal, 324 MPa (47 ksi); long transverse, 317 MPa (46 ksi). UNS A92024

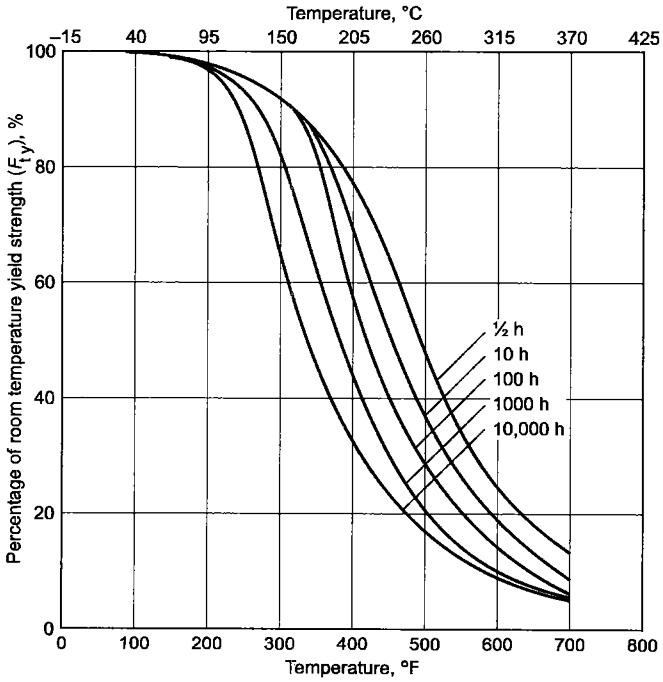
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.060 2024-T62 aluminum alloy (all products), effect of temperature on ultimate tensile strength

Up to 10,000 h exposure. UNS A92024

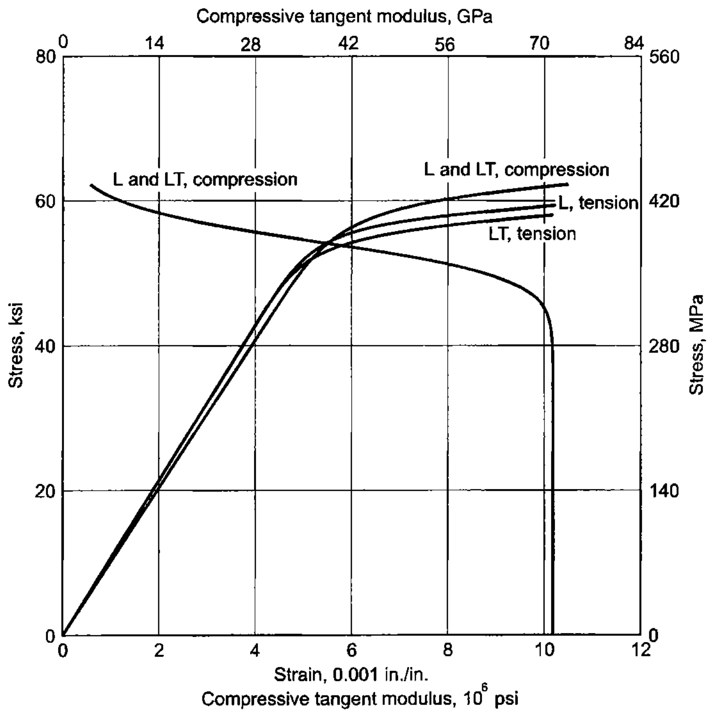
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.061 2024-T62 aluminum alloy (all products), effect of temperature on tensile yield strength

Up to 10,000 h exposure. UNS A92024

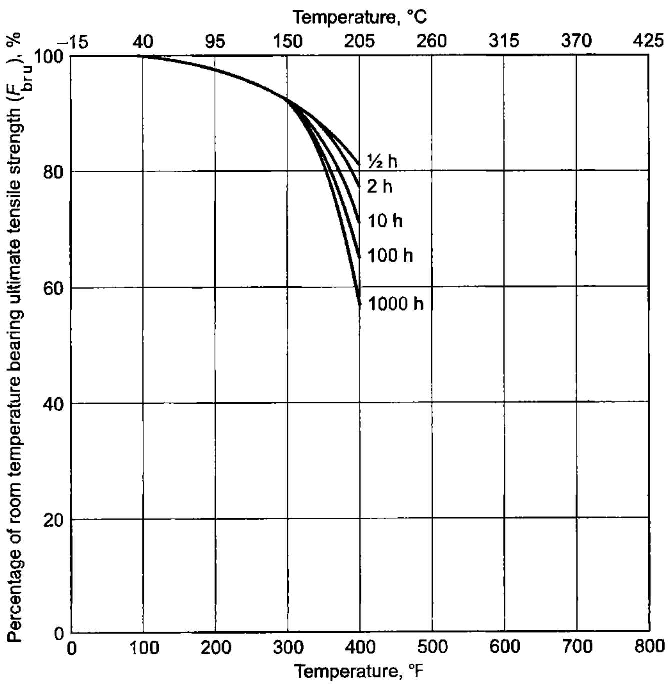
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.062 2024-T62 aluminum alloy plate, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for plate thickness 6.350–25.40 mm (0.250–1.000 in.). Ramberg-Osgood parameter: n(L, tension) = 28; n(LT, tension) = 24; n(L, compression) = 22; n(LT, compression) = 22.
UNS A92024

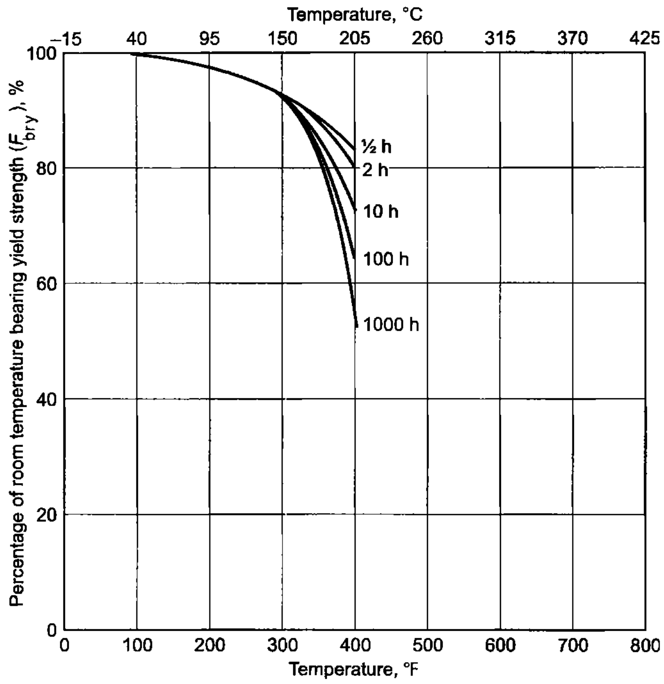
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.063 2024-T81, 2024-T851, 2024-T8510, and 2024-T8511 aluminum alloy (all products), effect of temperature on bearing ultimate strength

Up to 1000 h exposure. UNS A92024

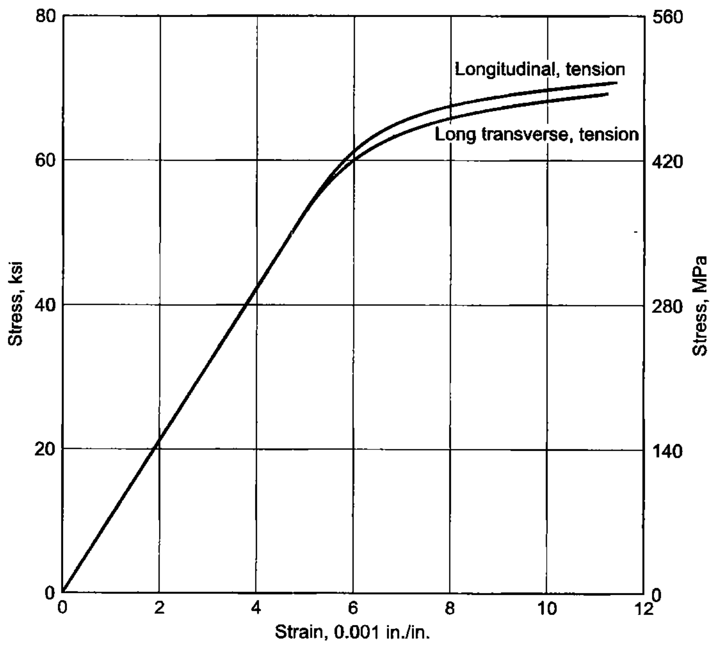
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.064 2024-T81, 2024-T851, 2024-T8510, and 2024-T8511 aluminum alloy (all products), effect of temperature on bearing yield strength

Up to 1000 h exposure. UNS A92024

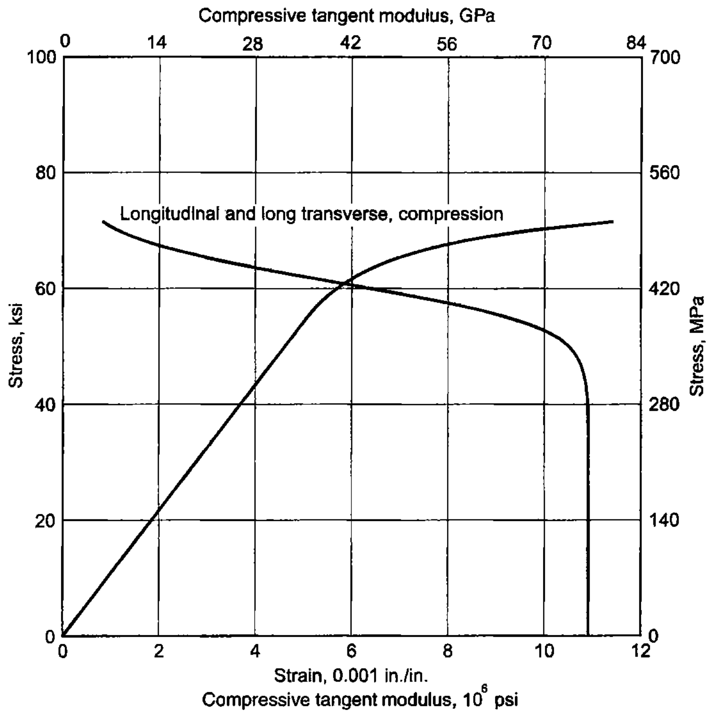
Source: *MIL-HDBK-5H*, 1 Dec 1998



WA.065 2024-T851 aluminum alloy plate, tensile stress-strain curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for plate thickness 6.350–25.40 mm (0.250–1.000 in.). Ramberg-Osgood parameter: n(L, tension) = 22, n(LT, tension) = 18. UNS A92024

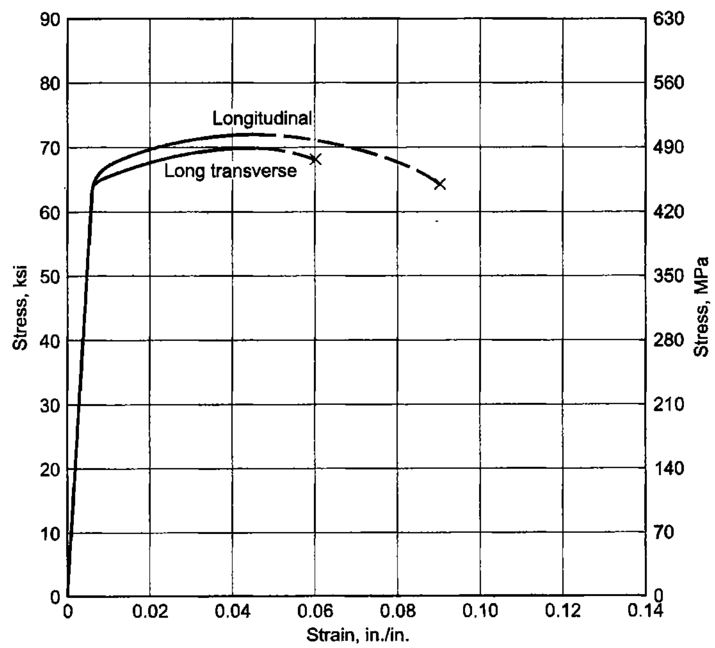
Source: *MIL-HDBK-5H*, 1 Dec 1998



WA.066 2024-T851 aluminum alloy plate, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for plate thickness 6.350–25.40 mm (0.250–1.000 in.). Ramberg-Osgood parameter: n(L and LT, compression) = 17. UNS A92024

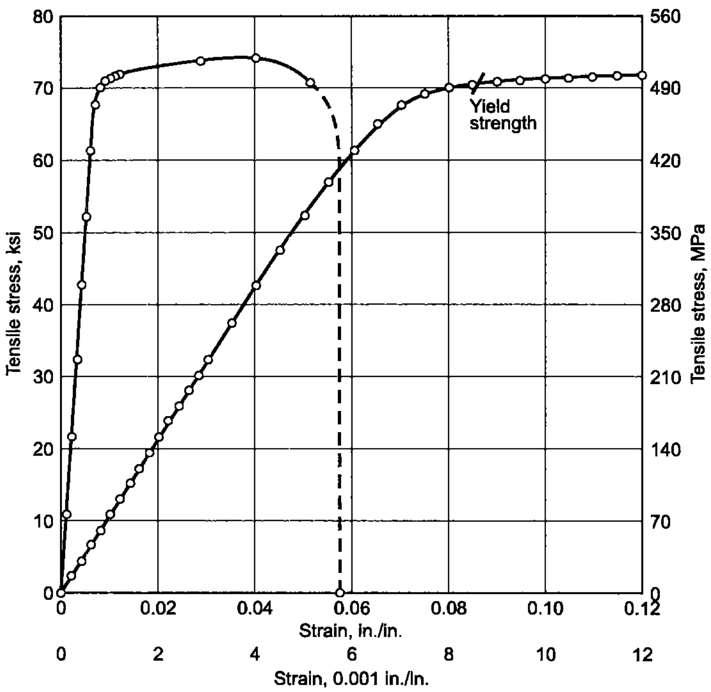
Source: *MIL-HDBK-5H,* 1 Dec 1998

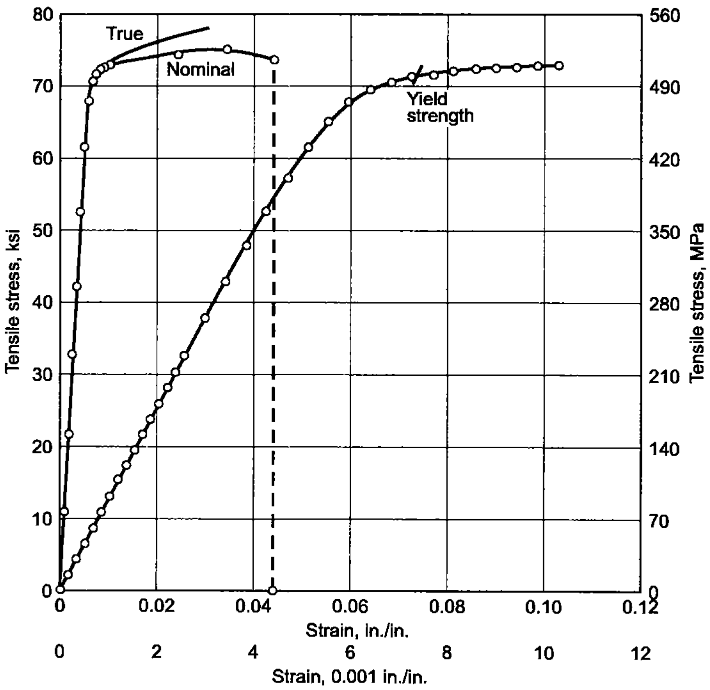


WA.067 2024-T851 aluminum alloy sheet, tensile stress-strain curves (full range)

Tested at room temperature. Typical for sheet thickness 6.350–38.075 mm (0.250–1.499 in.). UNS A92024

Source: *MIL-HDBK-5H,* 1 Dec 1998

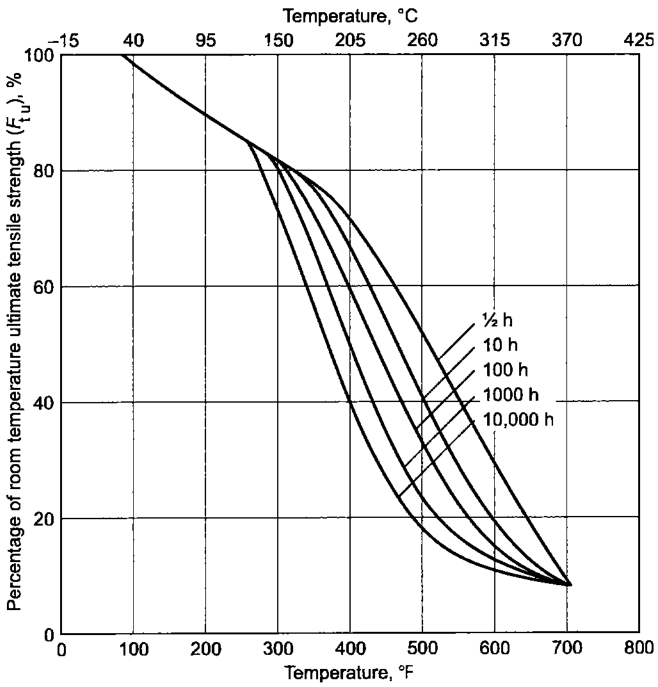




WA.068 2024-T86 aluminum alloy extruded plate, tensile stress strain curves

Test directions: upper curve, longitudinal; lower curve, transverse. The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test specimen thickness, 12.7 mm (0.5 in.). Gage length: 44.45 mm (1.75 in.). Nominal tensile strength, 517 MPa (75.0 ksi). True tensile strength, 534 MPa (77.5 ksi). Nominal yield strength (0.2% offset), 493 MPa (71.5 ksi). Elongation (in 50.8 mm, or 2 in.), 5.1%. Reduction of area, 17% (top), 11% (bottom). True strain at maximum load, 3.6%. A log-log plot of the stress-strain curve would yield a slope (n) of 0.06 in the area of uniform plastic deformation. UNS A92024

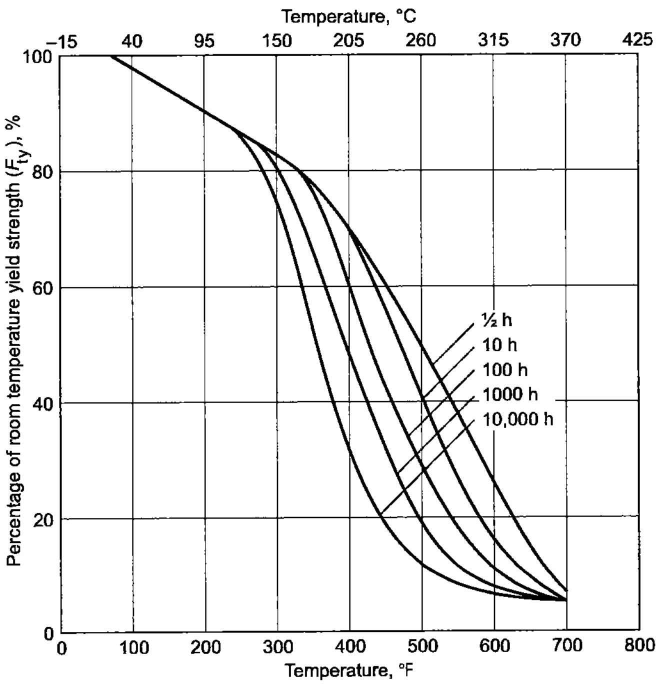
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA



WA.069 2024-T861 aluminum alloy sheet, effect of temperature on tensile ultimate strength

Up to 10,000 h exposure. UNS A92024

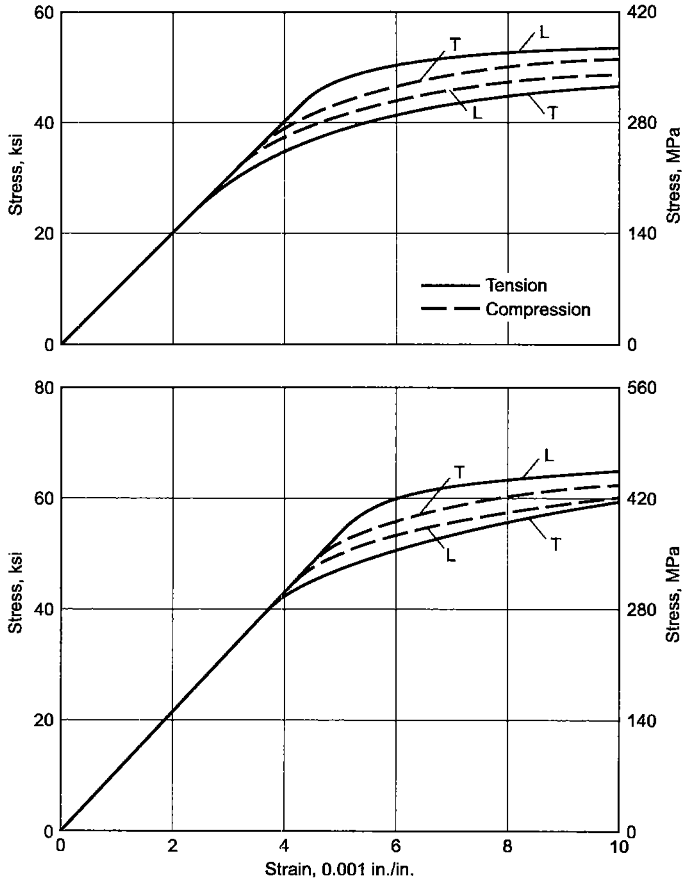
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.070 2024-T861 aluminum alloy sheet, effect of temperature on tensile yield strength

Up to 10,000 h exposure. UNS A92024

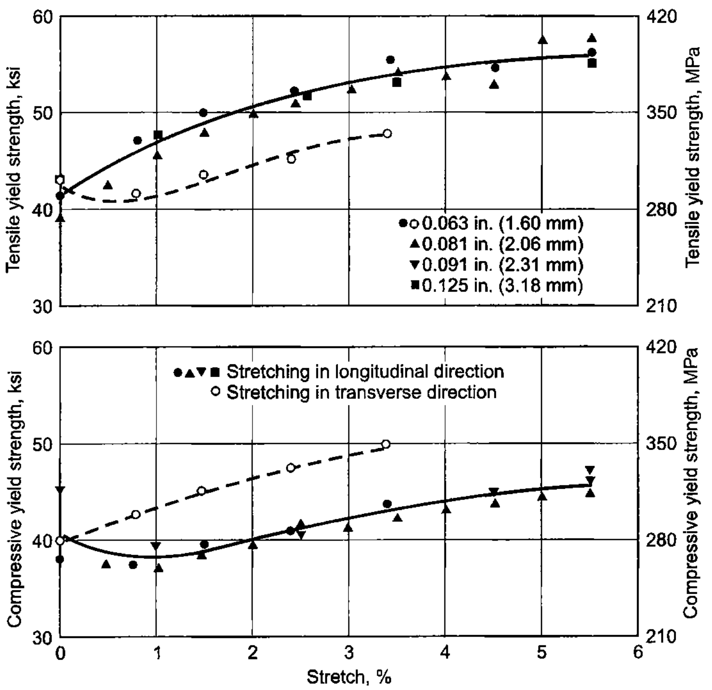
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.071 2024-T3 (top) and 2024-T36 (bottom) aluminum alloy, clad sheet, tensile and compressive stress-strain curves

Test direction: L, longitudinal; T, transverse. Composition: Al-4.5Cu-1.5Mg-0.6Mn. UNS A92024

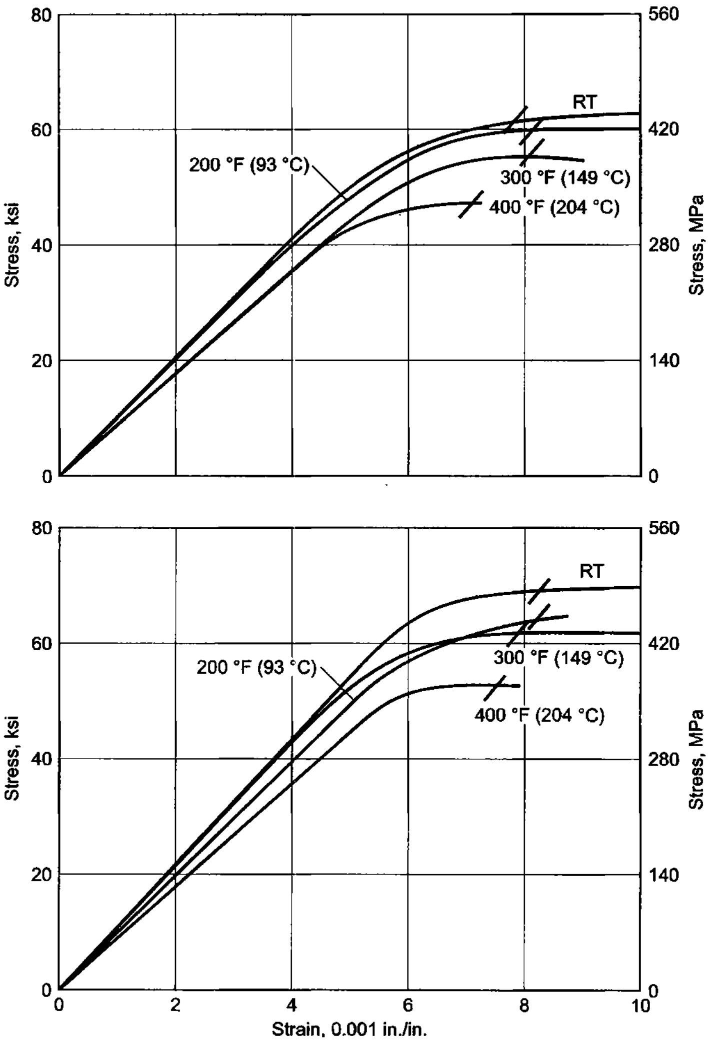
Source: L.J. Klinger and G. Sachs, Dependence of the Stress-Strain Curves of Cold Worked Metals upon the Testing Direction, *J. Aer. Sci.*, Vol 15, 1948, p 151. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3204, CINDAS/Purdue University, 1995, p 3



WA.072 2024-T4 aluminum alloy, clad 2024-T4, sheet, effect of stretching on tensile (top) and compressive (bottom) yield strengths

Composition: Al-4.5Cu-1.5Mg-0.6Mn. UNS A92024

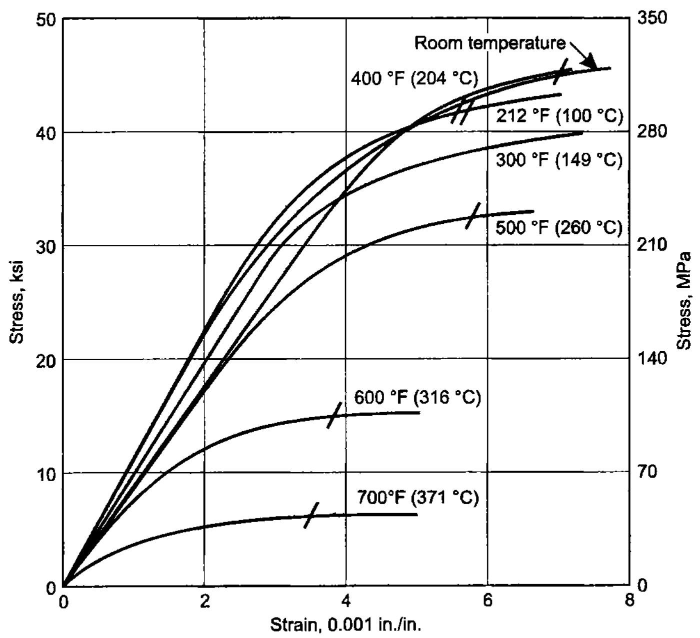
Source: L.J. Klinger and G. Sachs, Dependence of the Stress-Strain Curves of Cold Worked Metals upon the Testing Direction, *J. Aer. Sci.*, Vol 15, 1948, p 151. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3204, 1995, CINDAS/Purdue University, p 4



WA.073 2024-T81 (top) and 2024-T86 (bottom) aluminum alloy, clad 2024-T81 and 2024-T86, sheet, tensile stress strain curves

Tested at room and elevated temperature, 30 min. RT, room temperature. Sheet thickness 1.626 mm (0.064 in.). Composition: Al-4.5Cu-1.5Mg-0.6Mn. UNS A92024

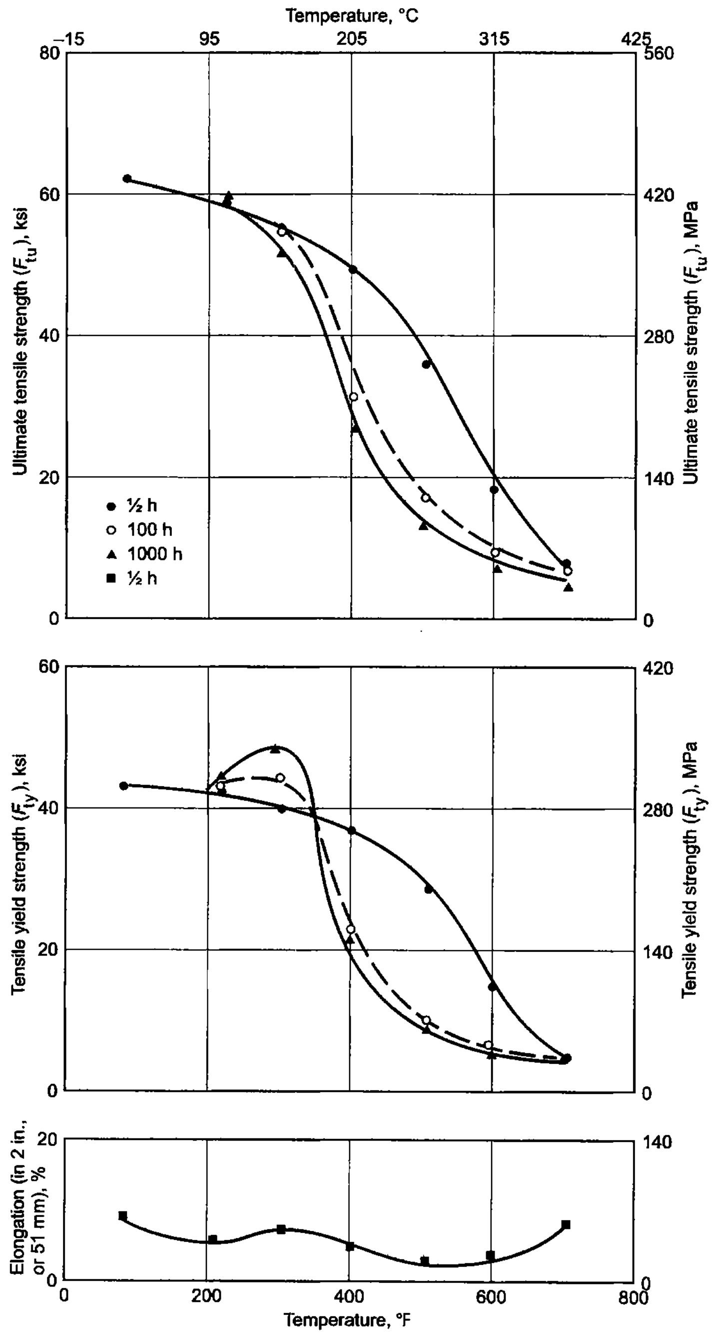
Source: D.E. Miller, "Determination of Physical Properties of Ferrous and Nonferrous Structural Sheet Materials at Elevated Temperatures," WADC AF TR No. 6517, Pt. 3, June 1954. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3204, CINDAS/Purdue University, 1995, p 4



WA.074 2024-T3 aluminum alloy, clad 2024-T3, sheet, tensile stress-strain curves

Tested at room and elevated temperatures 30 min. exposure at elevated temperature. Sheet thickness: 1.626 mm (0.064 in.). Composition: Al-4.5Cu-1.5Mg-0.6Mn. UNS A92024

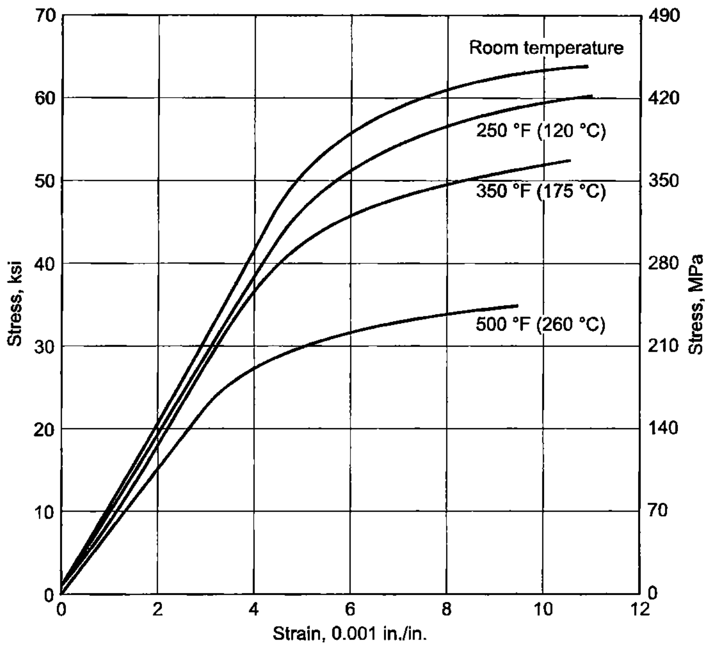
Source: D.D. Doerr, "Determination of Physical Properties of Ferrous and Nonferrous Structural Sheet Materials at Elevated Temperatures," WADC AF TR No. 6517, Pt. 1, Sup. 1, Feb 1953. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3204, CINDAS/Purdue University, 1995, p 4



WA.075 2024-T3 aluminum alloy, clad 2024-T3, sheet, effect of exposure and test temperature on tensile properties

Sheet thickness: 1.626 mm (0.064 in.). Composition: Al-4.5Cu-1.5Mg-0.6Mn. UNS A92024

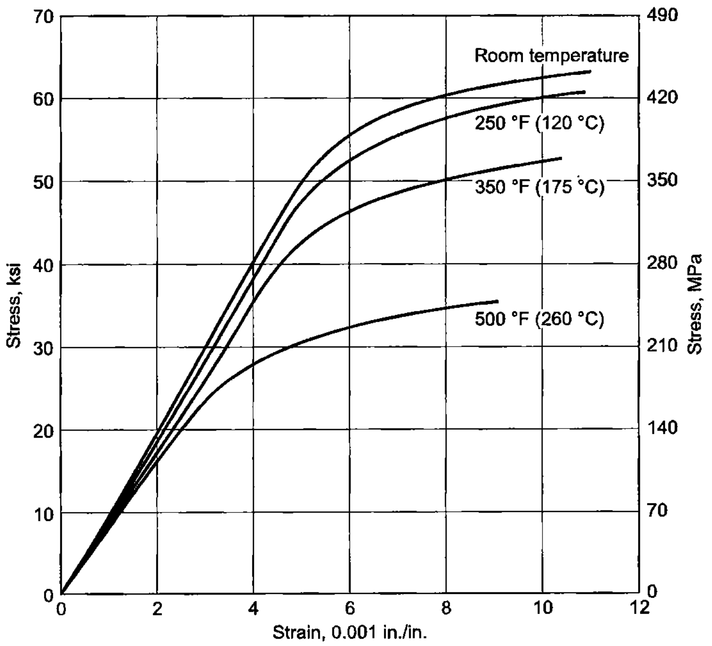
Source: Strength data: D.D. Doerr, "Determination of Physical Properties of Ferrous and Nonferrous Structural Sheet Materials at Elevated Temperatures," WADC AF TR No. 6517, Pt. 1, Sup. 1, Feb 1953. Elongation data: D.E. Miller, "Determination of Physical Properties of Ferrous and Nonferrous Structural Sheet Materials at Elevated Temperatures," WADC AF TR No. 6517, Pt. 3, June 1954. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3204, CINDAS/Purdue University, 1995, p 4. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3204, CINDAS/Purdue University, 1995, p 4



WA.076 2048-T851 aluminum alloy plate, tensile stress-strain curves

Test direction: longitudinal. Typical for plate thickness 76.2 mm (3 in.). Composition: Al-3.3Cu-1.5Mg-0.4Mn. UNS A92048

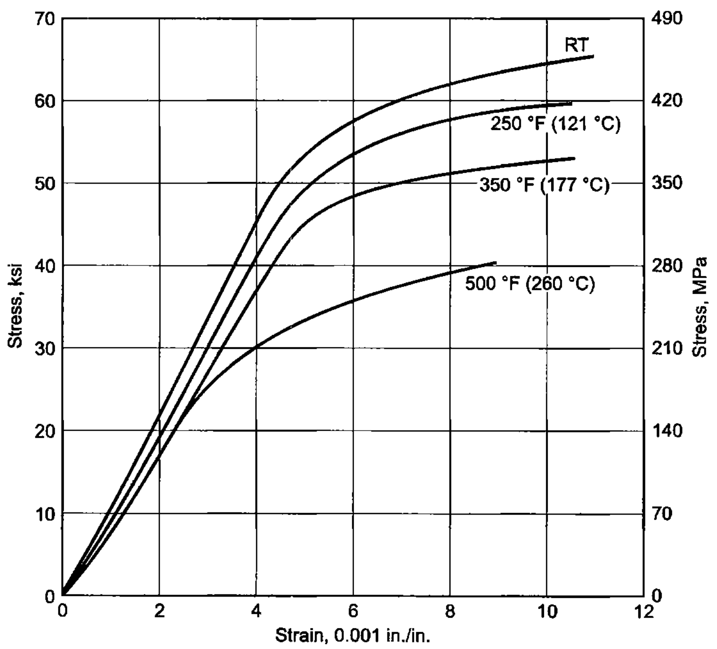
Source: O.L. Deel, P.E. Ruff, and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," Data Sheet F33615-72-C-1280, Technical Report AFML-TR-73-114, Battelle Memorial Institute, Columbus, OH, June 1973. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3223, CINDAS/Purdue University, 1995, p 2



WA.077 2048-T851 aluminum alloy plate, tensile stress-strain curves

Test direction: transverse. Typical for plate thickness 76.2 mm (3 in.). Composition: Al-3.3Cu-1.5Mg-0.4Mn. UNS A92048

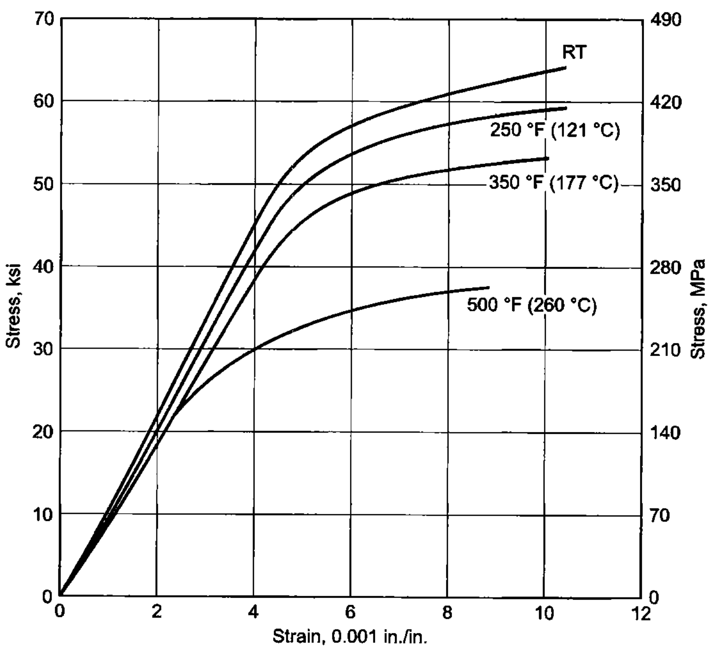
Source: O.L. Deel, P.E. Ruff, and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," Data Sheet F33615-72-C-1280, Technical Report AFML-TR-73-114, Battelle Memorial Institute, Columbus, OH, June 1973. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3223, CINDAS/Purdue University, 1995, p 3



WA.078 2048-T851 aluminum alloy plate, compressive stress-strain curves

Test direction: transverse. RT, room temperature. Typical for plate thickness 76.2 mm (3 in.). Composition: Al-3.3Cu-1.5Mg-04.Mn. UNS A92048

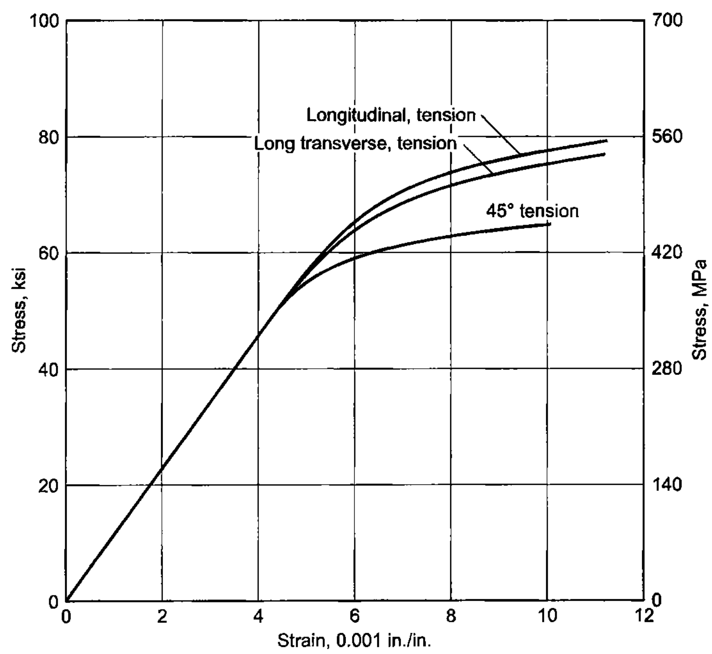
Source: O.L. Deel, P.E. Ruff, and H. Mindlin, "Engineering Data on New Aerospace Structural Metals," Data Sheet F33615-72-C-1280, Technical Report AFML-TR-73-114, Battelle Memorial Institute, June 1973. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3223, CINDAS/Purdue University, 1995, p 4



WA.079 2048-T851 aluminum alloy plate, compressive stress-strain curves

Test direction: longitudinal. RT, room temperature. Typical for plate thickness 76.2 mm (3 in.). Composition: Al-3.3Cu-1.5Mg-04.Mn. UNS A92048

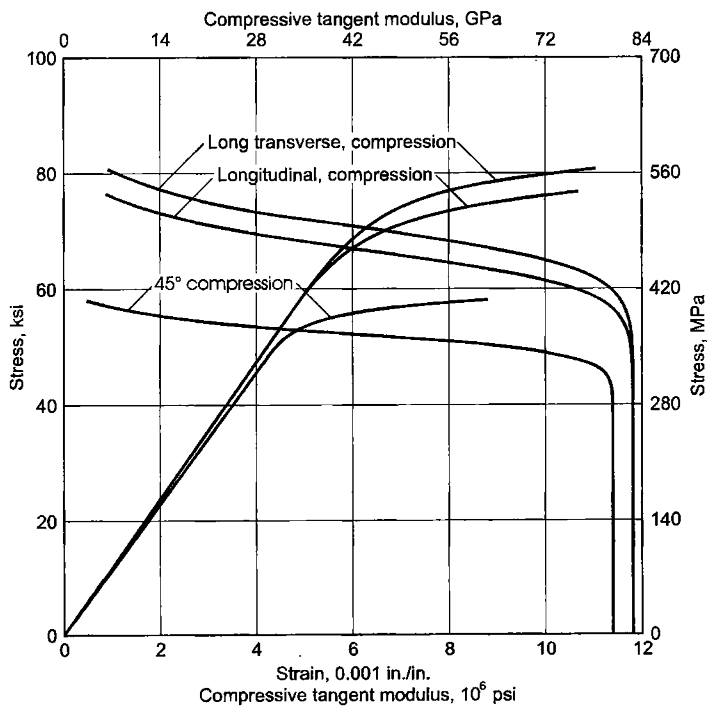
Source: O.L. Deel, P.E. Ruff, and H. Mindlin, "Engineering Data on New Aerospace Structural Metals," Data Sheet F33615-72-C-1280, Technical Report AFML-TR-73-114, Battelle Memorial Institute, June 1973. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3223, CINDAS/Purdue University, 1995, p 3



WA.080 2090-T83 aluminum alloy sheet, tensile stress-strain curves

Tested at room temperature. Typical for sheet thickness 1.016–6.325 mm (0.040–0.249 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 14; *n*(45°, tension) = 18; *n*(long transverse, tension) = 12. UNS A92090

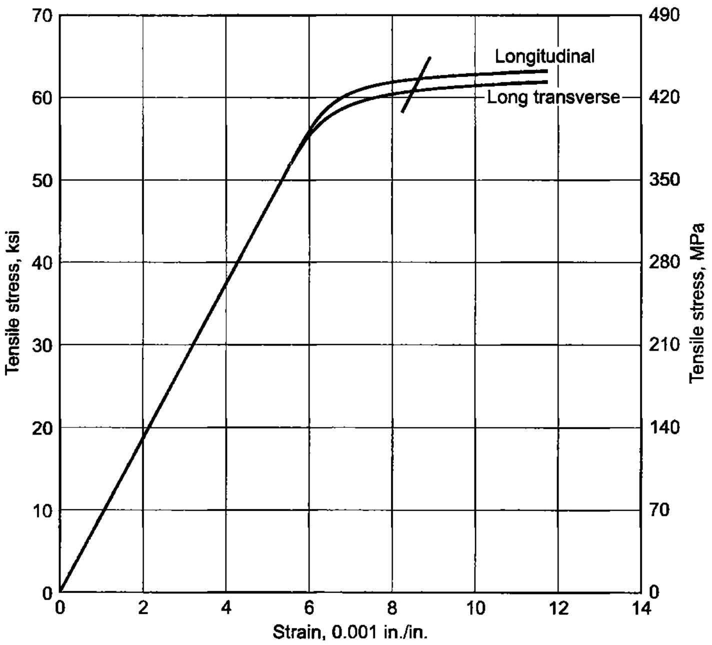
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.081 2090-T83 aluminum alloy sheet, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for sheet thickness 1.016–6.325 mm (0.040–0.249 in.). Ramberg-Osgood parameter, *n*(longitudinal, compression) = 20; *n*(45°, compression) = 30; *n*(long transverse, compression) = 19. UNS A92090

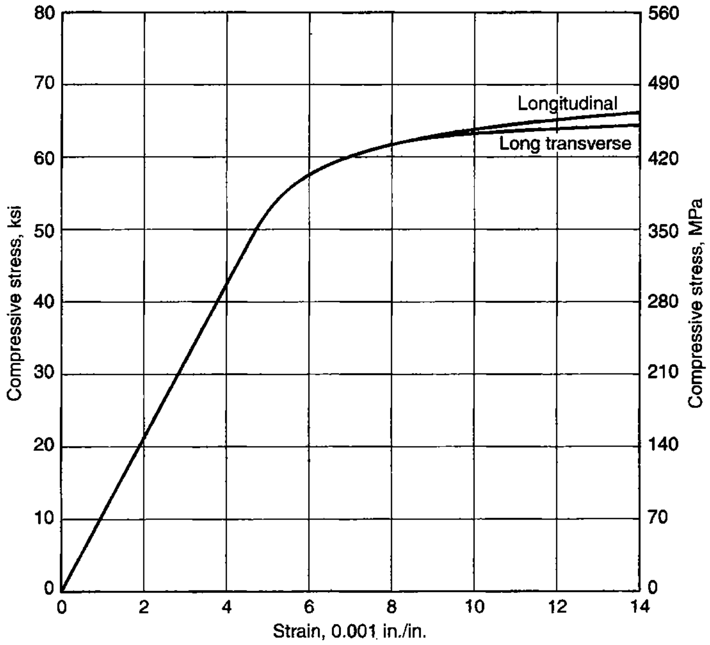
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.082 2124-T851 aluminum alloy plate, tensile stress-strain curves

Typical for plate thickness 101.6 mm (4 in.). Composition: Al-4.4Cu-1.5Mg-0.6Mn. UNS A92124

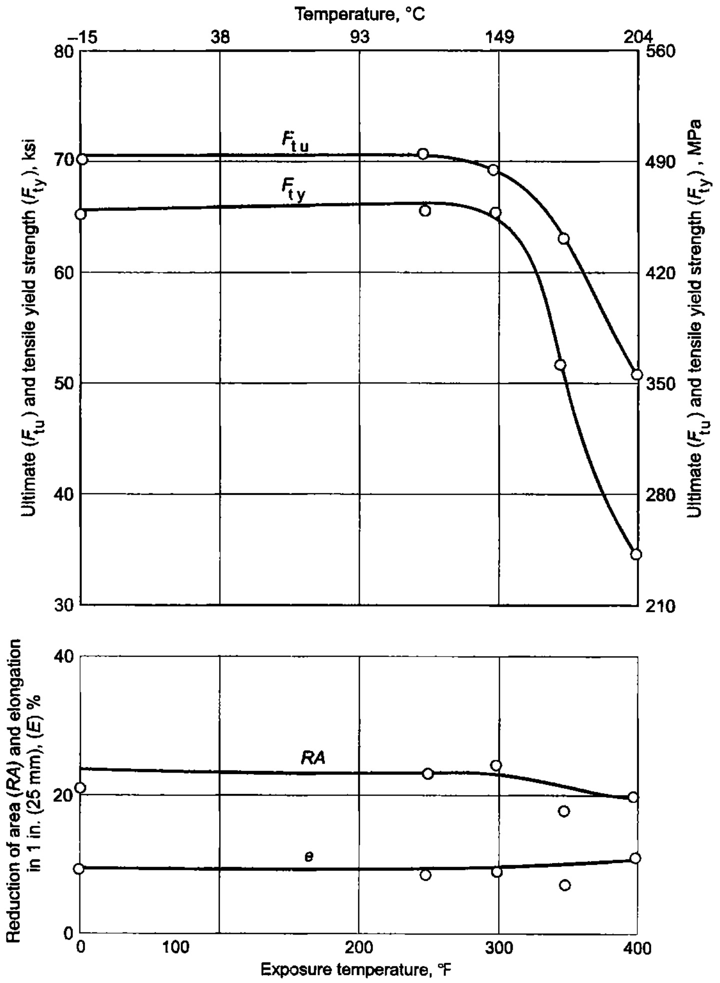
Source: R.M. Hart, "Aluminum Alloy 2124 Plate," Aluminum Company of America, Alcoa Technical Center, 1 April 1982. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3221, CINDAS/Purdue University, 1995, p 16



WA.083 2124-T851 aluminum alloy plate, compressive stress-strain curves

Typical for plate thickness 101.6 mm (4 in.). Composition: Al-4.4Cu-0.5Mg-0.6Mn. UNS A92124

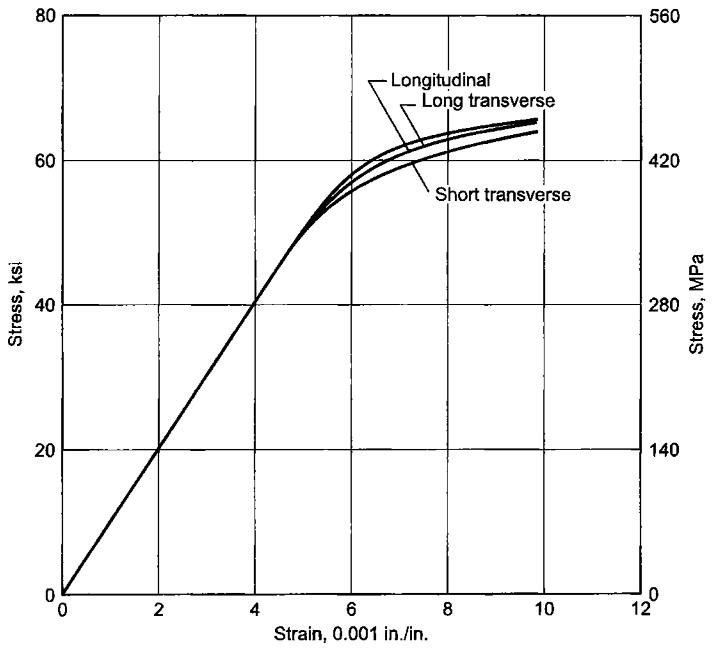
R.M. Hart, "Aluminum Alloy 2124 Plate," Aluminum Company of America, Alcoa Technical Center, 1 April 1982. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3221, CINDAS/ Purdue University, 1995, p 17



WA.084 2124-T851 aluminum alloy plate, effect of elevated temperatures on retained room-temperature tensile properties

1000 h exposure. Test direction: longitudinal. Plate thickness: 50.8 mm (2 in.). Composition: Al-4.4Cu-1.5Mg-0.6Mn. UNS A92124

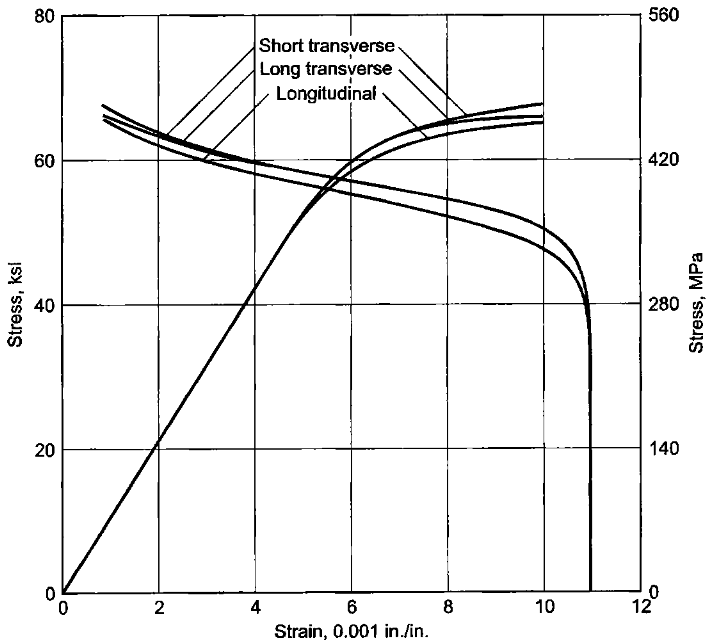
R.R. Cervay, "Temperature Effect on the Mechanical Properties of Aluminum Alloy 2124-T851," University of Dayton Research Institute, AFML-TR-75-208, 1975. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3221, CINDAS/Purdue University, 1995, p 17



WA.085 2124-T851 aluminum alloy plate, tensile stress-strain curves

Tested at room temperature. Typical for plate thickness 38.125–127.0 mm (1.501–5.000 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 22; *n*(long transverse, tension) = 16; *n*(short transverse, tension) = 13. UNS A92124

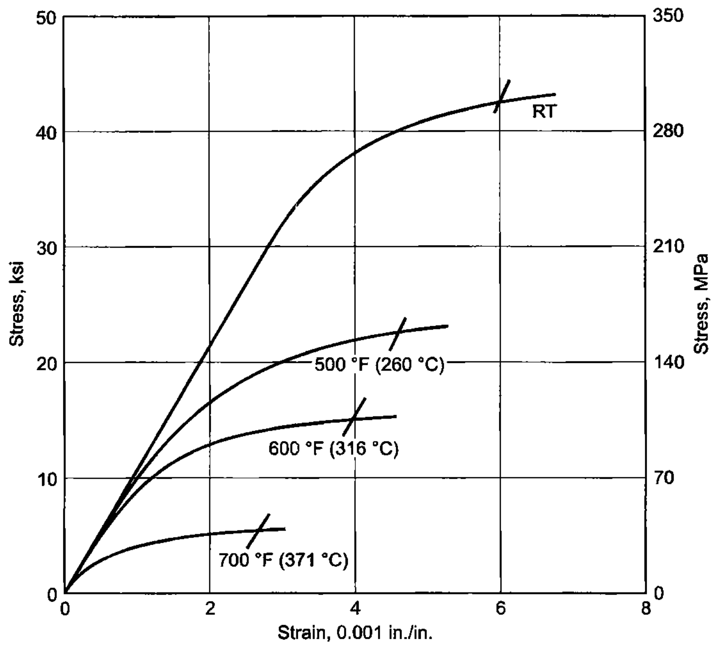
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.086 2124-T851 aluminum alloy plate, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for plate thickness 38.125–127.0 mm (1.501–5.000 in.). Ramberg-Osgood parameter, *n*(longitudinal, compression) = 14; *n*(long transverse, compression) = 19; *n*(short transverse, compression) = 17. UNS A92124

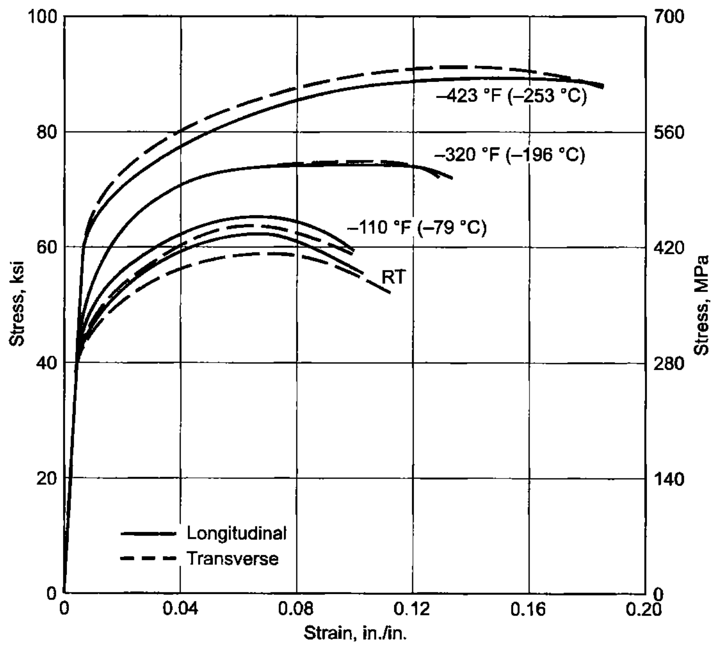
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.087 2219-T6 aluminum alloy forged rod, tensile stress-strain curves

Tested at room and elevated temperatures. 100 h exposure. Composition: Al-6.3Cu-0.3Mn-0.18Zr-0.10V-0.06Ti. UNS A92219

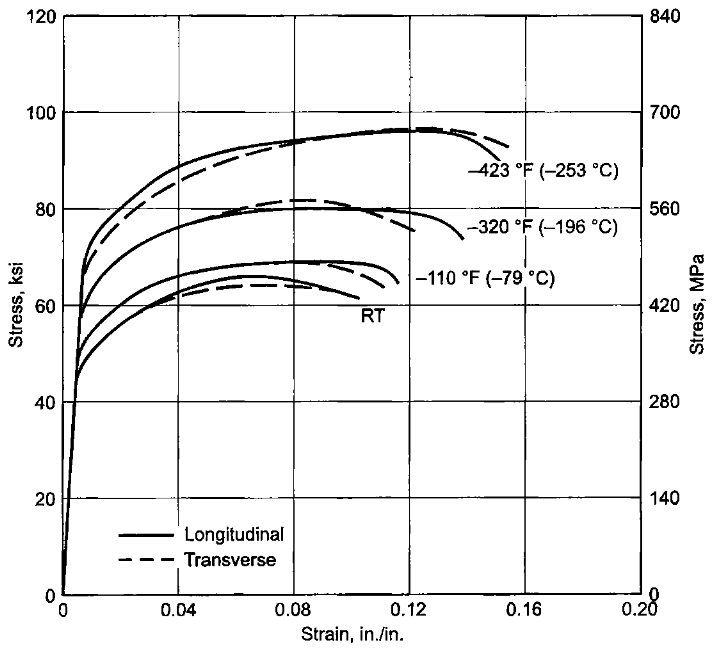
W.P. Achbach, R.J. Favor, and W.S. Hyler, "Material-Property-Design Criteria for Metals," WADC TR 55-150, Part VI, Oct 1955. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3205, CINDAS/Purdue University, 1995, p 9



WA.088 2219-T62 aluminum alloy sheet, tensile stress-strain curves

Tested at low temperatures. Sheet thickness: 2.540 mm (0.100 in.). Composition: Al-6.3Cu-0.3Mn-0.18Zr-0.10V-0.06Ti. UNS A92219

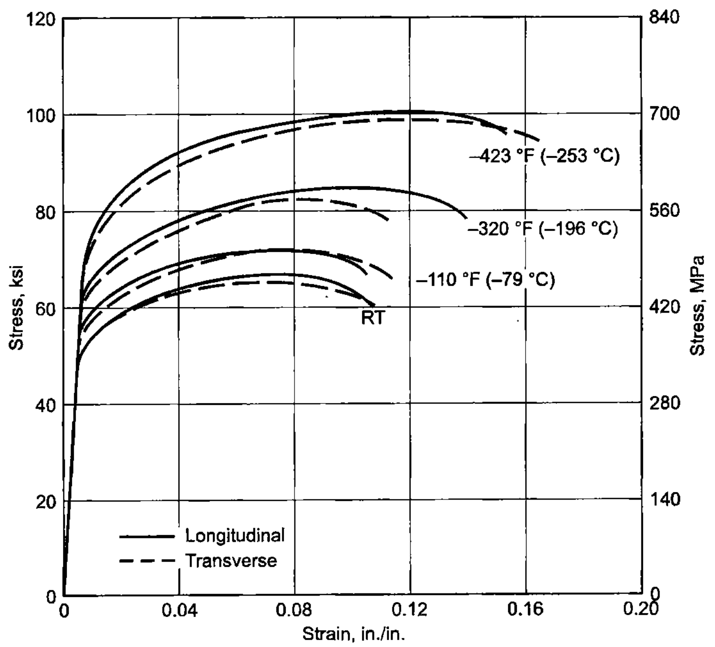
F.R. Schwartzberg et al., *Cryogenic Materials Data Handbook,* MIL-TDR-64-280, Aug 1964, and Progress Report No. 1, Feb 1965. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3205, CINDAS/Purdue University, 1995, p 9



WA.089 2219-T81 aluminum alloy sheet, tensile stress-strain curves

Tested at low temperatures. Sheet thickness: 2.540 mm (0.100 in.). Composition: Al-6.3Cu-0.3Mn-0.18Zr-0.10V-0.06Ti. UNS A92219

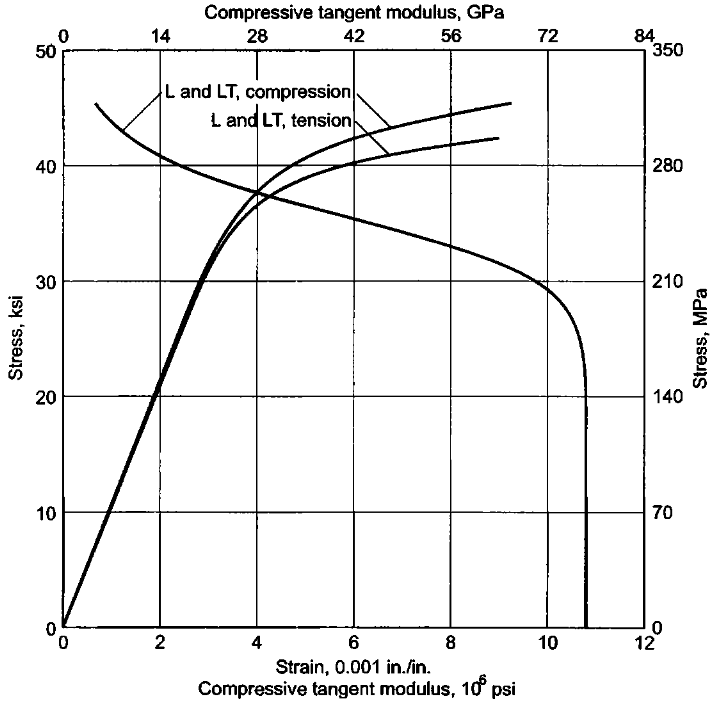
F.R. Schwartzberg et al., *Cryogenic Materials Data Handbook*, MIL-TDR-64-280, Aug 1964, and Progress Report No. 1, Feb 1965. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3205, CINDAS/Purdue University, 1995, p 9



WA.090 2219-T87 aluminum alloy sheet, tensile stress-strain curves

Tested at low temperatures. Sheet thickness: 2.540 mm (0.100 in.). Composition: Al-6.3Cu-0.3Mn-0.18Zr-0.10V-0.06Ti. UNS A92219

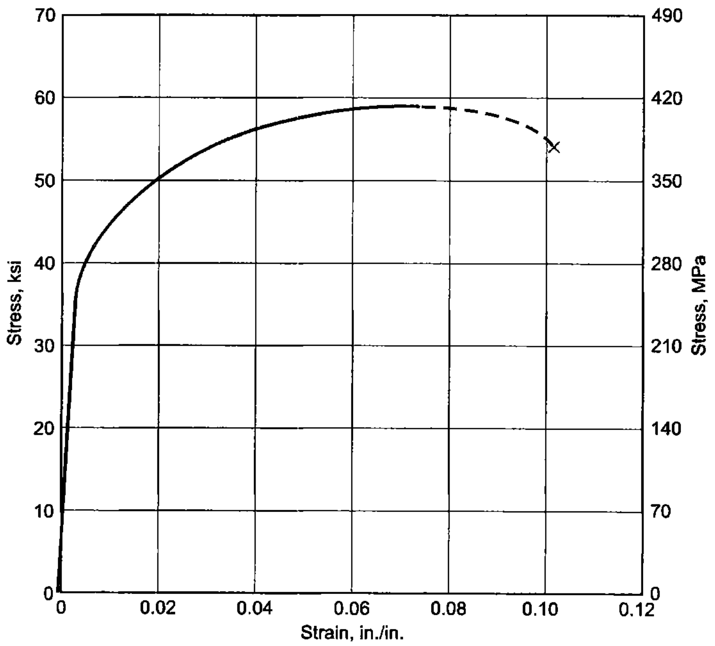
F.R. Schwartzberg et al., *Cryogenic Materials Data Handbook*, MIL-TDR-64-280, Aug 1964, and Progress Report No. 1, Feb 1965. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3205, CINDAS/Purdue University, 1995, p 9



WA.091 2219-T62 aluminum alloy sheet and plate, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for sheet and plate thickness 3.175–50.80 mm (0.125–2.000 in.). Ramberg-Osgood parameter, *n*(L and LT, tension) = 13; *n*(L and LT, compression) = 16. UNS A92219

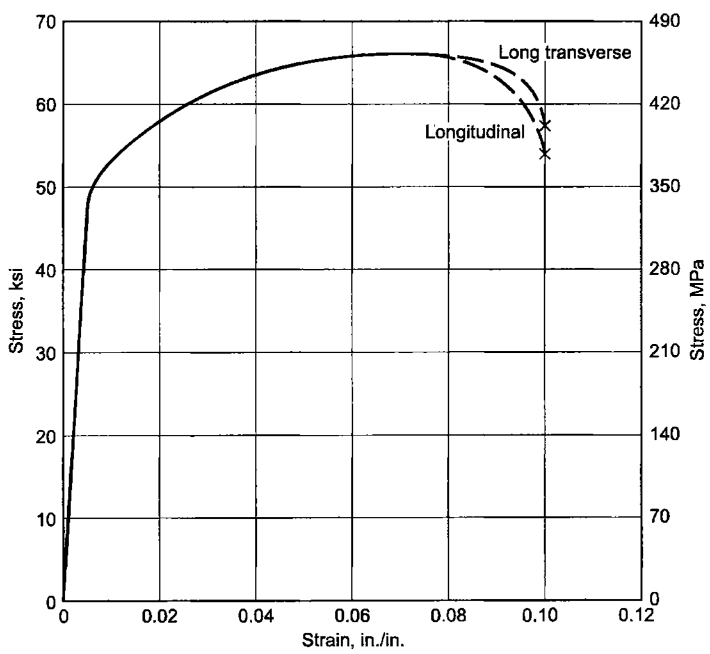
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–174



WA.092 2219-T62 aluminum alloy sheet and plate, tensile stress-strain curve (full range)

Tested at room temperature. Test direction: longitudinal and long transverse. Typical for sheet and plate thickness 3.175–50.80 mm (0.125–2.00 in.). UNS A92219

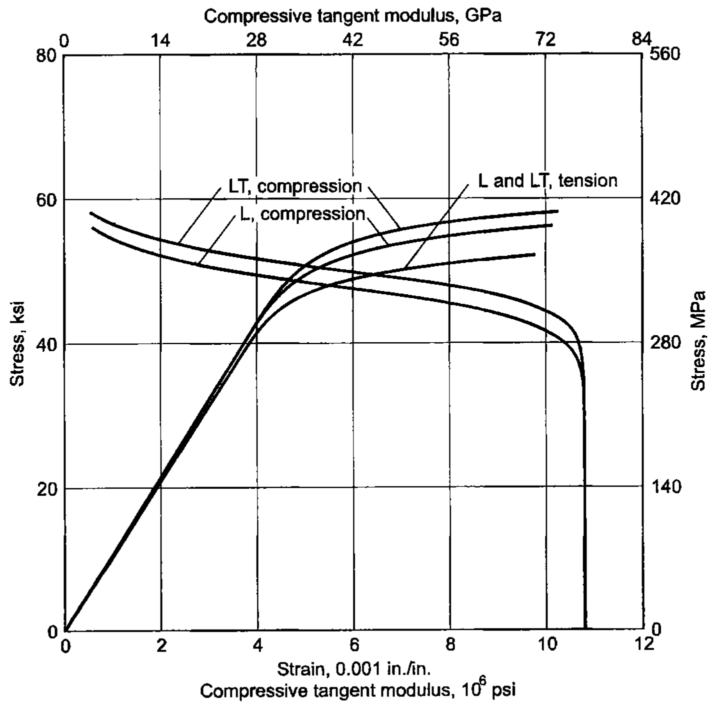
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–175



WA.093 2219-T81 aluminum alloy sheet and 2219-T851 aluminum alloy plate, tensile stress-strain curves (full range)

Tested at room temperature. Typical for sheet and plate thickness 1.016–63.50 mm (0.040–2.50 in.).
UNS A92219

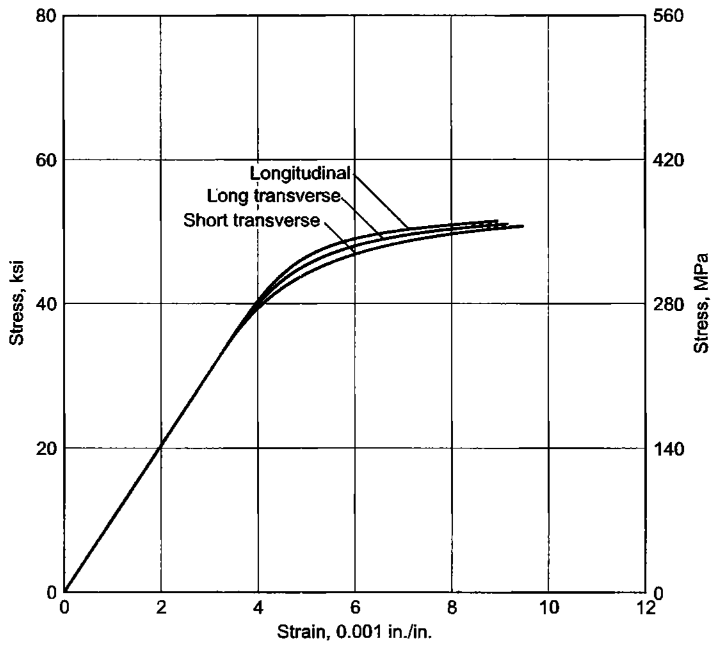
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–179



WA.094 2219-T81 aluminum alloy sheet and 2219-T851 aluminum alloy plate, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for sheet and plate thickness 1.016–63.50 mm (0.040–2.500 in.). Ramberg-Osgood parameter, n(L and LT, tension) = 20; n(L, compression) = 19; n(LT, compression) = 21.
UNS A92219

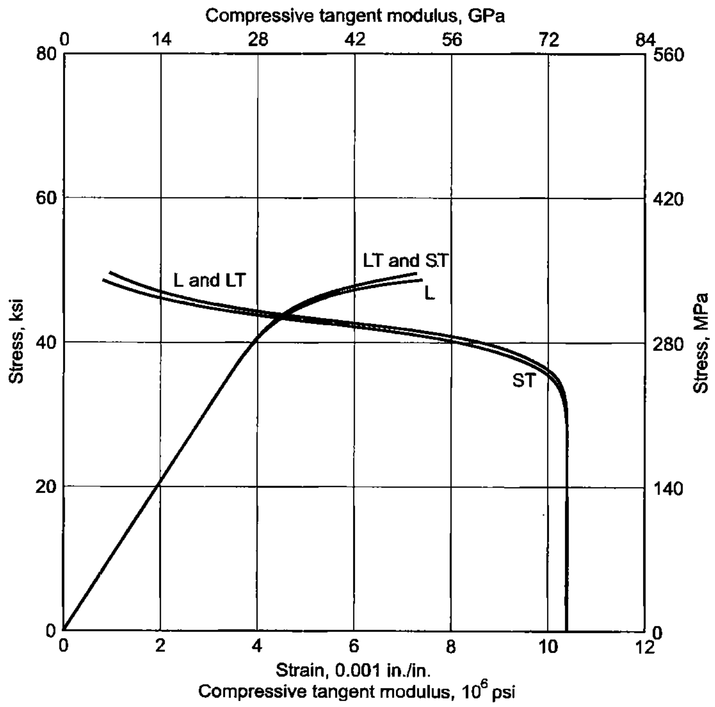
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–178



WA.095 2219-T852 aluminum alloy hand forging, tensile stress-strain curves

Tested at room temperature. Typical for forging thickness 101.6–152.4 mm (4.001–6.000 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 22; *n*(long transverse, tension) = 17; *n*(short transverse, tension) = 14. UNS A92219

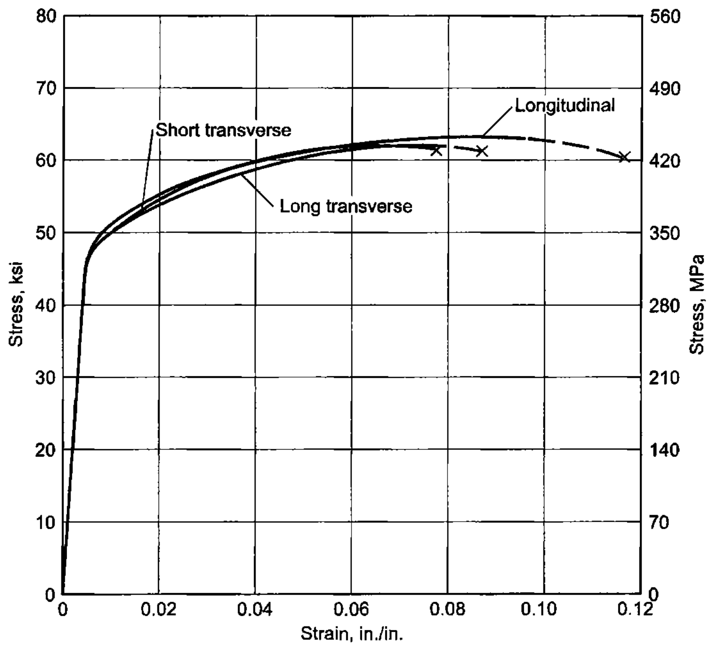
Source: *MIL-HDBK-5H*, 1 Dec 1998



WA.096 2219-T852 aluminum alloy hand forging, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse; ST, short transverse. Typical for forging thickness 101.652–152.40 mm (4.001–6.000 in.). Ramberg-Osgood parameter, *n*(L, compression) = 20; *n*(LT, compression) = 19; *n*(ST, compression) = 17. UNS A92219

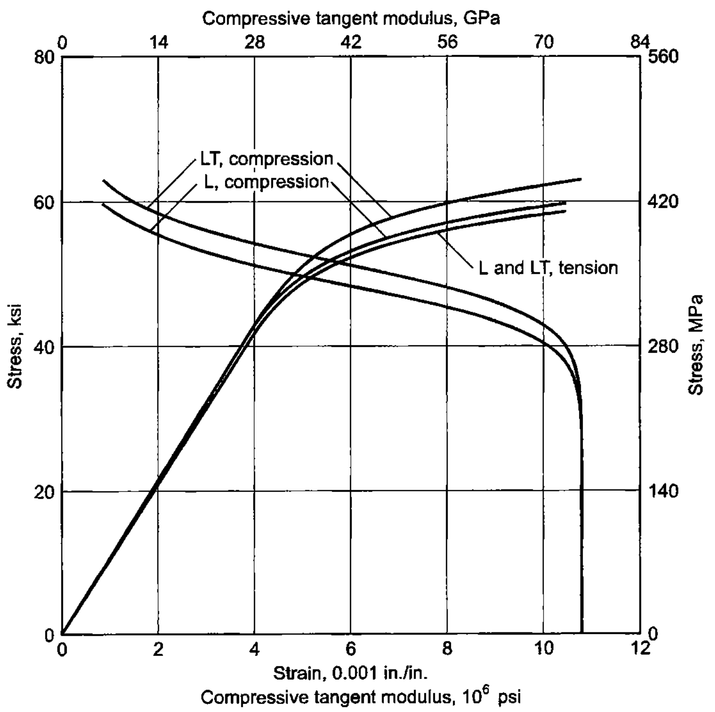
Source: *MIL-HDBK-5H*, 1 Dec 1998



WA.097 2219-T852 aluminum alloy hand forging, tensile stress-strain curves (full range)

Tested at room temperature. Typical forging thickness for 152.4–203.2 mm (6.001–8.000 in.). UNS A92219

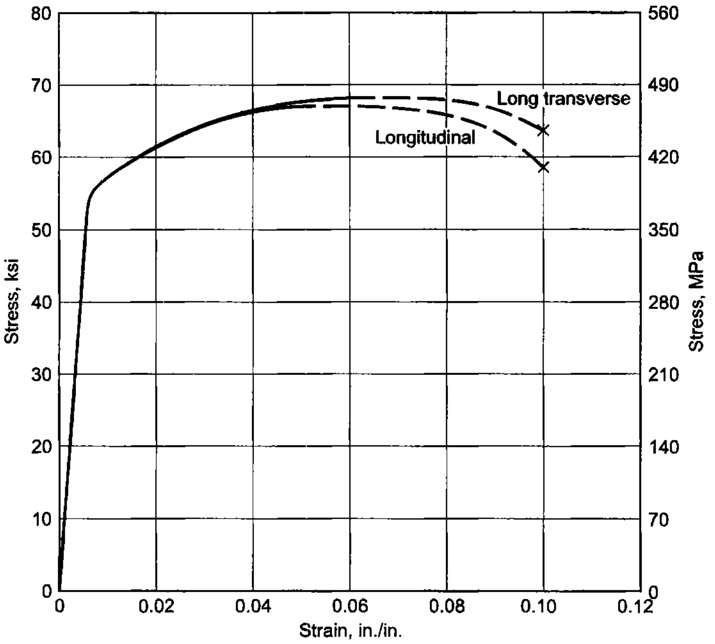
Source: *MIL-HDBK-5H*, 1 Dec 1998, p 3–186



WA.098 2219-T87 aluminum alloy sheet and plate, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for sheet and plate thickness 3.175–25.40 mm (0.125–1.000 in.). Ramberg-Osgood parameter, *n*(L and LT, tension) = 14; *n*(L and LT, compression) = 14. UNS A92219

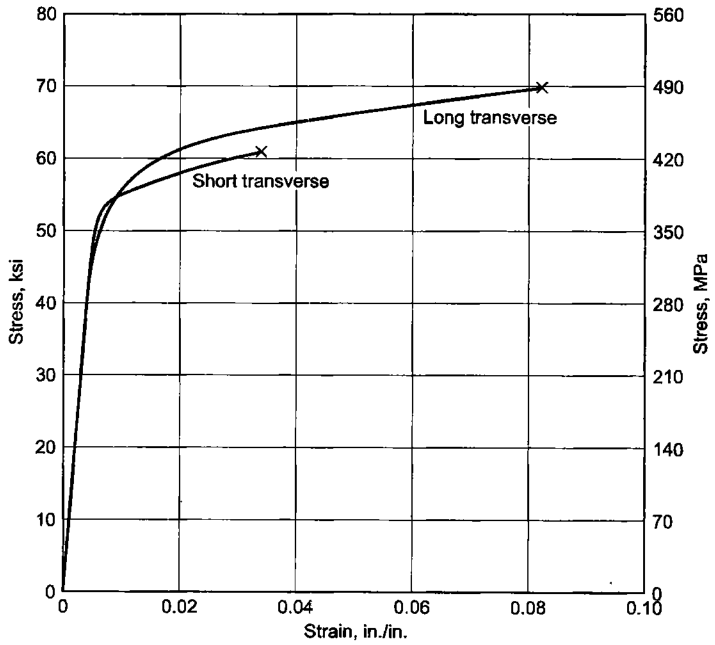
Source: *MIL-HDBK-5H*, 1 Dec 1998, p 3–189



WA.099 2219-T87 aluminum alloy sheet and plate, tensile stress-strain curves (full range)

Tested at room temperature. Typical for sheet and plate thickness 3.175–25.40 mm (0.125–1.000 in.).
UNS A92219

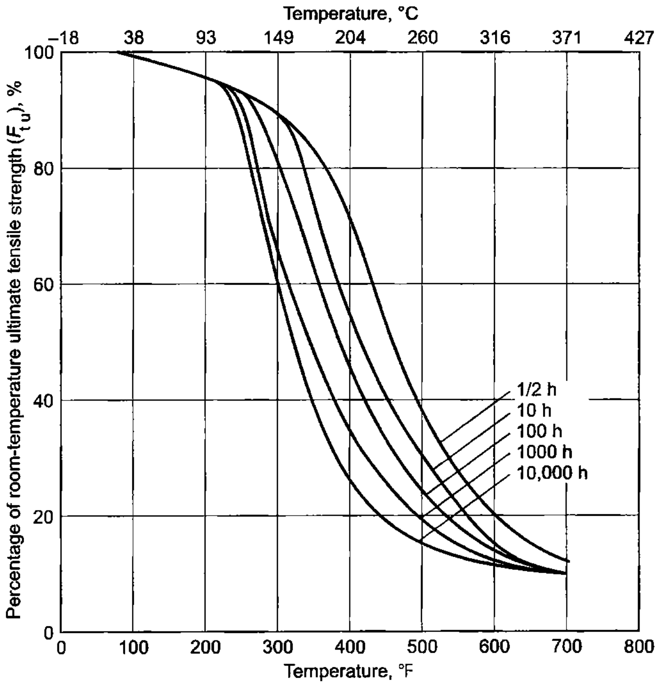
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–190



WA.100 2219-T87 aluminum alloy plate, tensile stress-strain curves (full range)

Tested at room temperature. Typical for plate thickness 40.64–101.6 mm (1.600–4.000 in.). UNS A92219

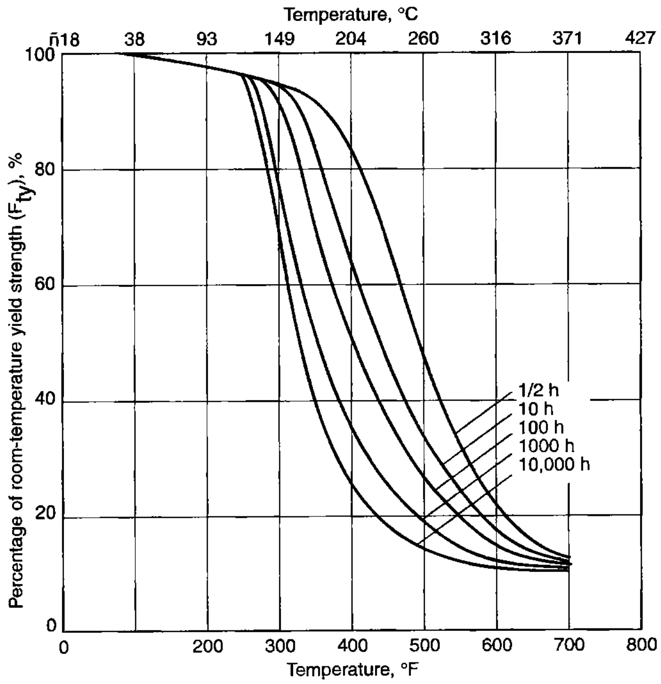
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–192



WA.101 2519-T87 aluminum alloy plate, effect of temperature on ultimate tensile strength

Typical strength at temperature after various exposures up to 10,000 h. UNS A92519

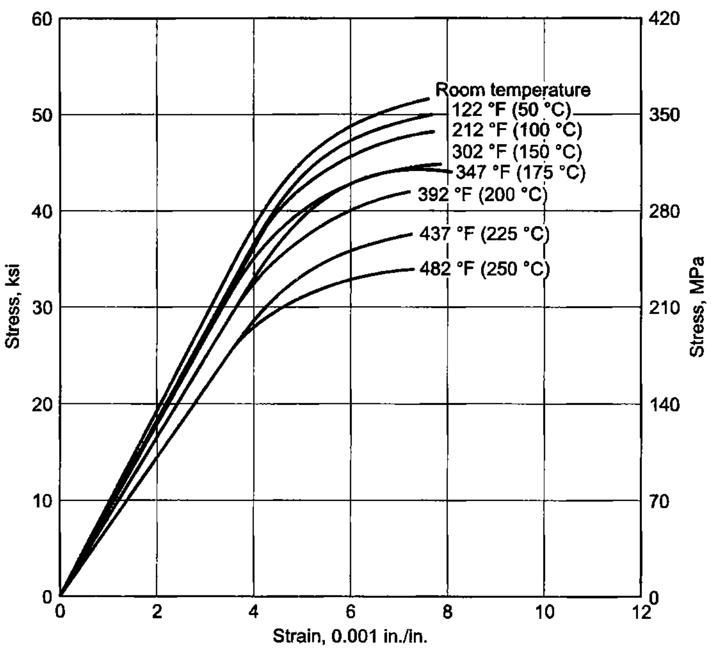
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.102 2519-T87 aluminum alloy plate, effect of temperature on tensile yield strength curves

Typical strength at temperature after various exposures. UNS A92519

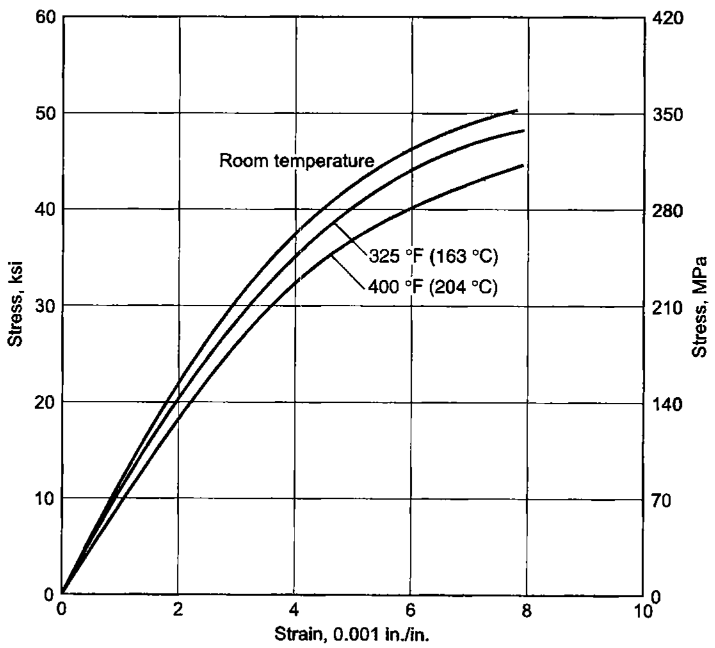
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.103 2618 aluminum alloy clad sheet, tensile stress-strain curves at elevated temperatures

Test direction: transverse. Heat treatment: 530 °C (986 °F), 1 h, water quenched, flattened, and aged, 200 °C (392 °F), 2 h, 1 h soak. Composition: Al-2.5Cu-1.5Mg-1.2Ni-1.0Fe-0.2Si-0.1Ti. UNS A92618

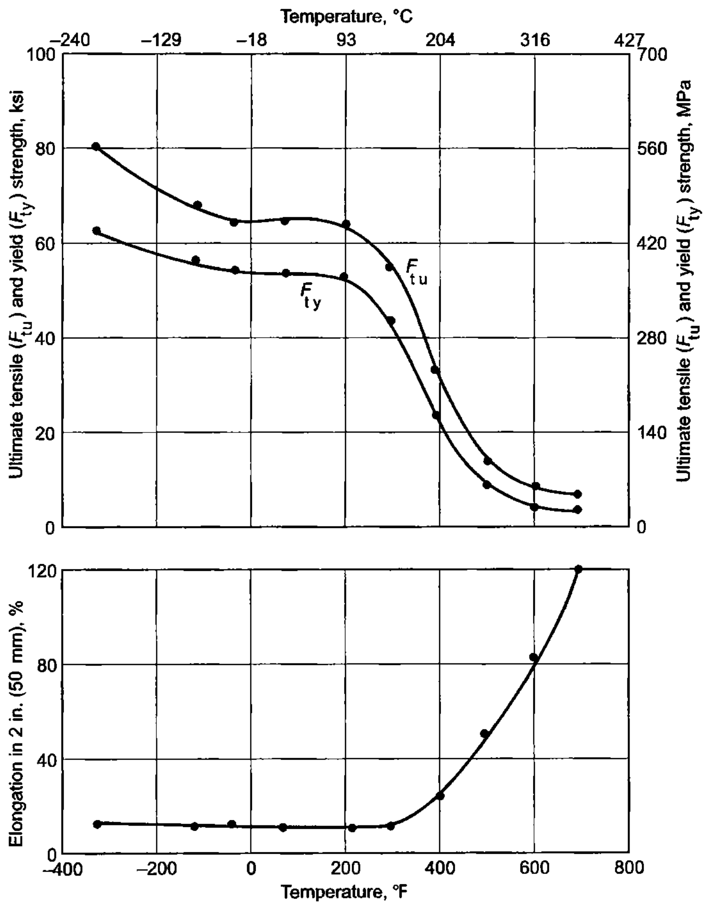
Source: "Hiduminium Elevated Temperature Alloys," High Duty Alloys Ltd., 1956, As published in *Aerostructural Metals Handbook,* Vol 3, Code 3213, CINDAS/Purdue University, 1995, p 6



WA.104 2618-T61 aluminum alloy hand-forged billets, tensile stress-strain curves

Tested at elevated temperatures. Typical for several hand-forged billets: 76.2 × 165.1 mm (3 × 6½ in.), 101.6 × 203.2 mm (4 × 8 in.), and 203.2 × 279.4 mm (8 × 11 in.). Composition: Al-2.5Cu-1.5Mg-1.2Ni-1.0Fe-0.2Si-0.1Ti. UNS A92618

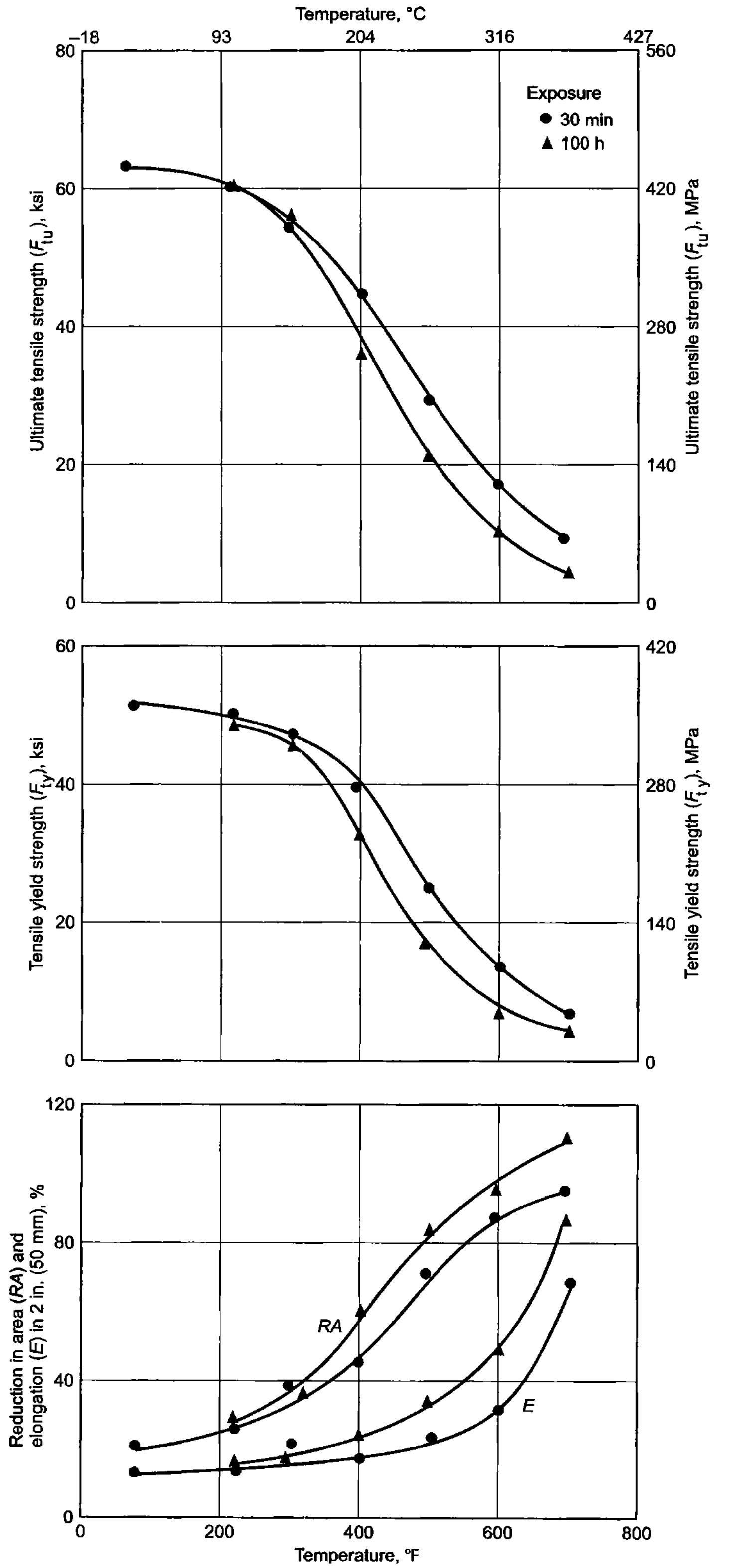
Source: J.A. Lumm, "Mechanical Properties of 2618 Aluminum Alloy," Technical Report AFML-TR-66-238, North American Aviation, Inc., July 1966. As published in *Aerostructural Metals Handbook,* Vol 3, Code 3213, CINDAS/Purdue University, 1995, p 6



WA.105 2618-T61 aluminum alloy forging, tensile properties at various temperatures

Typical. Composition: Al-2.5Cu-1.5Mg-1.2Ni-1.0Fe-0.2Si-0.1Ti. UNS A92618

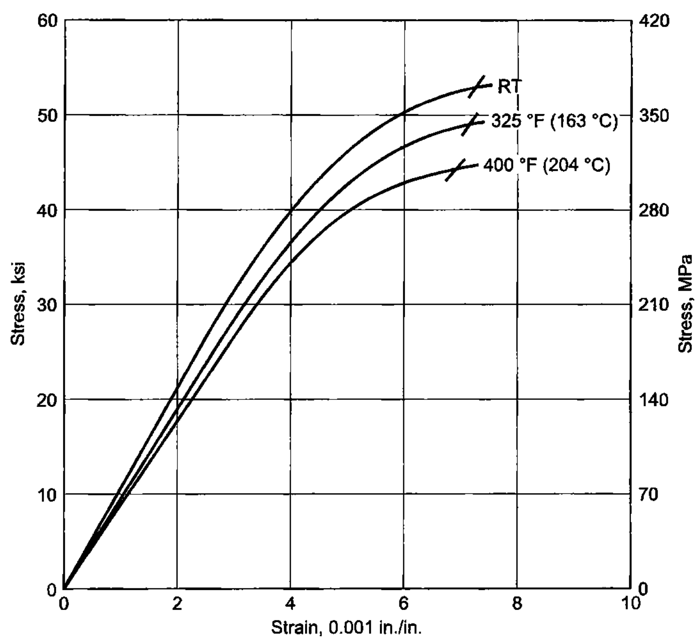
Source: *Aluminum Standards and Data, 1968–69,* The Aluminum Association, 1st ed., April 1968. As published in *Aerostructural Metals Handbook,* Vol 3, Code 3213, CINDAS/Purdue University, 1995, p 9



WA.106 2618-T61 aluminum alloy forged bar, effect of elevated temperatures and exposure time on tensile properties

Composition: Al-2.5Cu-1.5Mg-1.2Ni-1.0Fe-0.2Si-0.1Ti. UNS A92618

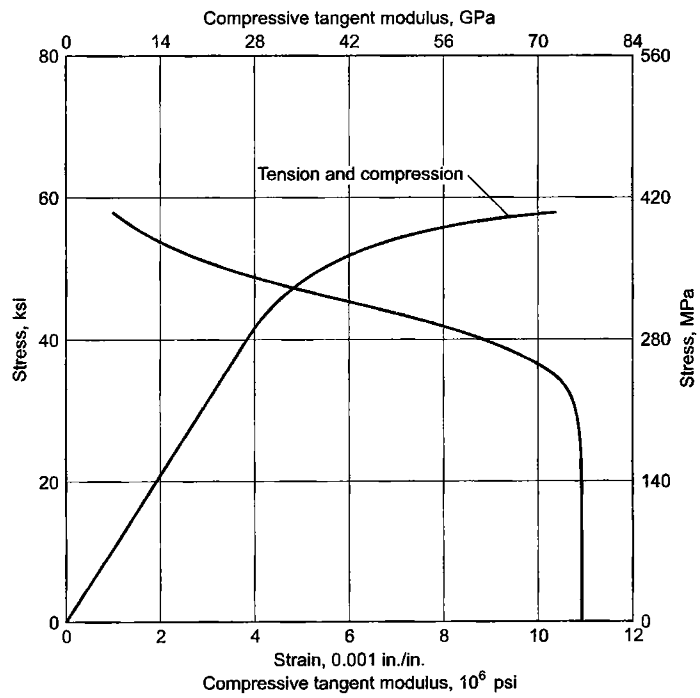
Source: R.H. Voorhees and J.W. Freeman, *Report on the Elevated-Temperature Properties of Aluminum and Magnesium Alloys,* STP 291, ASTM, 1960. As published in *Aerostructural Metals Handbook,* Vol 3, Code 3213, CINDAS/Purdue University, 1995, p 9



WA.107 2618-T61 aluminum alloy hand-forged billets, compressive stress-strain curves

Tested at elevated temperature. Typical for several hand-forged billets: 76.2 × 165.1 mm (3 × 6½ in.), 101.6 × 203.2 mm (4 × 8 in.), and 203.2 × 279.4 mm (8 × 11 in.). Composition: Al-2.5Cu-1.5Mg-1.2Ni-1.0Fe-0.2Si-0.1Ti. UNS A92618

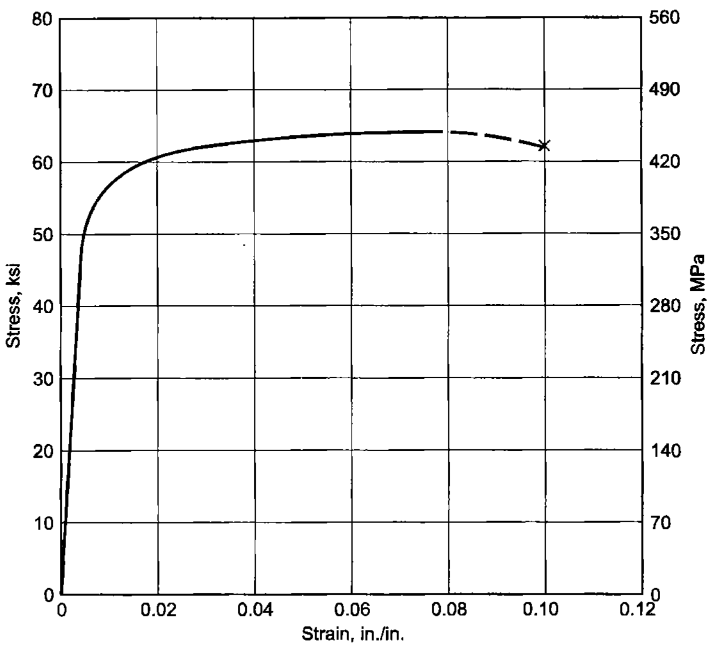
Source: J.A. Lumm, "Mechanical Properties of 2618 Aluminum Alloy," Technical Report AFML-TR-66-238, North American Aviation, Inc., July 1966. As published in *Aerostructural Metals Handbook*, Vol 3, Code 3213, CINDAS/Purdue University, 1995, p 9



WA.108 2618-T61 aluminum alloy forged bar, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: longitudinal. Typical for forged bar thickness 25.40 mm (1.000 in.). Ramberg-Osgood parameter, n(longitudinal, tension) = 13; n(longitudinal, compression) = 13. UNS A92618

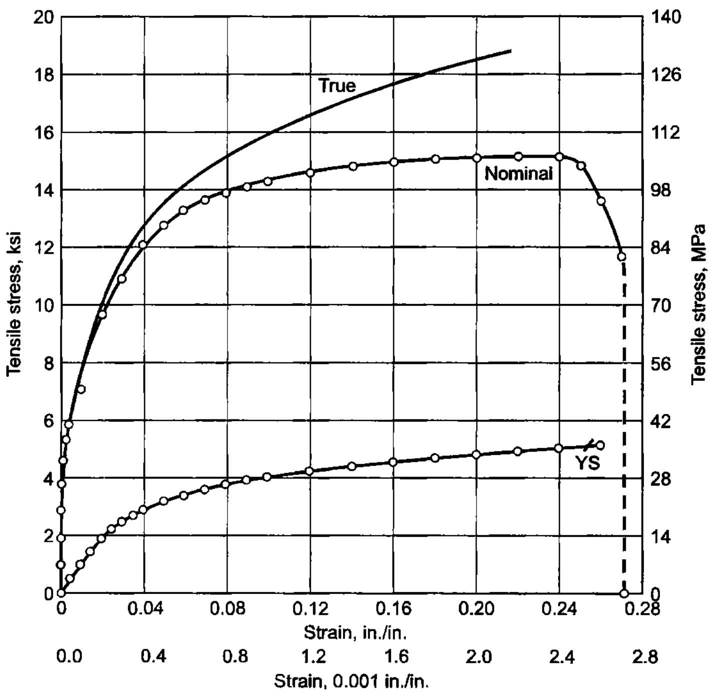
Source: *MIL-HDBK-5H*, 1 Dec 1998, p 3–205



WA.109 2618-T61 aluminum alloy forged bar, tensile stress-strain curve (full range)

Tested at room temperature. Test direction: longitudinal. Typical for forged bar thickness 25.40 mm (1.000 in.). UNS A92618

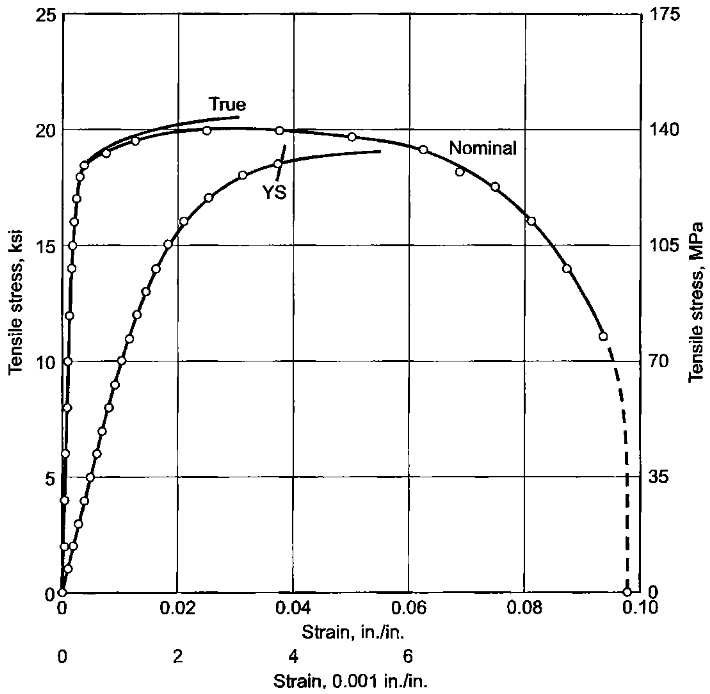
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–206



WA.110 3003-O aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 105 MPa (15.2 ksi). True tensile strength, 130 MPa (18.8 ksi). Nominal yield strength (0.2% offset), 36 MPa (5.2 ksi). Elongation (in 50.8 mm, or 2 in.), 27.2%. Reduction of area, 71%. True strain at maximum load, 21.5%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.24 in the area of uniform plastic deformation. UNS A93003

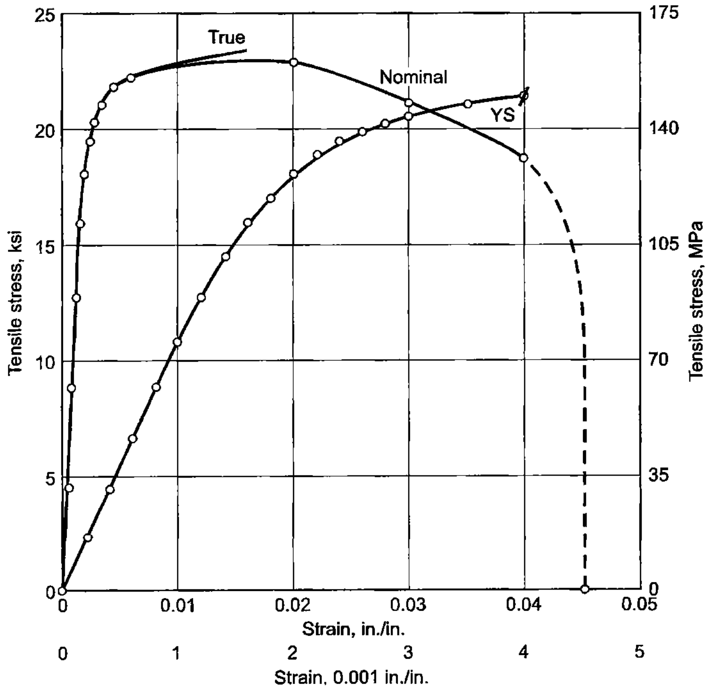
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA



WA.111 3003-H12 aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 138 MPa (20.0 ksi). True tensile strength, 142 MPa (20.6 ksi). Nominal yield strength (0.2% offset), 119 MPa (17.3 ksi). Elongation (in 50.8 mm, or 2 in.), 9.8%. Reduction of area, 76%. True strain at maximum load, 3.0%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.06 in the area of uniform plastic deformation. UNS A93003

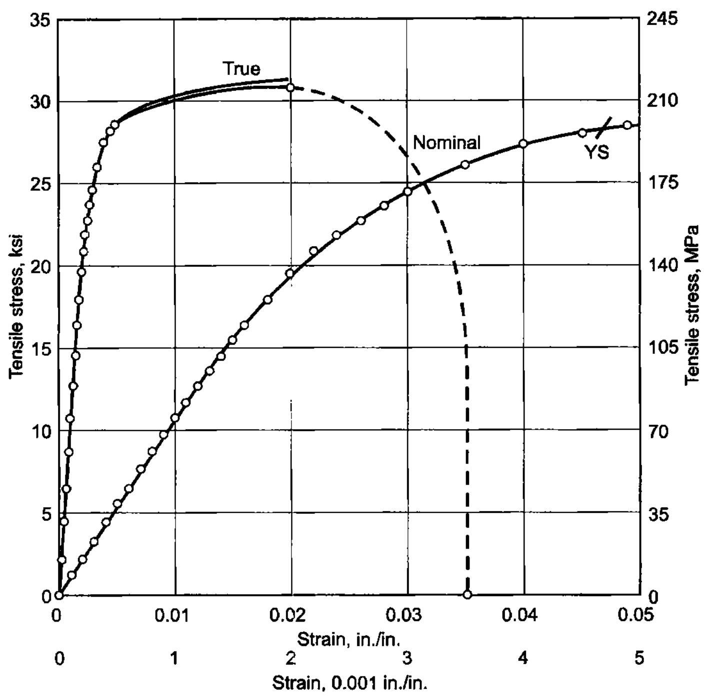
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, July 1954



WA.112 3003-H14 aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 159 MPa (23.0 ksi). True tensile strength, 161 MPa (23.4 ksi). Nominal yield strength (0.2% offset), 147 MPa (21.3 ksi). Elongation (in 50.8 mm, or 2 in.), 4.5%. Reduction of area, 54%. True strain at maximum load, 1.6%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.05 in the area of uniform plastic deformation. UNS A93003

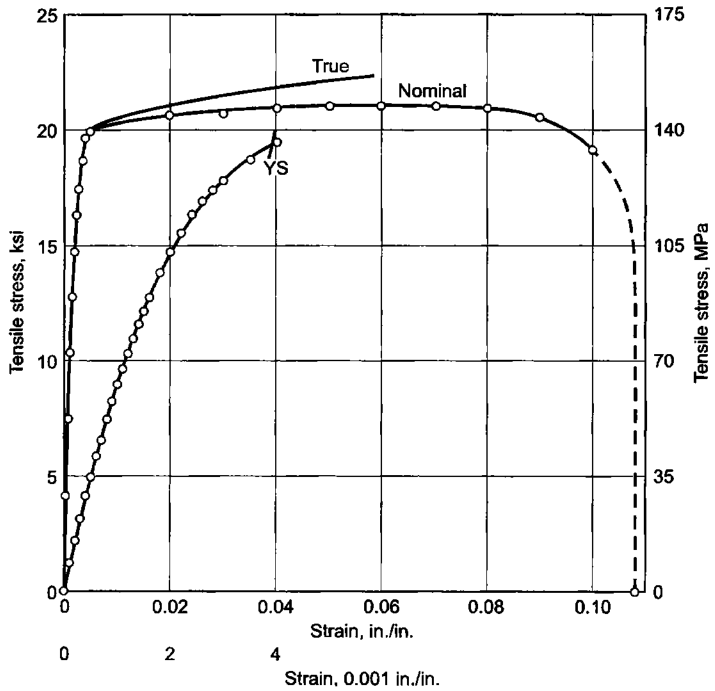
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA



WA.113 3003-H18 aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 212 MPa (30.8 ksi). True tensile strength, 216 MPa (31.3 ksi). Nominal yield strength (0.2% offset), 195 MPa (28.3 ksi). Elongation (in 50.8 mm, or 2 in.), 3.5%. Reduction of area, 34%. True strain at maximum load, 2.0%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.06 in the area of uniform plastic deformation. UNS A93003

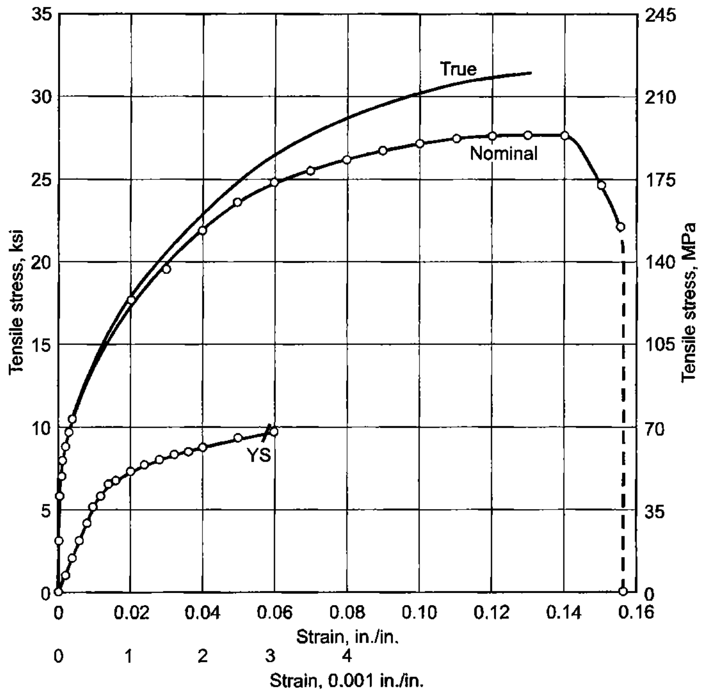
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, July 1954



WA.114 3003-H24 aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 145 MPa (21.0 ksi). True tensile strength, 223 MPa (32.3 ksi). Nominal yield strength (0.2% offset), 133 MPa (19.3 ksi). Elongation (in 50.8 mm, or 2 in.), 10.8%. Reduction of area, 55%. True strain at maximum load, 5.8%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.06 in the area of uniform plastic deformation. UNS A93003

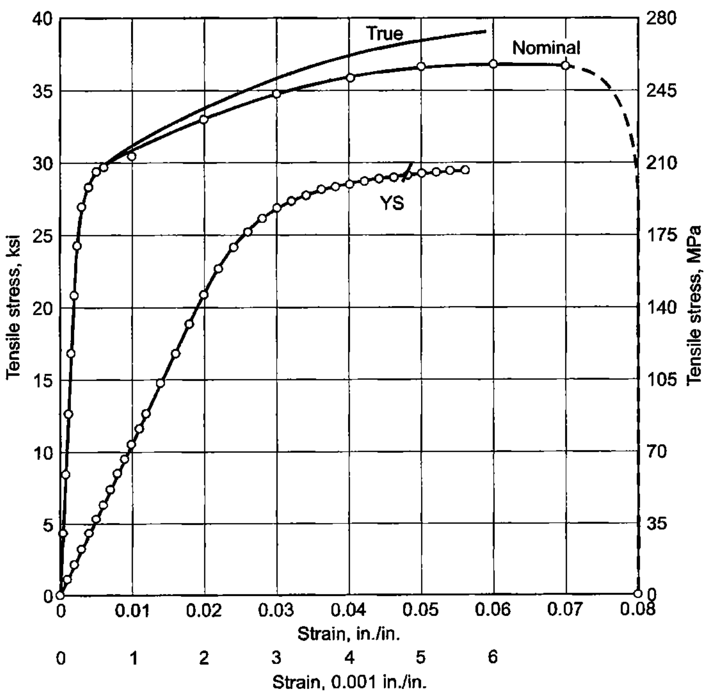
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, July 1954



WA.115 3004-O aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 191 MPa (27.7 ksi). True tensile strength, 218 MPa (31.6 ksi). Nominal yield strength (0.2% offset), 67 MPa (9.7 ksi). Elongation (in 50.8 mm, or 2 in.), 15.6%. Reduction of area, 47%. True strain at maximum load, 13.1%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.24 in the area of uniform plastic deformation. UNS A93004

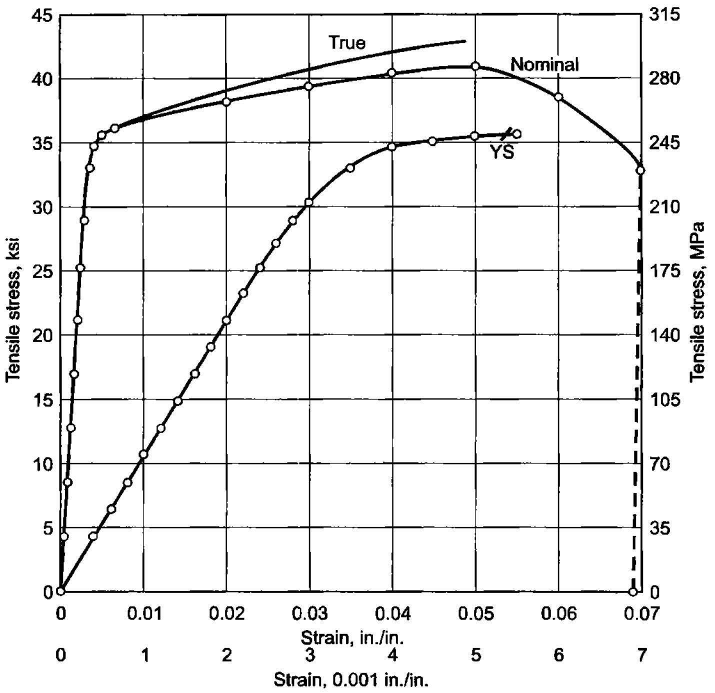
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, July 1954



WA.116 3004-H34 aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 255 MPa (37.0 ksi). True tensile strength, 270 MPa (39.2 ksi). Nominal yield strength (0.2% offset), 201 MPa (29.2 ksi). Elongation (in 50.8 mm, or 2 in.), 8.0%. Reduction of area, 54%. True strain at maximum load, 5.8%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.14 in the area of uniform plastic deformation. UNS A93004

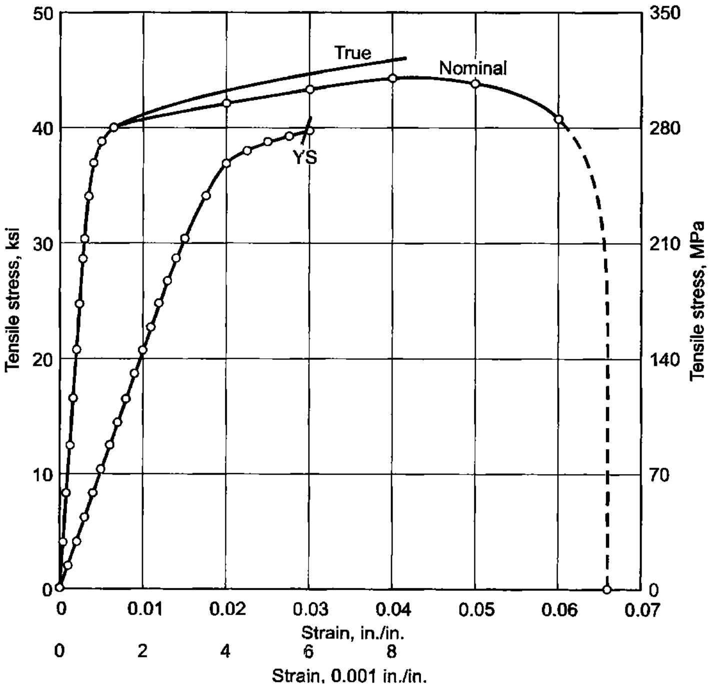
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, July 1954



WA.117 3004-H38 aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 283 MPa (41.0 ksi). True tensile strength, 317 MPa (46.0 ksi). Nominal yield strength (0.2% offset), 247 MPa (35.8 ksi). Elongation (in 50.8 mm, or 2 in.), 6.9%. Reduction of area, 46%. True strain at maximum load, 4.9%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.10 in the area of uniform plastic deformation. UNS A93004

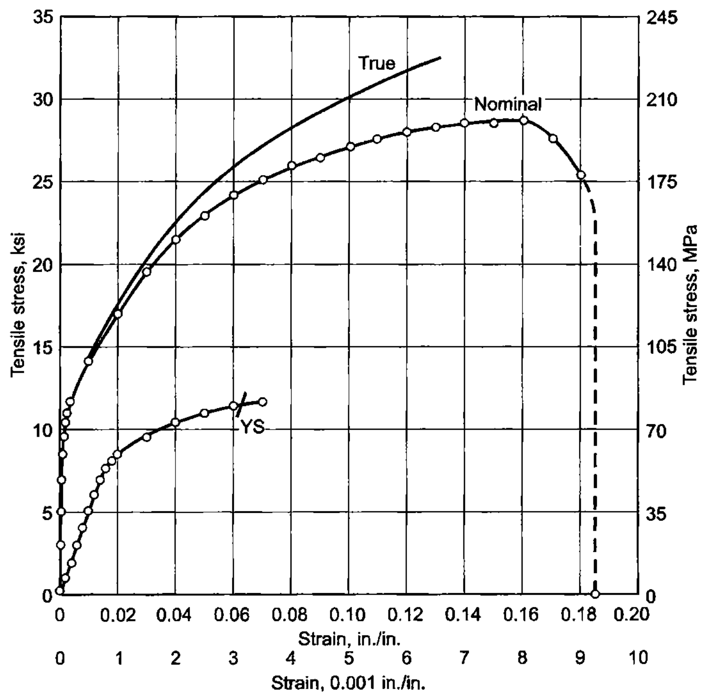
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, July 1954



WA.118 3004-H39 aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 307 MPa (44.5 ksi). True tensile strength, 314 MPa (45.6 ksi). Nominal yield strength (0.2% offset), 273 MPa (39.6 ksi). Elongation (in 50.8 mm, or 2 in.), 6.6%. Reduction of area, 40%. True strain at maximum load, 4.2%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.09 in the area of uniform plastic deformation. UNS A93004

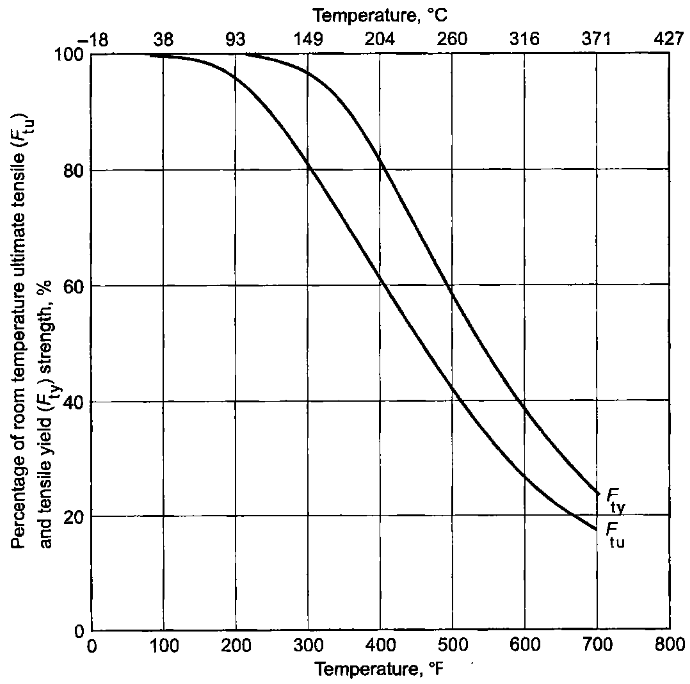
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, July 1954



WA.119 5052-O aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 198 MPa (28.7 ksi). True tensile strength, 230 MPa (33.3 ksi). Nominal yield strength (0.2% offset), 71.0 MPa (10.3 ksi). Elongation (in 50.8 mm, or 2 in.), 18.5%. Reduction of area, 70%. True strain at maximum load, 14.8%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.20 in the area of uniform plastic deformation. UNS A95052

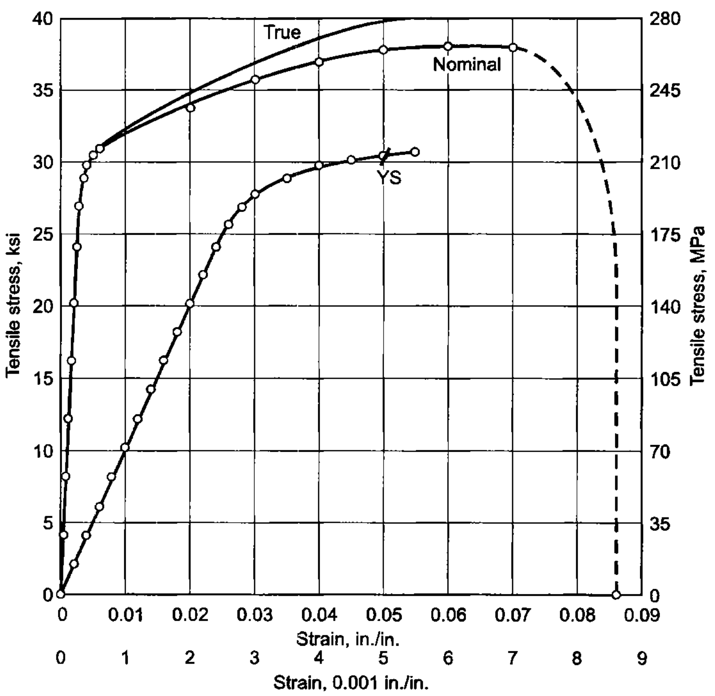
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, July 1952



WA.120 5052-O aluminum alloy, all products, effect of elevated temperature on tensile properties

Strength at temperature after exposure up to 10,000 h. UNS A95052

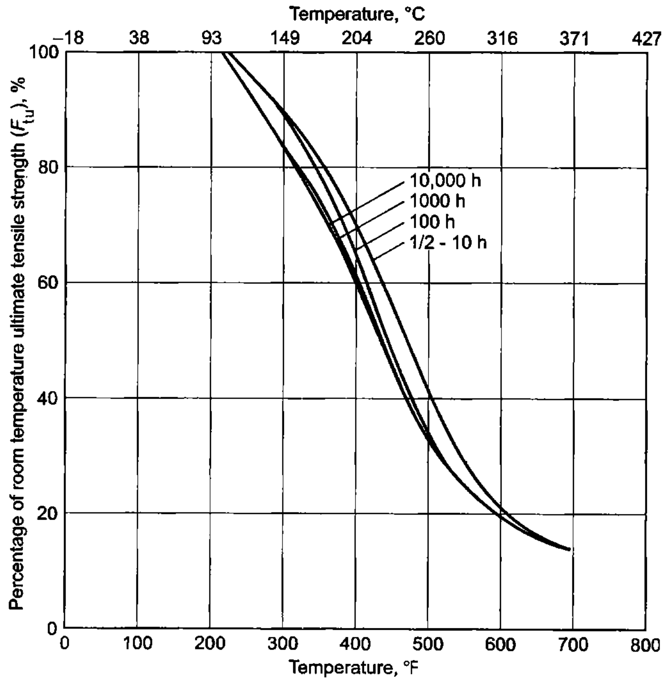
Source: *MIL-HDBK-5H*, 1 Dec 1998, p 3–212



WA.121 5052-H34 aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 262 MPa (38.0 ksi). True tensile strength, 279 MPa (40.5 ksi). Nominal yield strength (0.2% offset), 211 MPa (30.6 ksi). Elongation (in 50.8 mm, or 2 in.), 8.6%. Reduction of area, 58%. True strain at maximum load, 5.8%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.14 in the area of uniform plastic deformation. UNS A95052

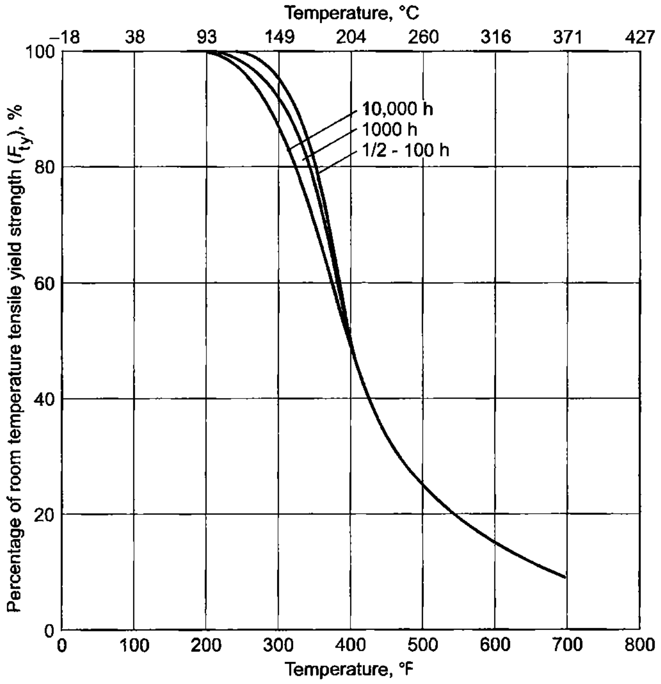
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA



WA.122 5052-H34 aluminum alloy sheet and plate, effect of elevated temperature on ultimate tensile strength

Strength at temperature after exposure up to 10,000 h. UNS A95052

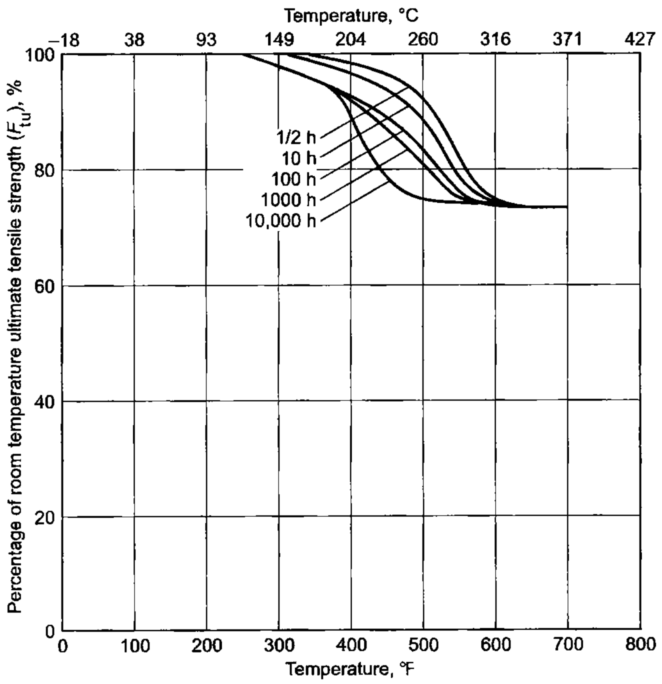
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–214



WA.123 5052-H34 aluminum alloy sheet and plate, effect of elevated temperature on tensile yield strength

Strength at temperature after exposure up to 10,000 h. UNS A95052

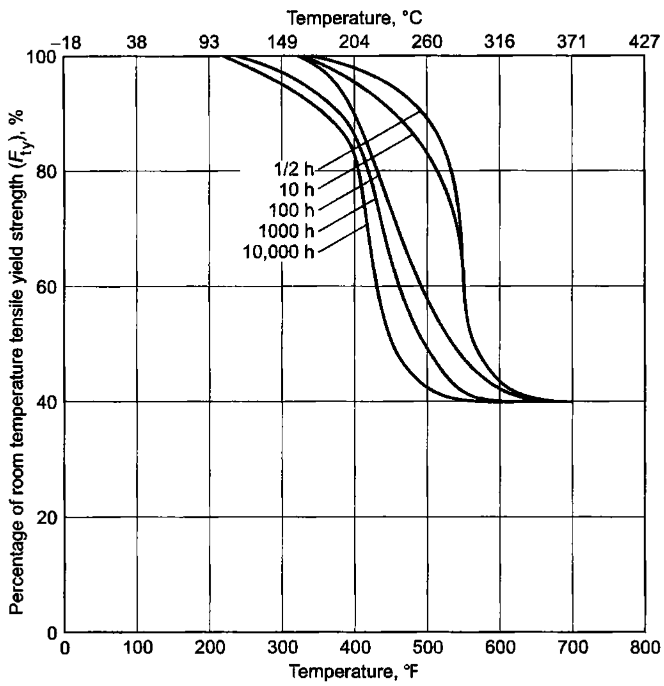
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–214



WA.124 5052-H34 aluminum alloy sheet and plate, effect of elevated temperature on ultimate tensile strength

Strength at temperature after exposure up to 10,000 h, as indicated. UNS A95052

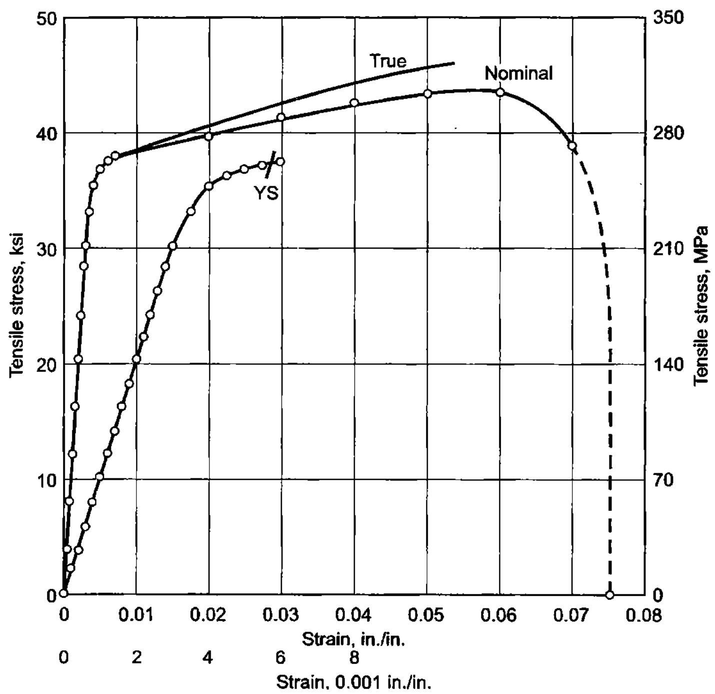
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–215



WA.125 5052-H34 aluminum alloy sheet and plate, effect of elevated temperature tensile yield strength

Strength at temperature after exposure up to 10,000 h, as indicated. UNS A95052

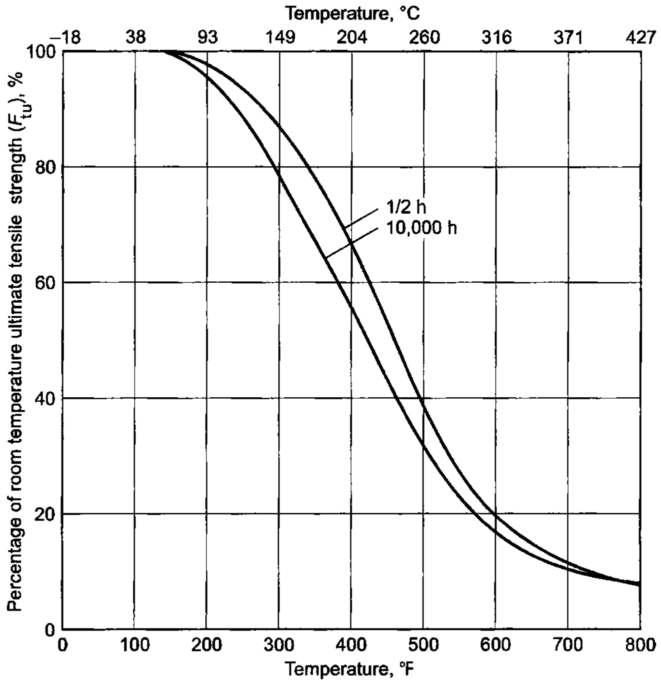
Source: *MIL-HDBK-5H*, 1 Dec 1998, p 3–215



WA.126 5052-H38 aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 301 MPa (43.6 ksi). True tensile strength, 317 MPa (46.0 ksi). Nominal yield strength (0.2% offset), 259 MPa (37.5 ksi). Elongation (in 50.8 mm, or 2 in.), 7.5%. Reduction of area, 49%. True strain at maximum load, 5.4%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.12 in the area of uniform plastic deformation. UNS A95052

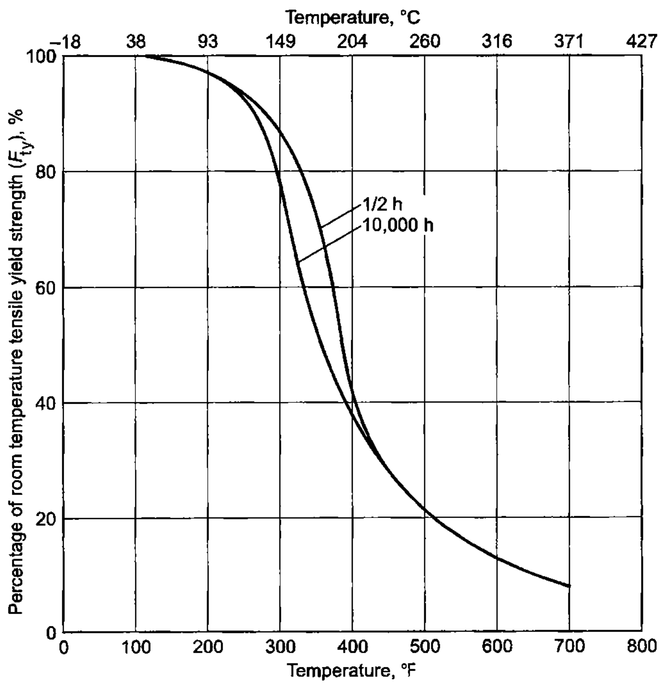
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, July 1954



WA.127 5052-H38 aluminum alloy, all products, effect of temperature on ultimate tensile strength

Strength at temperature after exposure up to 10,000 h. UNS A95052

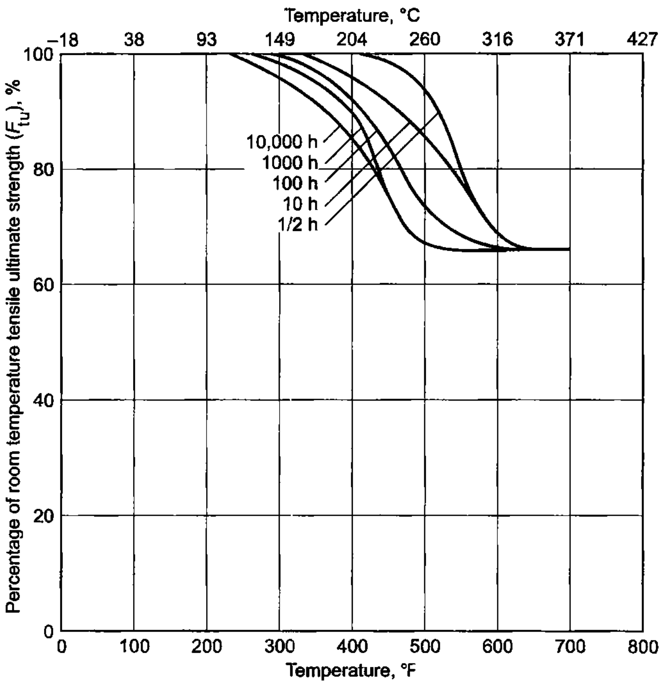
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–217



WA.128 5052-H38 aluminum alloy, all products, effect of temperature on tensile yield strength

Strength at temperature after exposure up to 10,000 h. UNS A95052

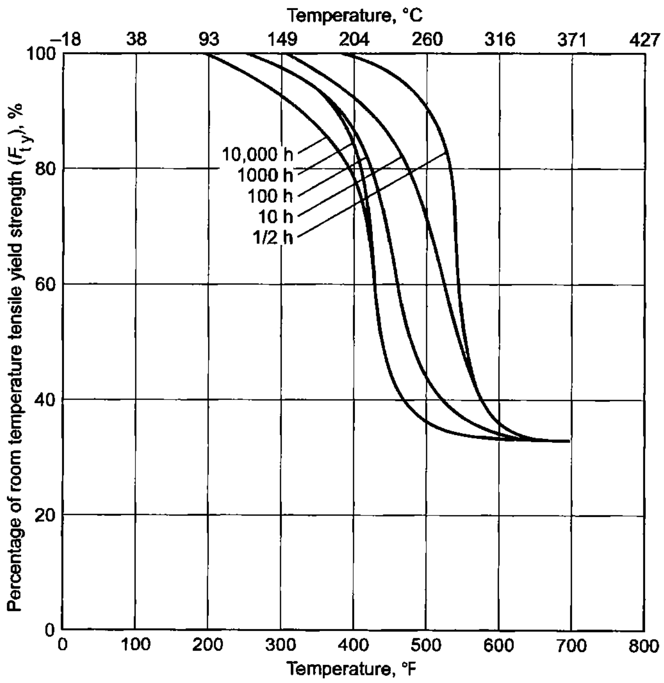
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–217



WA.129 5052-H38, aluminum alloy, all products, effect of exposure at elevated temperatures on room-temperature ultimate tensile strength

Exposure up to 10,000 h. UNS A95052

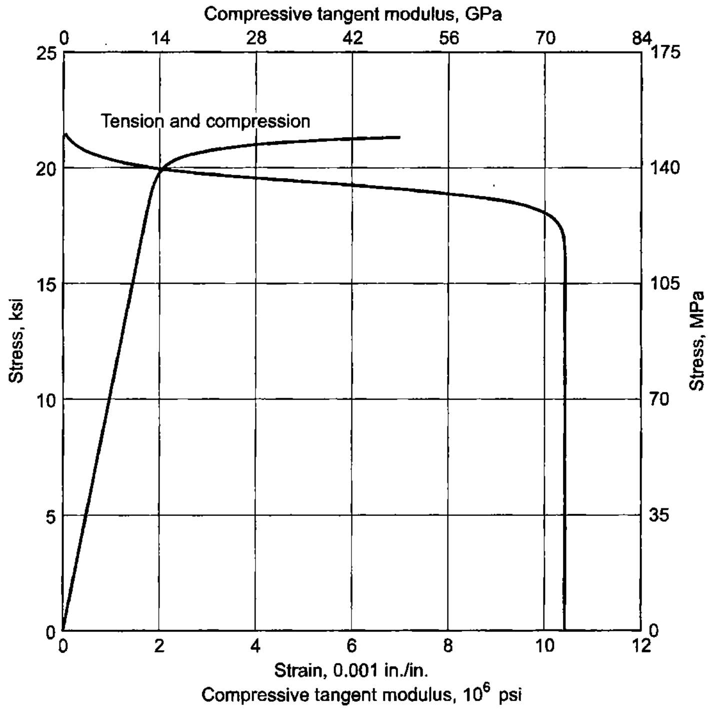
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–218



WA.130 5052-H38 aluminum alloy, all products, effect of exposure at elevated temperatures on room-temperature tensile yield strength

Exposure up to 10,000 h. UNS A95052

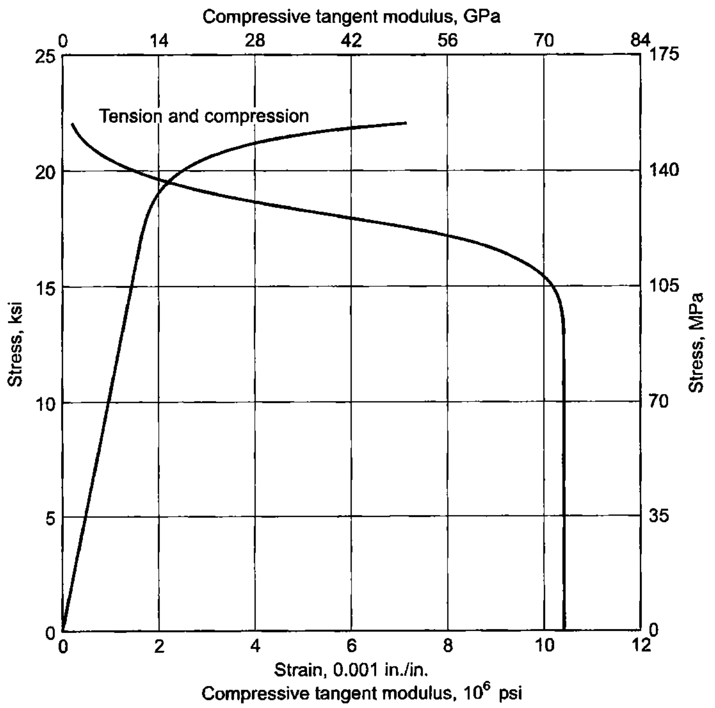
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–218



WA.131 5083-O aluminum alloy sheet, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: longitudinal and long transverse. Typical. Ramberg-Osgood parameter, n(longitudinal and long transverse, tension) = 50; n(longitudinal and long transverse, compression) = 50. UNS A95083

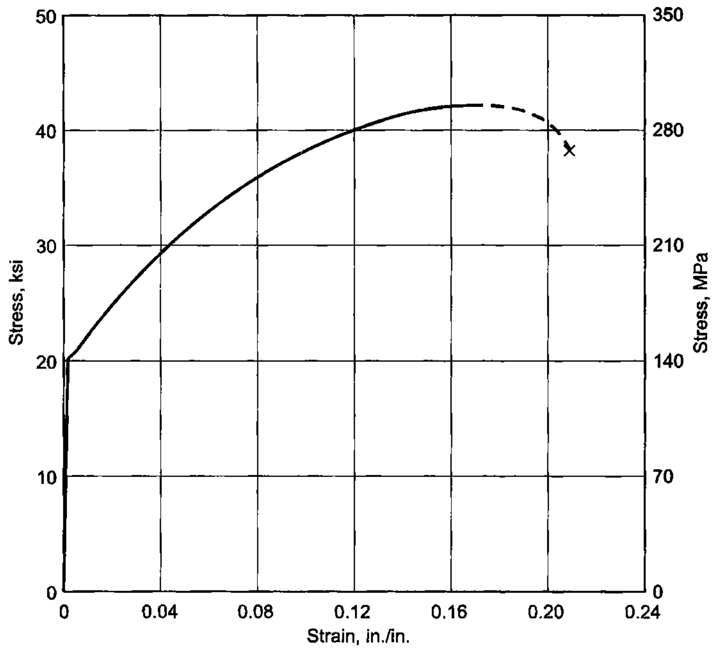
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–224



WA.132 5083-O aluminum alloy plate, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: longitudinal and long transverse. Typical. Ramberg-Osgood parameter, n(longitudinal and long transverse, tension) = 21; n(longitudinal and long transverse, compression) = 21. UNS A95083

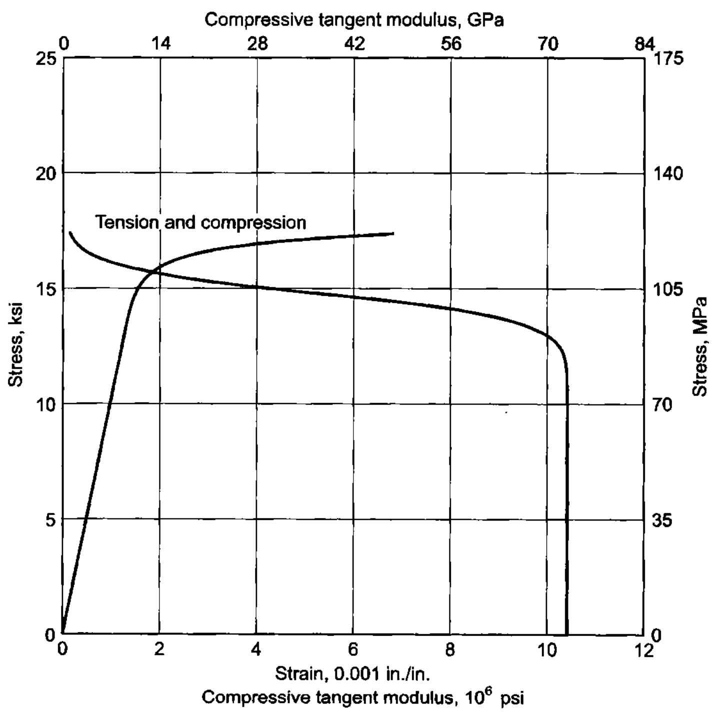
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–224



WA.133 5083-O aluminum alloy plate, tensile stress-strain curve (full range)

Tested at room temperature. Test direction: longitudinal. Typical. UNS A95083

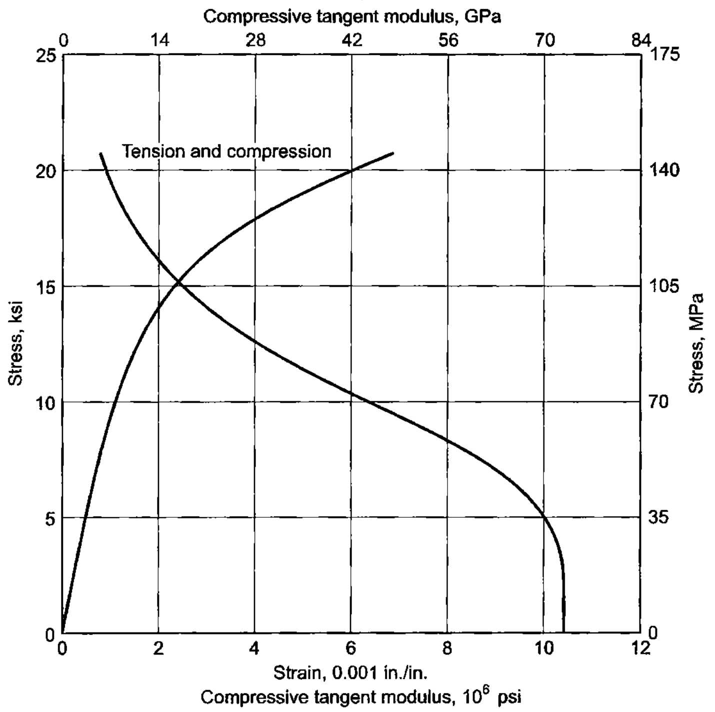
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–225



WA.134 5086-O aluminum alloy sheet, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: longitudinal and long transverse. Typical. Ramberg-Osgood parameter, n(longitudinal and long transverse, tension) = 27; n(longitudinal and long transverse, compression) = 27. UNS A95086

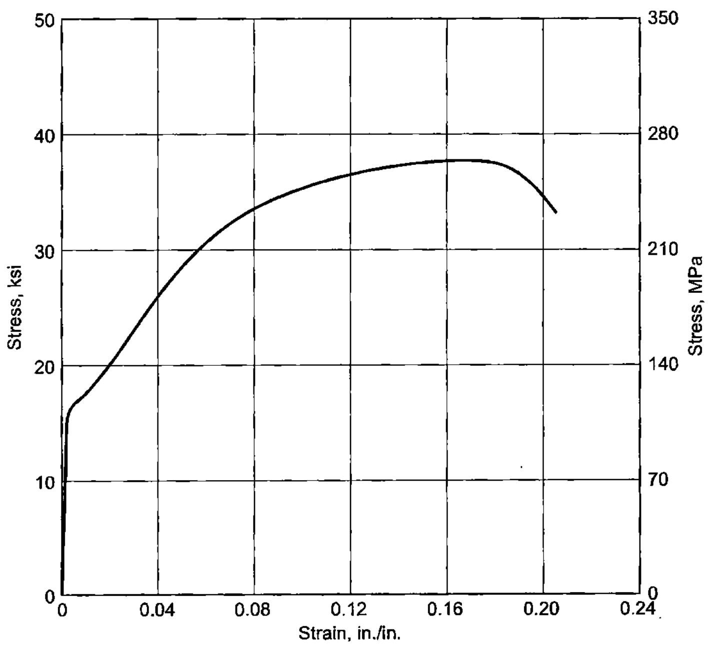
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–229



WA.135 5086-O aluminum alloy plate and extrusion, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: longitudinal and long transverse. Typical. Ramberg-Osgood parameter, n(longitudinal and long transverse, tension) = 5.0; n(longitudinal and long transverse, compression) = 5.0.
UNS A95086

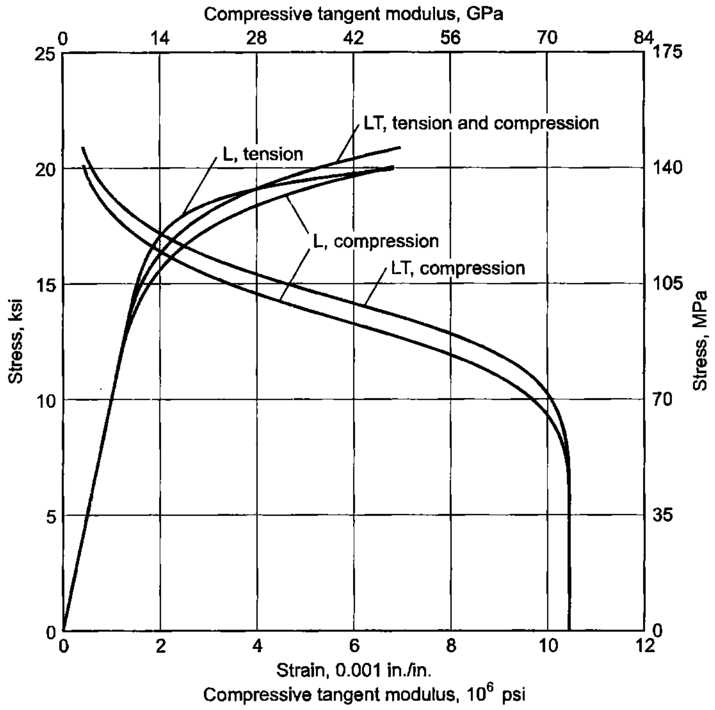
Source: *MIL-HDBK-5H*, 1 Dec 1998, p 3–229



WA.136 5086-O aluminum alloy 5086-O sheet, tensile stress-strain curve (full range)

Tested at room temperature. Test direction: longitudinal. Typical. UNS A95086

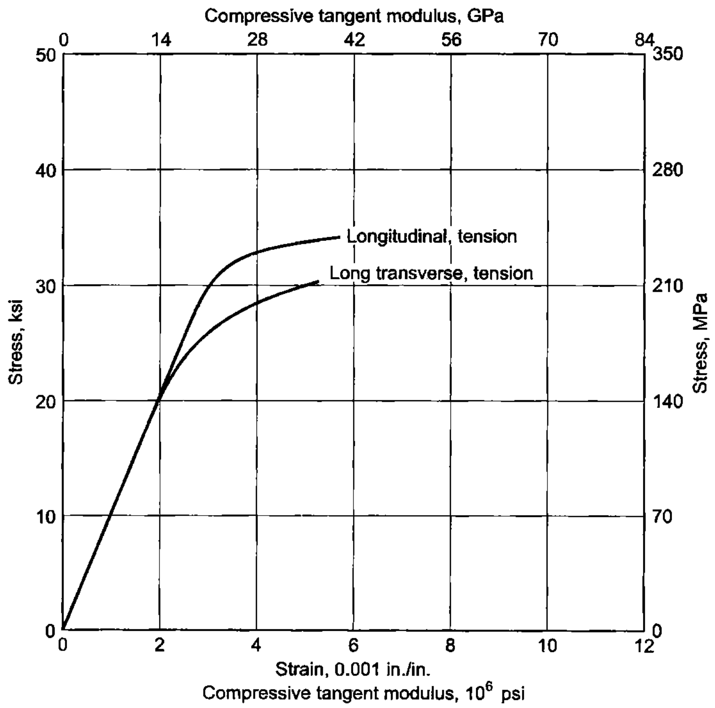
Source: *MIL-HDBK-5H*, 1 Dec 1998, p 3–230



WA.137 5086-H112 aluminum alloy plate, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for plate thickness 12.70–25.40 mm (0.500–1.000 in.). Ramberg-Osgood parameter, n(L, tension) = 18; n(LT, tension) = 10; n(L, compression) = 9.3; n(LT, compression) = 10.
UNS A95086

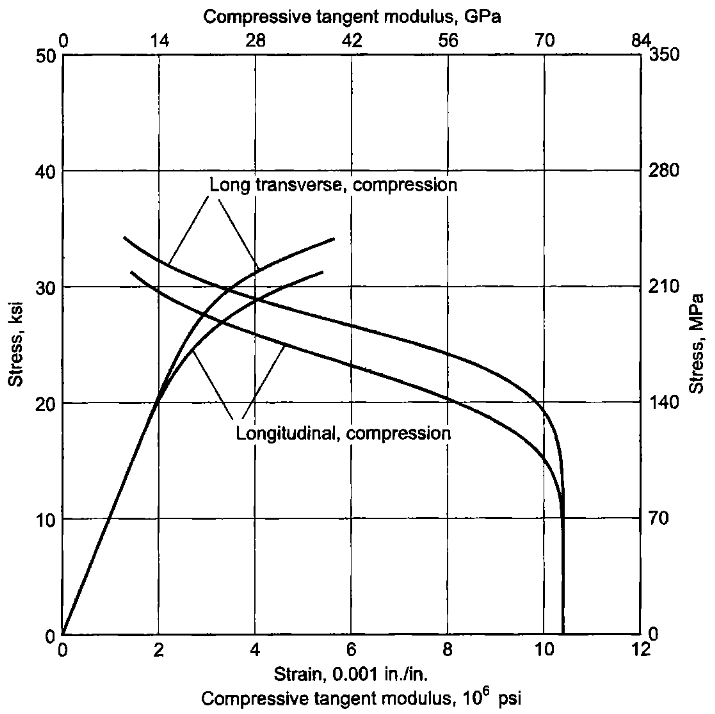
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–234



WA.138 5086-H32 aluminum alloy sheet, tensile stress-strain curves

Tested at room temperature. Typical for sheet thickness 3.175 mm (0.125 in.). Ramberg-Osgood parameter, n(longitudinal, tension) = 28; n(long transverse, tension) = 10.
UNS A95086

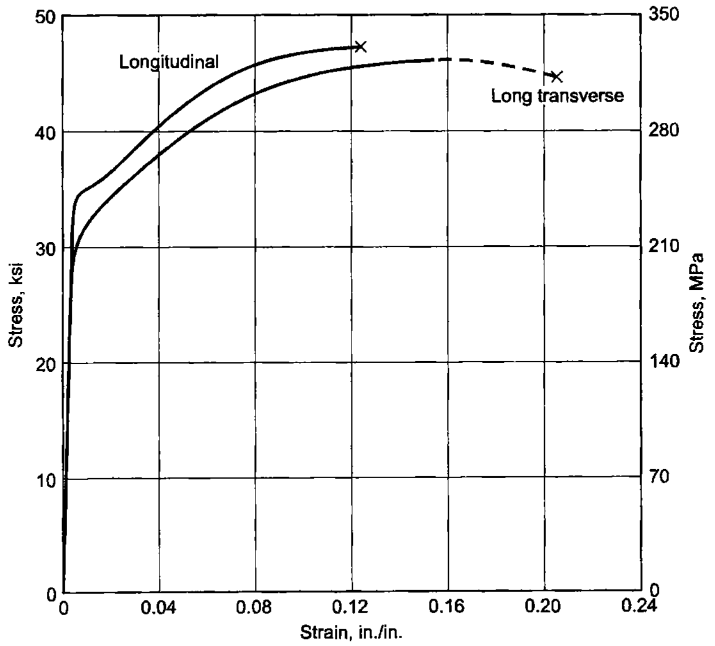
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–230



WA.139 5086-H32 aluminum alloy sheet, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for sheet thickness 3.175 mm (0.125 in.). Ramberg-Osgood parameter, *n*(longitudinal, compression) = 8.0; *n*(long transverse, compression) = 10. UNS A95086

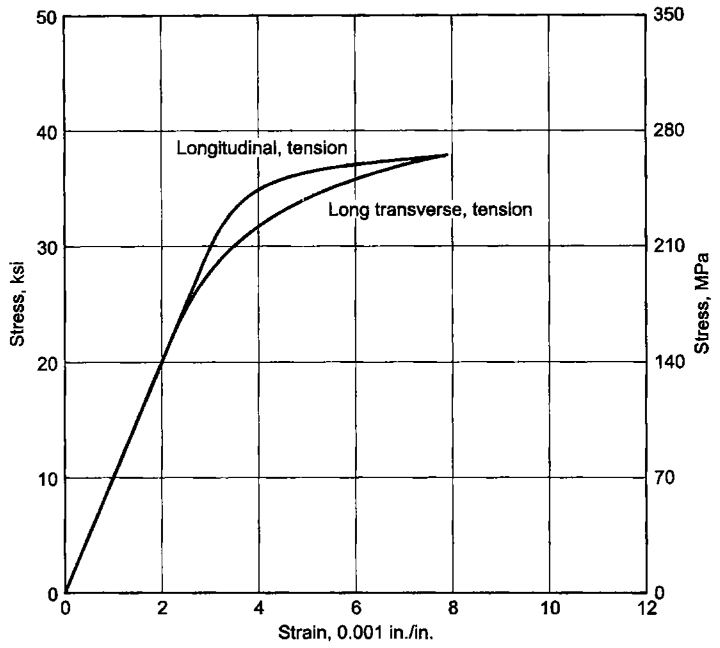
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–231



WA.140 5086-H32 aluminum alloy sheet, tensile stress-strain curves (full range)

Tested at room temperature. Typical for sheet thickness 3.175 mm (0.125 in.). Based on one lot. UNS A95086

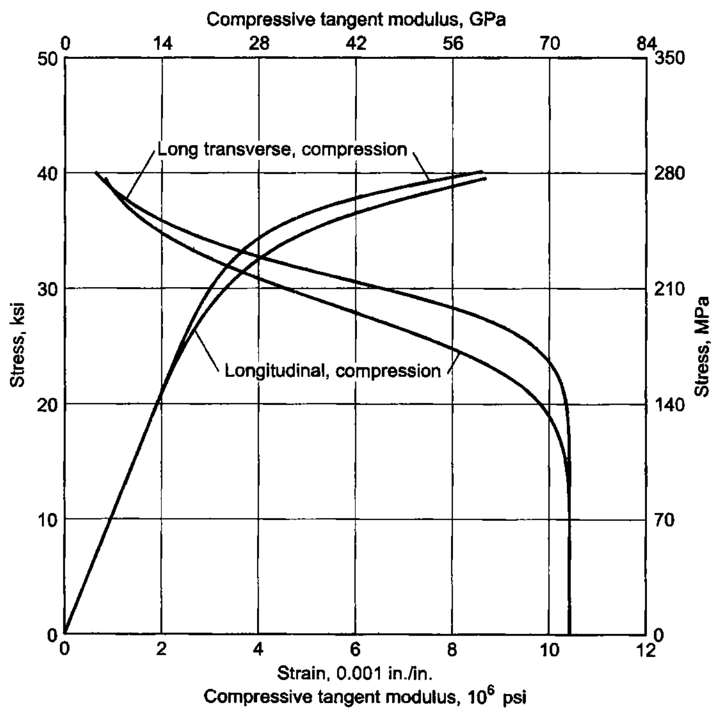
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–231



WA.141 5086-H34 aluminum alloy sheet, tensile stress-strain curves

Tested at room temperature. Typical. Ramberg-Osgood parameter, *n*(longitudinal, tension) = 24; *n*(long transverse, tension) = 9.3. UNS A95086

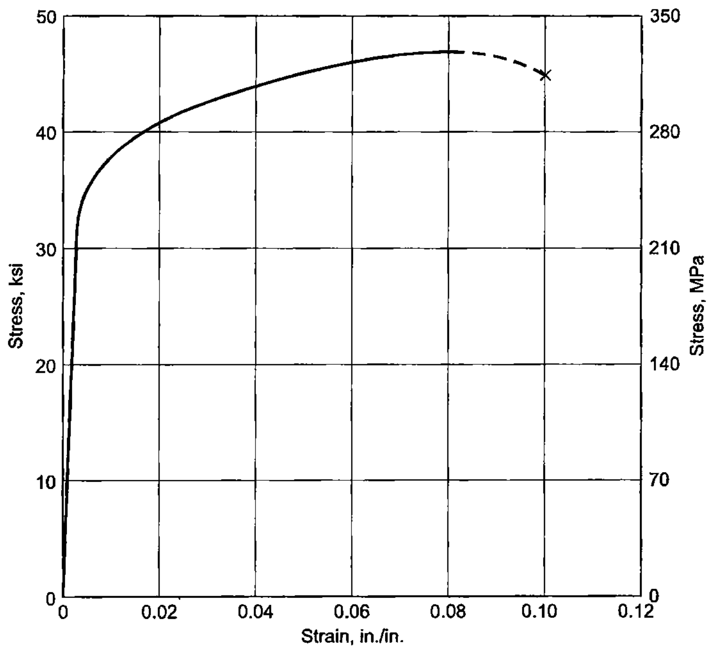
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–231



WA.142 5086-H34 aluminum alloy sheet, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical. Ramberg-Osgood parameter, *n*(longitudinal, compression) = 8.6; *n*(long transverse, compression) = 12. UNS A95086

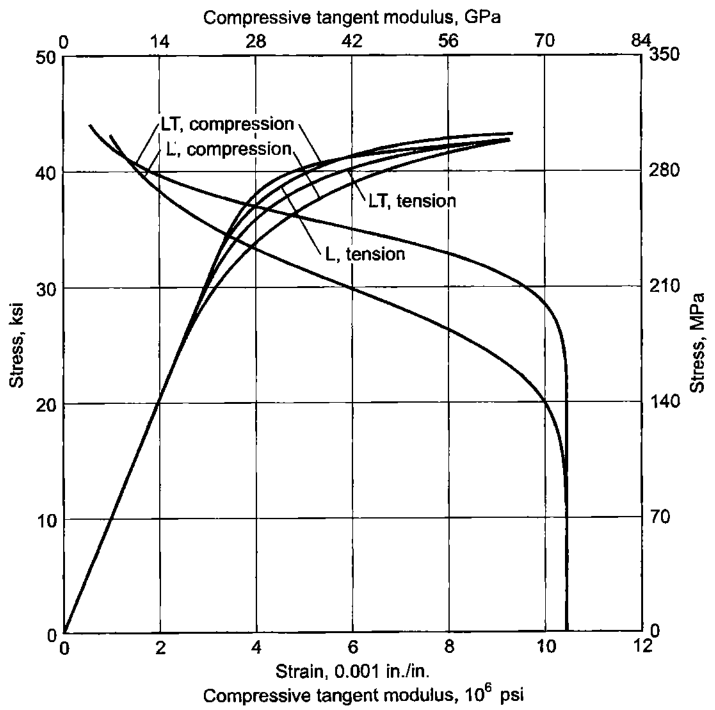
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–232



WA.143 5086-H34 aluminum alloy sheet, tensile stress-strain curve (full range)

Tested at room temperature. Test direction: longitudinal. Typical. UNS A95086

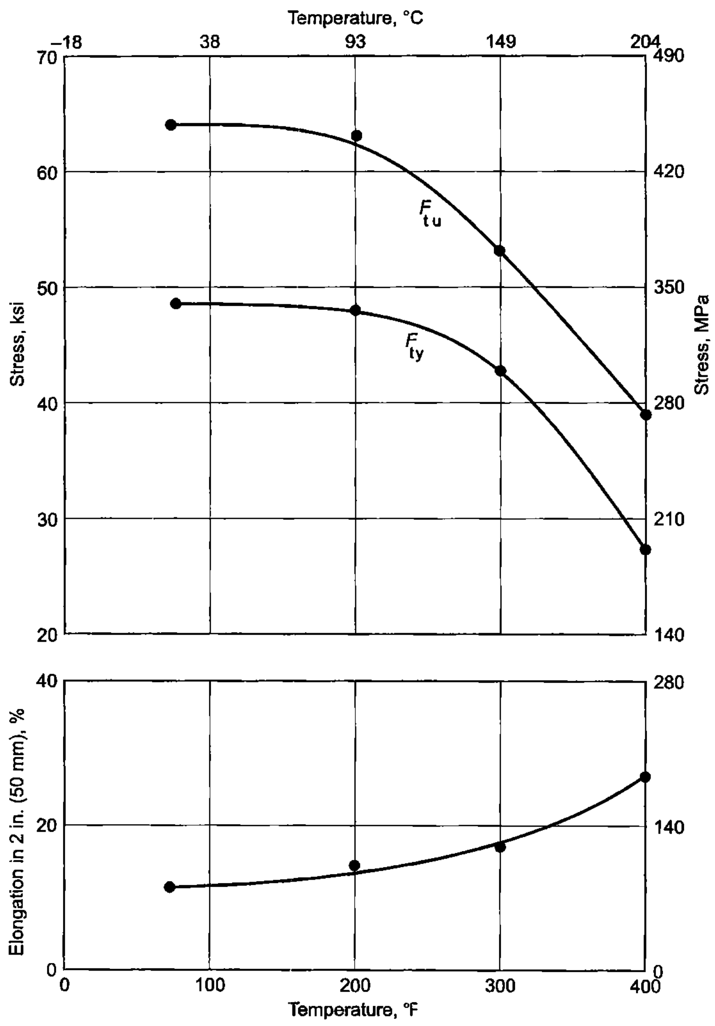
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–233



WA.144 5086-H36 aluminum alloy sheet, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical. Ramberg-Osgood parameter, n(L, tension) = 27; n(LT, tension) = 13; n(L, compression) = 8.0; n(LT, compression) = 15. UNS A95086

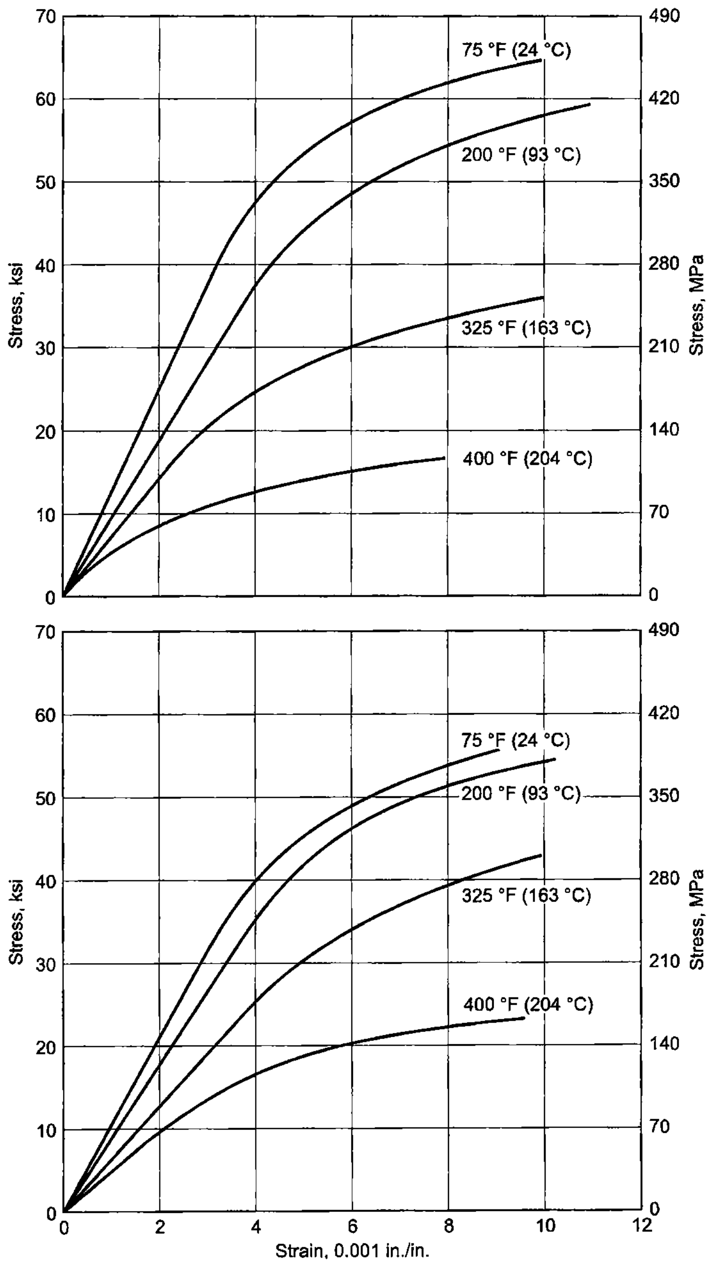
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–233



WA.145 X5090-H36 aluminum alloy sheet, effect of temperature on tensile properties after 30 min at test temperature

Test direction: longitudinal. F_{tu}, ultimate tensile strength; F_{ty}, tensile yield strength. Composition: Al-7Mg-0.2Cr-0.005B-0.005Be

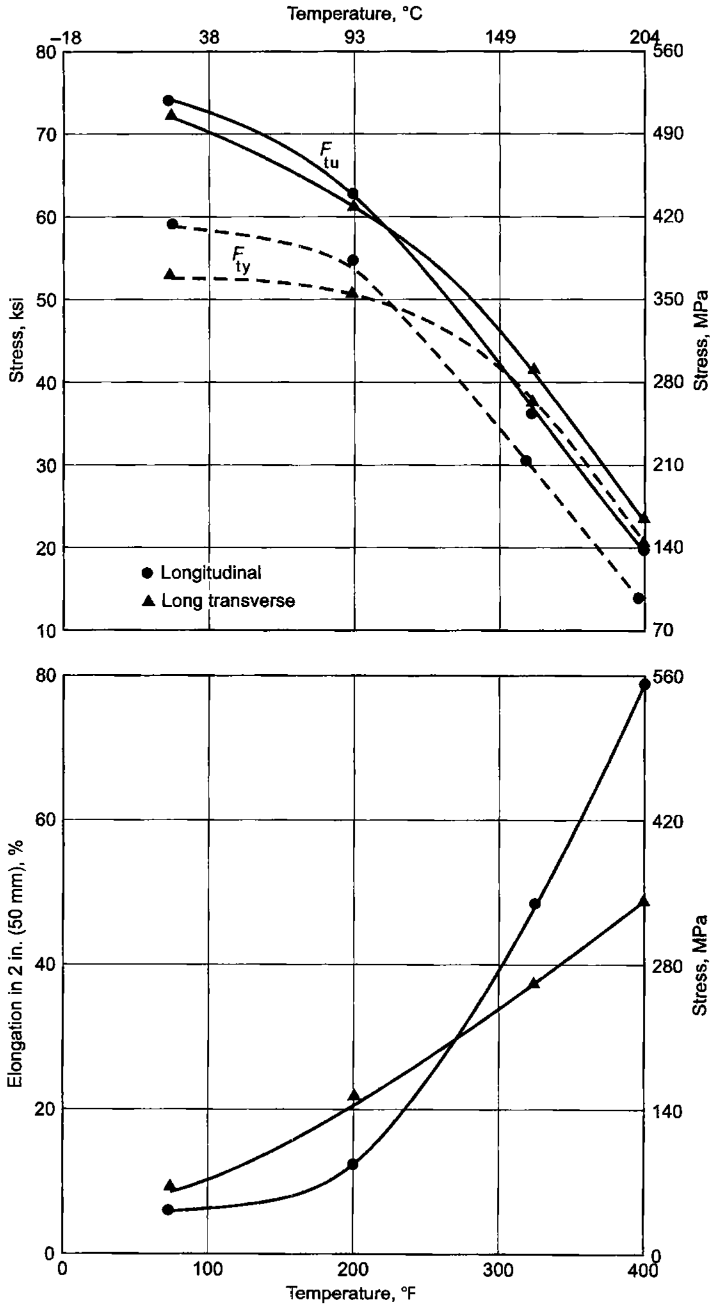
Source: "Properties and Characteristics of Aluminum Alloy X5090, a High-Strength Work Hardening Sheet Material," Technical Information Report MRL-71-TIR-5, Metals Research Laboratory, Olin Corporation, 11 Oct 1971. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3304, CINDAS/Purdue University, 1995, p 4



WA.146 X5090-H38 aluminum alloy sheet, stress-strain curves at various temperatures

Test direction: longitudinal (top); long transverse (bottom). Composition: Al-7Mg-0.2Cr-0.005B-0.005Be

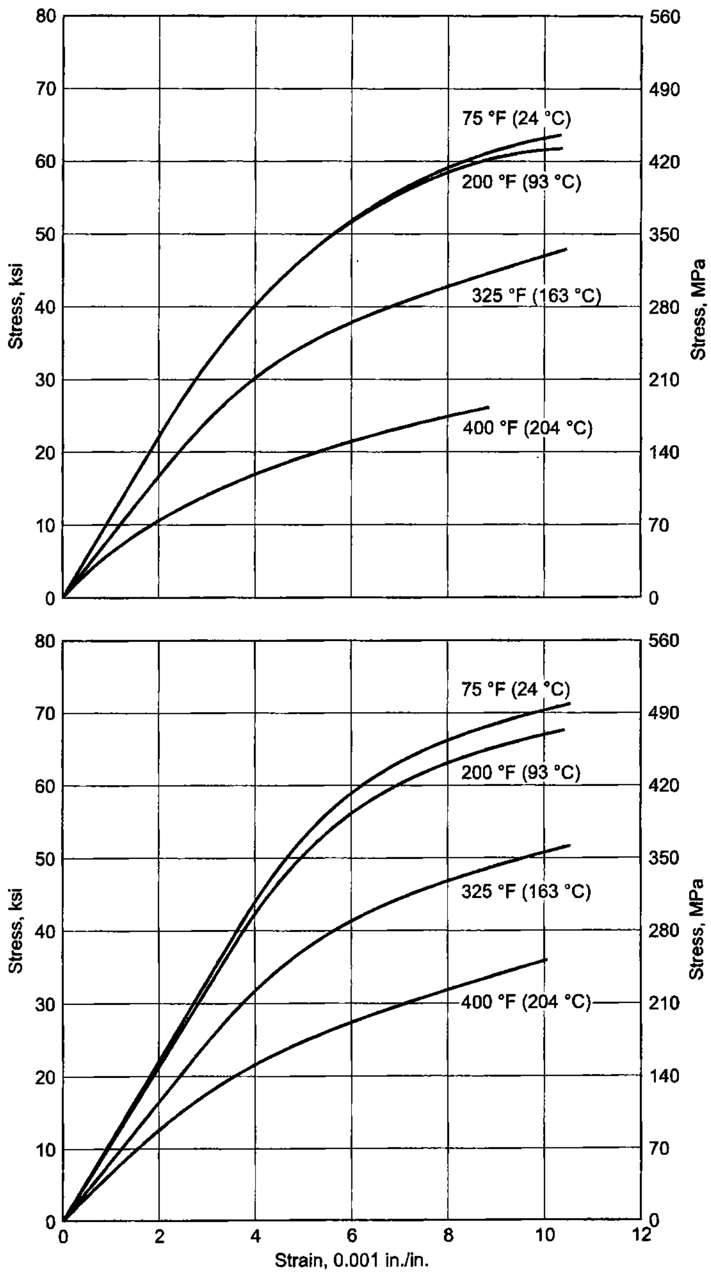
Source: O.L. Deel and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," Technical Report AFML-TR-71-249, Battelle Memorial Institute, Dec 1971. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3304, CINDAS/Purdue University, 1995, p 3



WA.147 X5090-H38 aluminum alloy sheet, effect of temperature on tensile properties after 20 min at test temperature

F_{tu}, ultimate tensile strength; F_{ty}, tensile yield strength. Composition: Al-7Mg-0.2Cr-0.005B-0.005Be

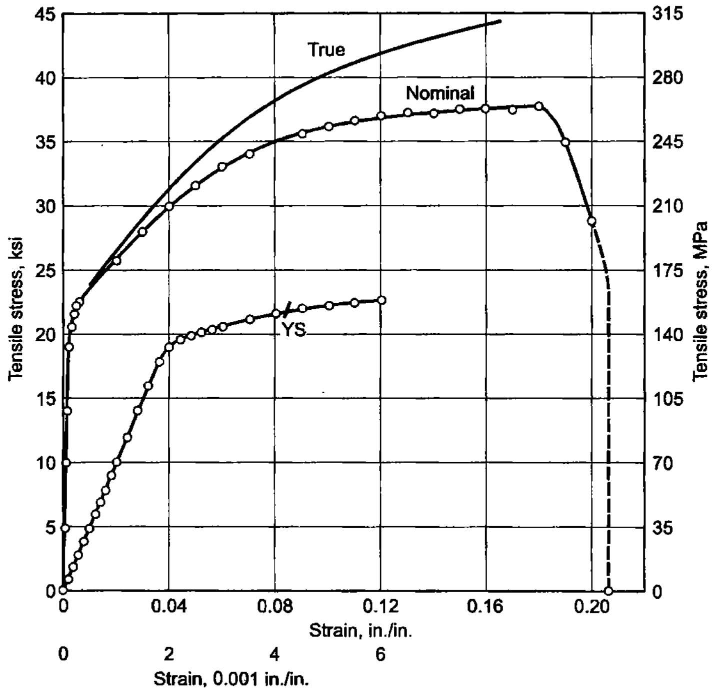
Source: O.L. Deel and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," Technical Report AFML-TR-71-249, Battelle Memorial Institute, Dec 1971. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3304, CINDAS/Purdue University, 1995, p 4



WA.148 X5090-H38 aluminum alloy sheet, compressive stress-strain curves at various temperatures

Test direction: longitudinal (top); long transverse (bottom). Composition: Al-7Mg-0.2Cr-0.005B-0.005Be

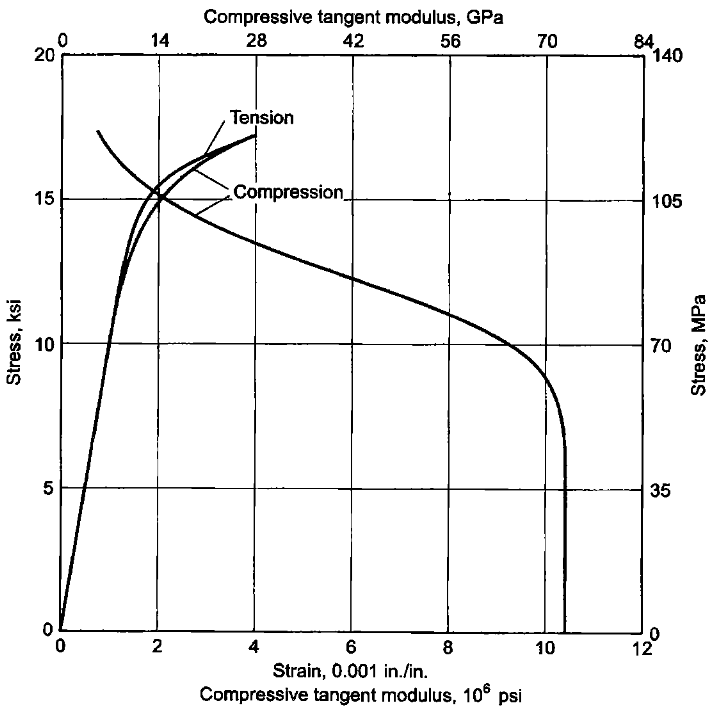
Source: O.L. Deel and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," Technical Report AFML-TR-71-249, Battelle Memorial Institute, Dec 1971. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3304, CINDAS/Purdue University, 1995, p 4



WA.149 5154-O aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Nominal size: 19 mm (3/4 in.) diam. Test specimen diam, 12.7 mm (1/2 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 260 MPa (37.7 ksi). True tensile strength, 307 MPa (44.5 ksi). Nominal yield strength (0.2% offset), 150 MPa (21.7 ksi). Elongation (in 50.8 mm, or 2 in.), 21.5%. Reduction of area, 66%. True strain at maximum load, 16.6%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.19 in the area of uniform plastic deformation. UNS A95154

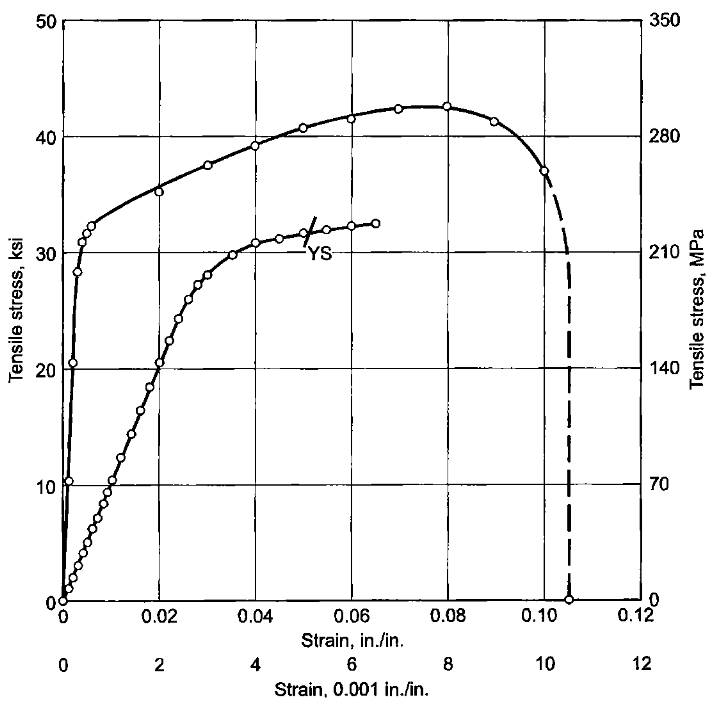
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA



WA.150 5454-O aluminum alloy sheet, plate, and extrusion, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: longitudinal and long transverse. Typical. Ramberg-Osgood parameter, n(longitudinal and long transverse, tension) = 16; n(longitudinal and long transverse, compression) = 9.6.
UNS A95454

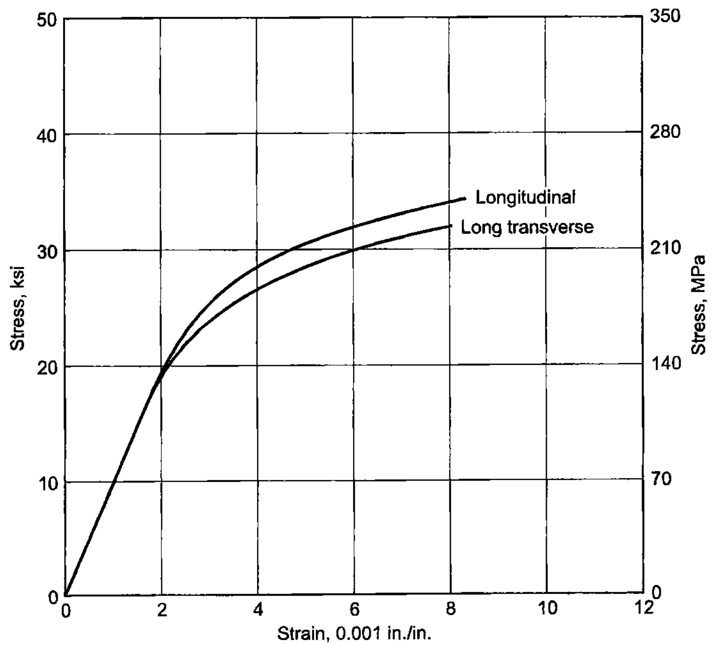
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–238



WA.151 5454-H32 aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Nominal size: 19 mm (3/4 in.) diam. Test specimen diam, 12.7 mm (0.50 in.). Gage length: 203.2 mm (8 in.). UNS A95454

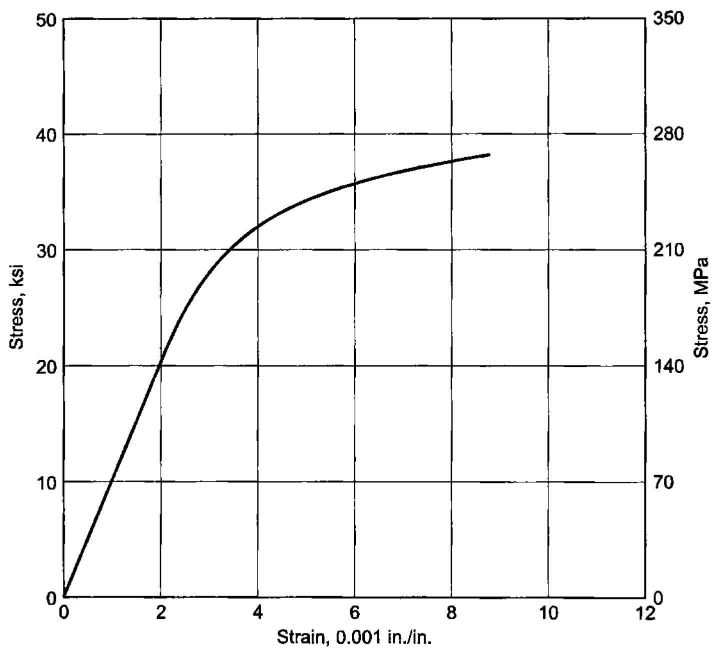
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA



WA.152 5454-H32 aluminum alloy plate, tensile stress-strain curves

Tested at room temperature. Typical. Ramberg-Osgood parameter, n(longitudinal, tension) = 7.5; n(long transverse, tension) = 6.8. UNS A95454

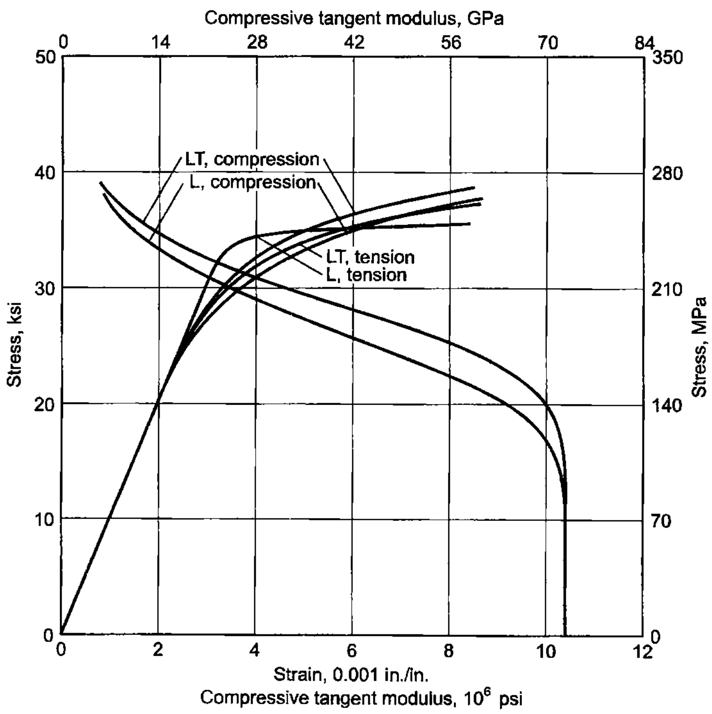
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–238



WA.153 5454-H34 aluminum alloy plate, tensile stress-strain curve

Tested at room temperature. Test direction: longitudinal. Typical. Ramberg-Osgood parameter, n(longitudinal, tension) = 10. UNS A95454

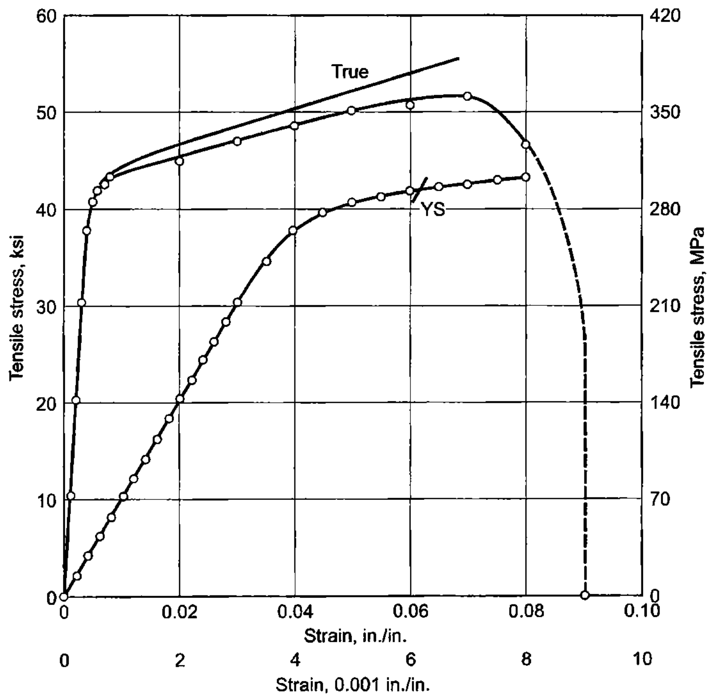
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–239



WA.154 5454-H34 aluminum alloy sheet, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical. Ramberg-Osgood parameter, n(L, tension) = 50; n(LT, tension) = 11; n(L, compression) = 8.1; n(LT, compression) = 9.8. UNS A95454

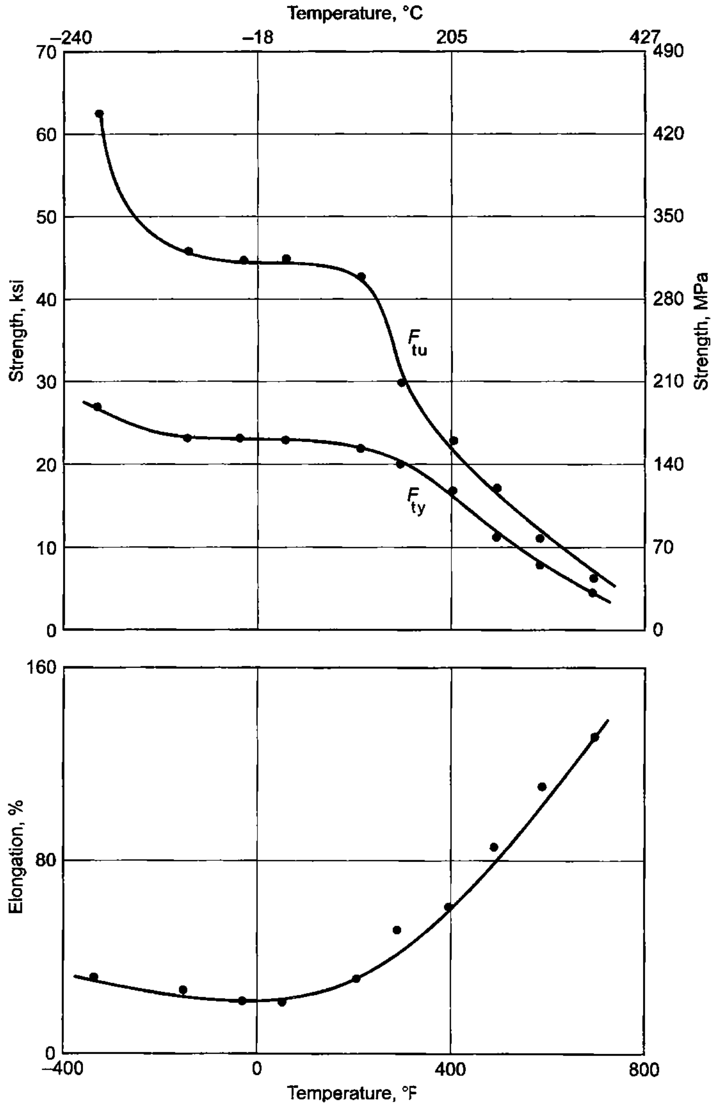
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–239



WA.155 5454-H38 aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Nominal size: 19 mm (3/4 in.) diam. Test specimen diam, 12.7 mm (0.50 in.). Gage length: 203.2 mm (8 in.). UNS A95454

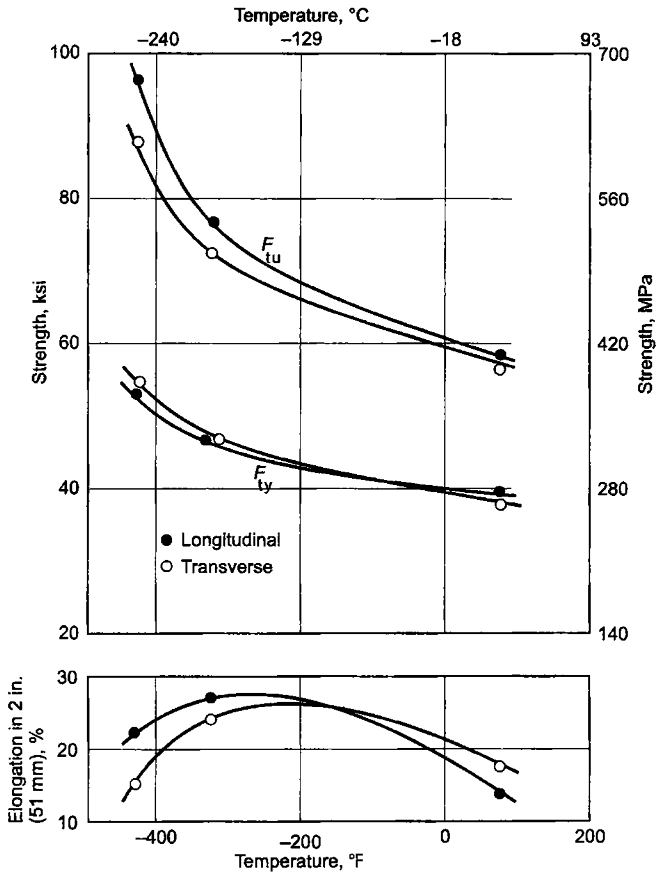
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA



WA.156 5456-O aluminum alloy, effect of low and elevated temperature on tensile properties

F_{tu}, ultimate tensile strength; F_{ty}, tensile yield strength. Composition: Al-5.1Mg-0.8Mn-0.10Cr. UNS A95456

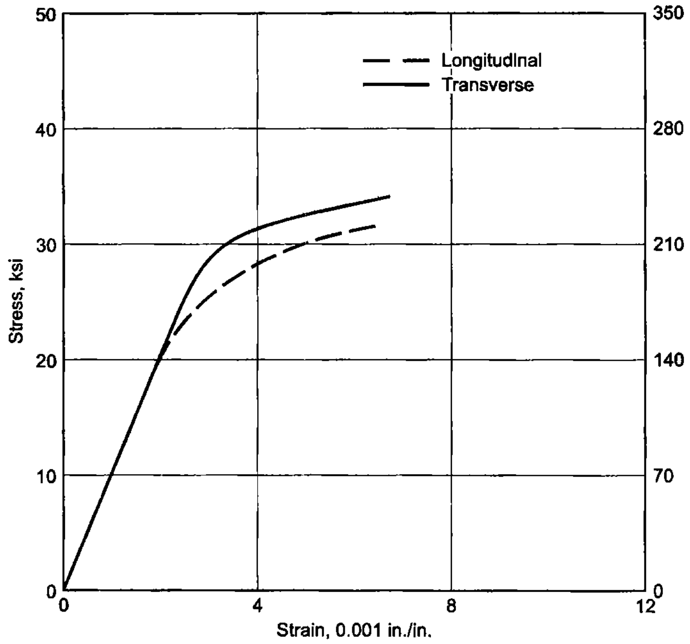
Source: *Alcoa Aluminum Handbook,* Aluminum Company of American, 1962. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3303, CINDAS/Purdue University, 1995, p 6



WA.157 5456-H321 aluminum alloy sheet, effect of low and room temperature on tensile properties

F_{tu}, ultimate tensile strength; F_{ty}, tensile yield strength. Sheet thickness: 31.7 mm (1/8 in.). Composition: Al-5.1Mg-0.8Mn-0.10Cr. UNS A95456

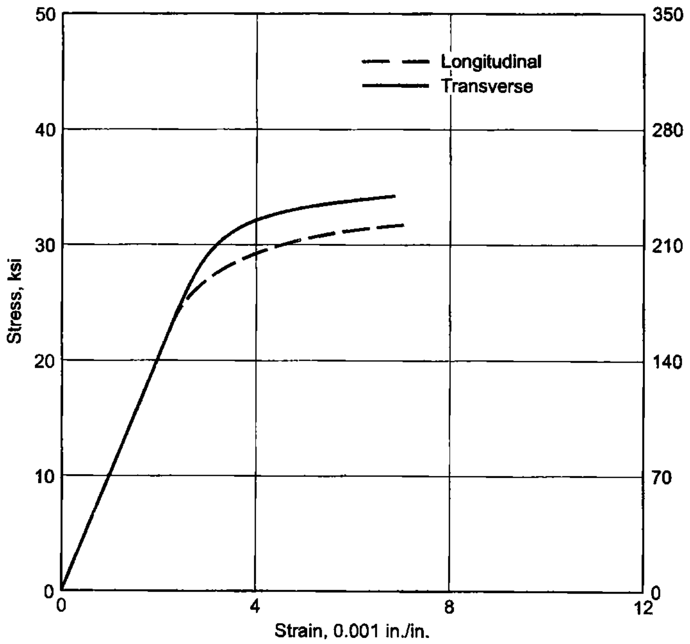
Source: J.E. Campbell, "Review of Current Data on the Tensile Properties of Metals at Very Low Temperatures," DMIC Report 148, Batelle Memorial Institute, 14 Feb 1961. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3303, CINDAS/Purdue University, 1995, p 6



WA.158 5456-H311 aluminum alloy extrusion, compressive stress-strain curves

Tested at room temperature. Composition: Al-51.Mg-0.8Mn-0.10Cr. UNS A95456

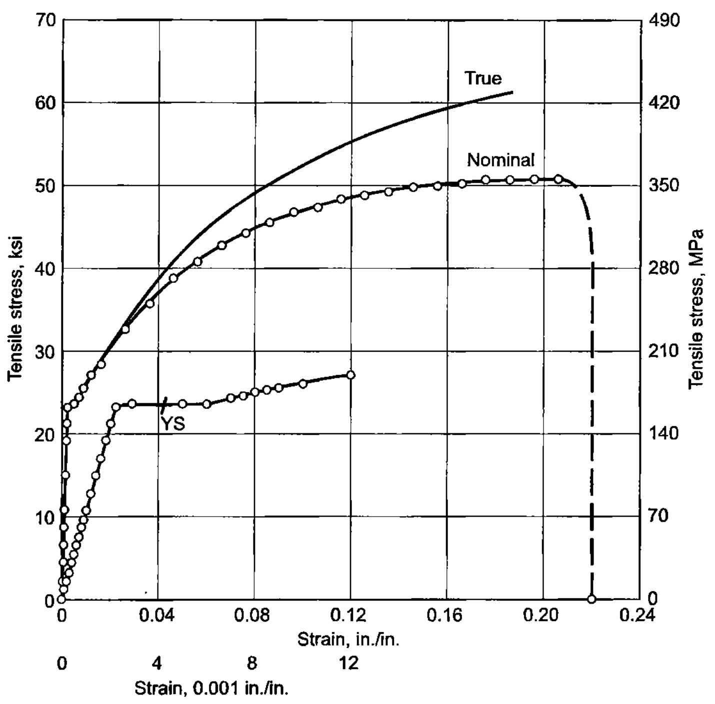
Source: *Metallic Materials and Elements for Flight Vehicle Structures, MIL-HDBK-5,* Aug 1962. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3303, CINDAS/Purdue University, 1995, p 6



WA.159 5456-H311 aluminum alloy extrusion, tensile stress-strain curves

Tested at room temperature. Composition: Al-51.Mg-0.8Mn-0.10Cr. UNS A95456

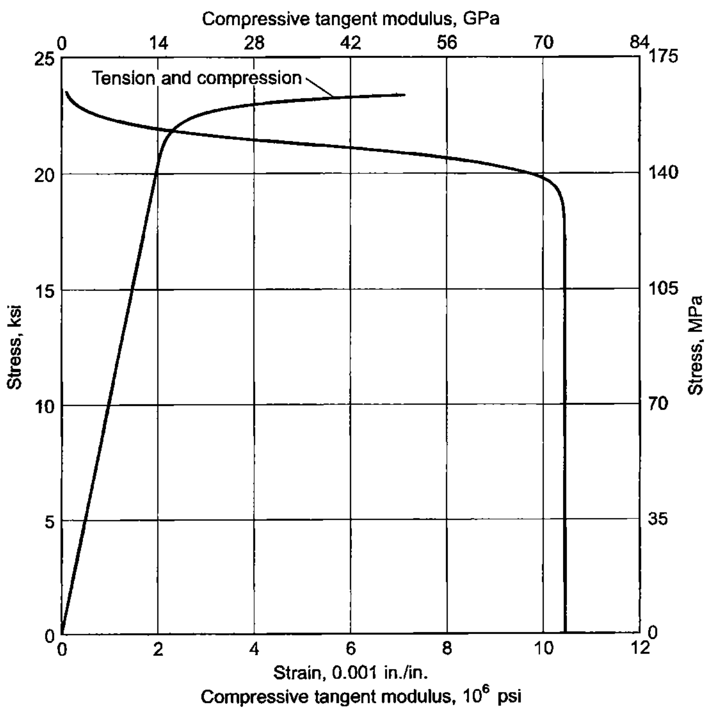
Source: *Metallic Materials and Elements for Flight Vehicle Structures, MIL-HDBK-5,* Aug 1962. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3303, CINDAS/Purdue University, 1995, p 6



WA.160 5456-O aluminum alloy plate, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Nominal thickness: 19 mm (0.750 in.) diam. Test specimen diam, 12.7 mm (1/2 in.). Gage length: 50.8 mm (2 in.). Nominal tensile strength, 350 MPa (50.8 ksi). True tensile strength, 423 MPa (61.3 ksi). Nominal yield strength (0.2% offset), 163 MPa (23.6 ksi). Elongation (in 50.8 mm, or 2 in.), 22.0%. Reduction of area, 28%. True strain at maximum load, 18.7%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.22 in the area of uniform plastic deformation. UNS A95456

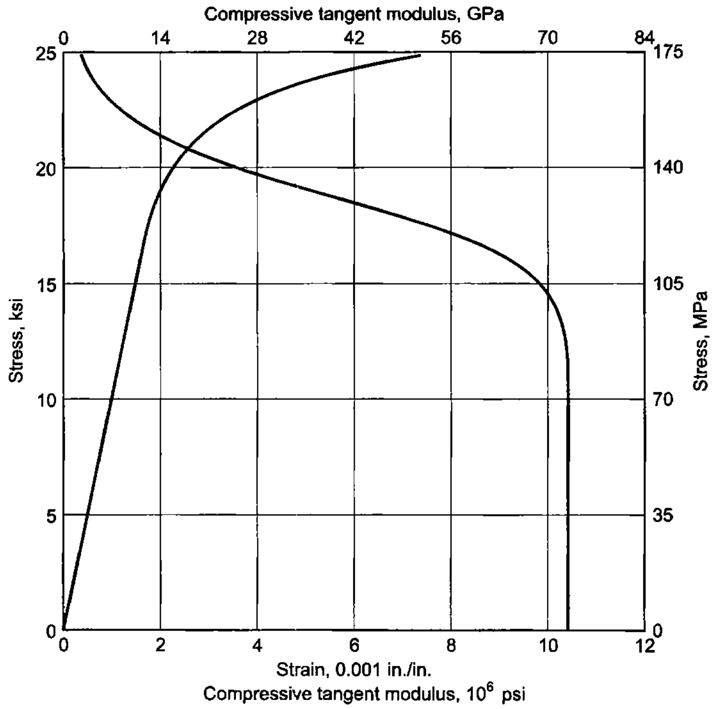
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA



WA.161 5456-O aluminum alloy sheet and plate, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: longitudinal and long transverse. Typical. Ramberg-Osgood parameter, n(longitudinal and long transverse, tension) = 50; n(longitudinal and long transverse, compression) = 50. UNS A95456

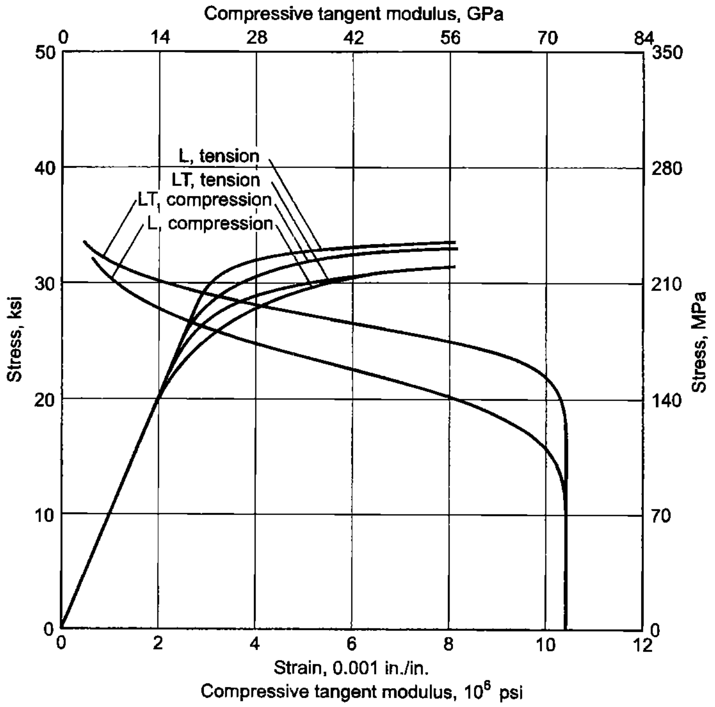
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–244



WA.162 5456-O aluminum alloy extrusion, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: longitudinal and long transverse. Typical. Ramberg-Osgood parameter, *n*(longitudinal and long transverse, tension) = 13; *n*(longitudinal and long transverse, compression) = 13.
UNS A95456

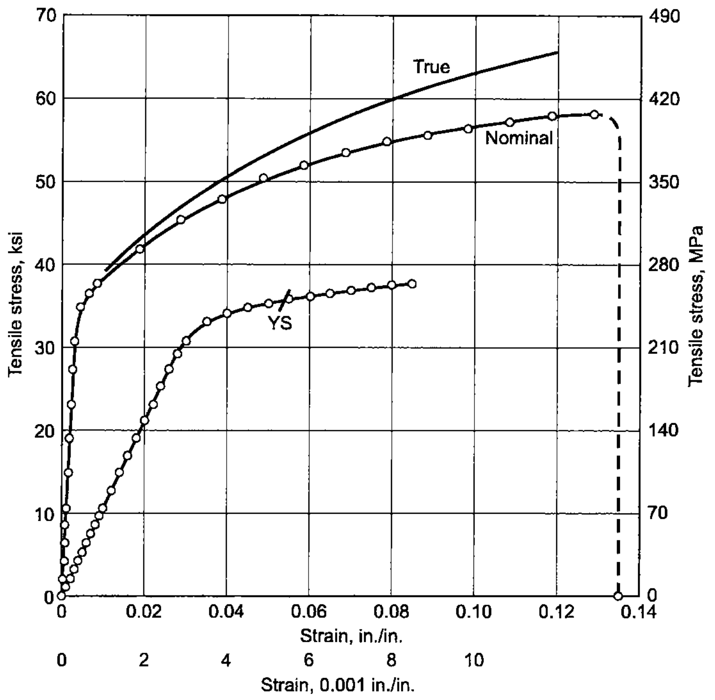
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–244



WA.163 5456-H111 aluminum alloy extrusion, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical. Ramberg-Osgood parameter, *n*(L, tension) = 32; *n*(LT, tension) = 16; *n*(L, compression) = 9.5; *n*(LT, compression) = 16.
UNS A95456

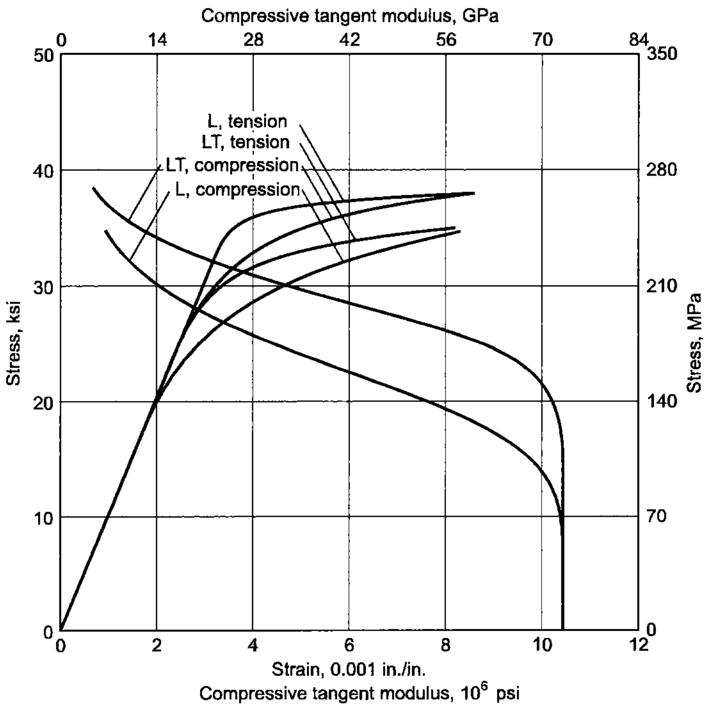
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–245



WA.164 5456-H321 aluminum alloy plate, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Nominal thickness: 19.05 mm (0.750 in.) diam. Test specimen diam, 12.7 mm (1/2 in.). Gage length: 50.8 mm (2 in.). Nominal tensile strength, 400 MPa (58.0 ksi). True tensile strength, 452 MPa (65.6 ksi). Nominal yield strength (0.2% offset), 247 MPa (35.8 ksi). Elongation (in 50.8 mm, or 2 in.), 13.5%. Reduction of area, 17%. True strain at maximum load, 12.0%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.24 in the area of uniform plastic deformation. UNS A95456

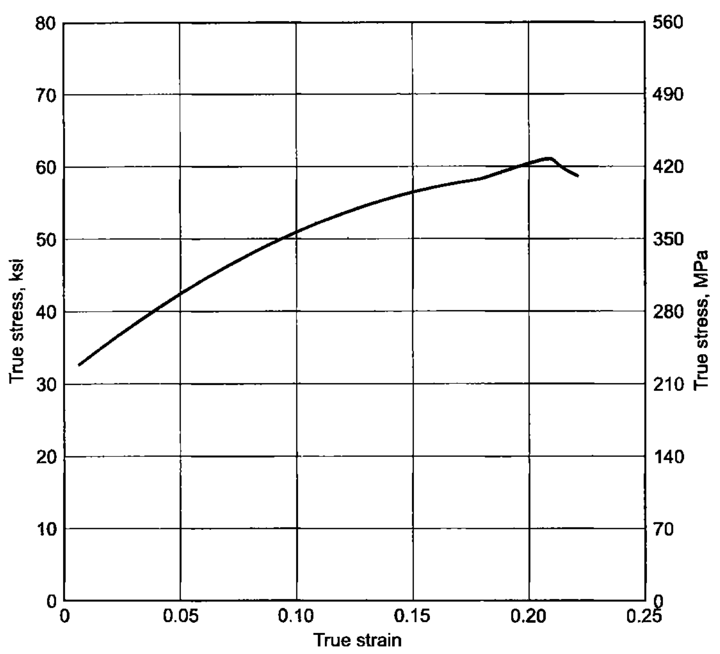
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, Aug 1956



WA.165 5456-H321 aluminum alloy plate, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for plate thickness 15.875–31.750 mm (0.625–1.250 in.). Ramberg-Osgood parameter, n(L, tension) = 42; n(LT, tension) = 16; n(L, compression) = 7.0; n(LT, compression) = 11. UNS A95456

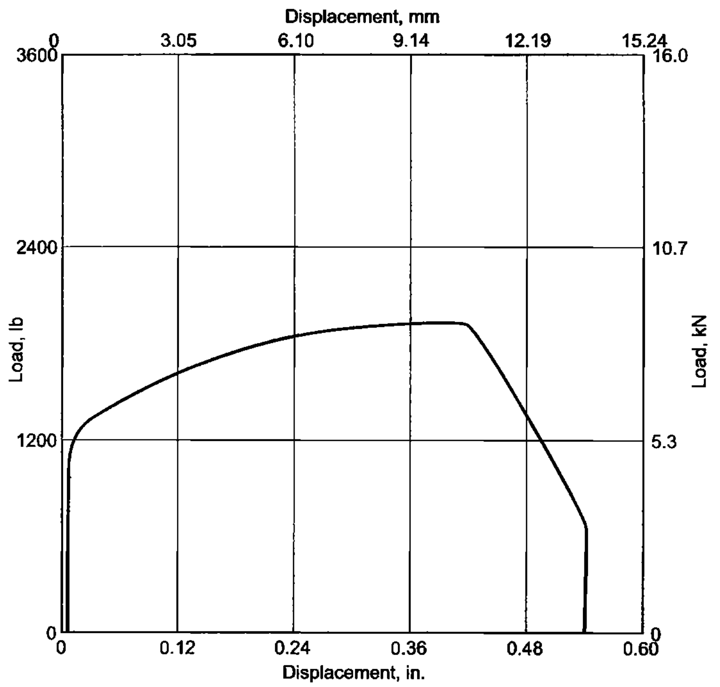
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–245



WA.166 6013-T4 aluminum alloy sheet, tensile true stress, true strain curve

Sheet thickness: 1.60 mm (0.063 in.). Composition: Al-0.90Mg-0.80Si-0.85Cu-0.50Mn. UNS A96013

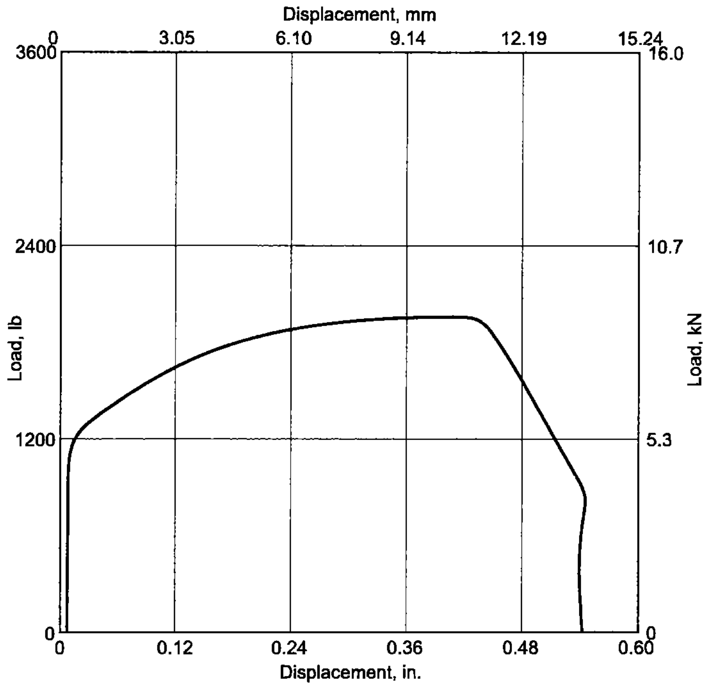
Source: J.W. Hardy, "Formability of Aluminum Alloy 6013 Sheet," Report MDC H5866, McDonnell Douglas Space Systems Co., Feb 1990. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3226, CINDAS/Purdue University, 1995, p 8



WA.167 6013-T4 aluminum alloy sheet, load-displacement curve (tensile test)

Test direction: longitudinal. Specimen width: 12.7 mm (0.5 in.); thickness: 2.032 mm (0.080 in.). Gage length: 50.8 mm (2.0 in.). Ultimate tensile strength (F_{tu}): 336.4 MPa (48.8 ksi). Tensile yield strength (F_{ty}): 215.8 MPa (31.3 ksi). Elongation: 21.8%. Electrical conductivity: 38.1%IACS. Water quenched. Composition: Al-0.90Mg-0.80Si-0.85Cu-0.50Mn. UNS A96013

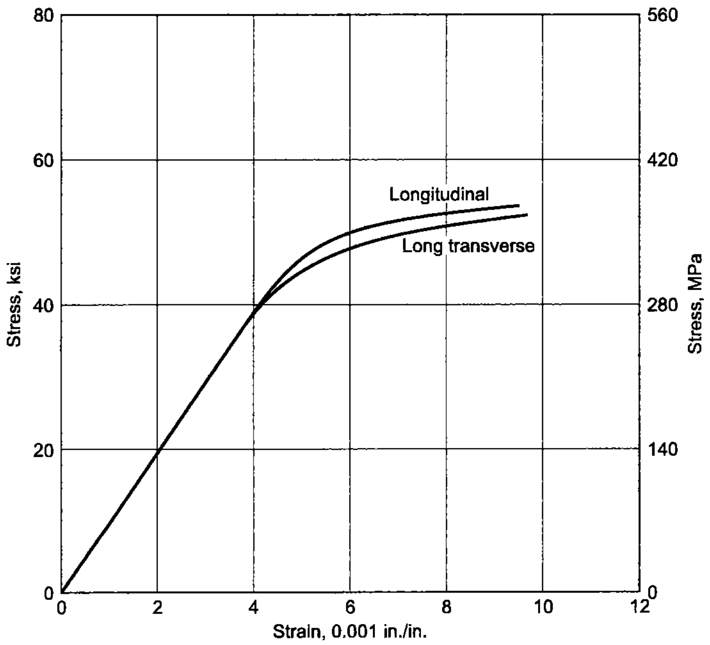
Source: J.T. Gutierrez, B.F. Larson, and J.F. Charles, "Fracture Mechanics Forming and Weld Properties for 6013 Sheet," Report MDC K0818, Douglas Aircraft Co., Dec 1989. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3226, CINDAS/Purdue University, 1995, p 8



WA.168 6013-T4 aluminum alloy sheet, load-displacement curve (tensile test)

Test direction: long transverse. Specimen width: 12.7 mm (0.5 in.); thickness: 2.032 mm (0.080 in.). Gage length: 50.8 mm (2.0 in.). Ultimate tensile strength (F_{tu}): 340.6 MPa (49.4 ksi). Tensile yield strength (F_{ty}): 197.9 MPa (28.7 ksi). Elongation: 22.6%. Electrical conductivity: 38.2%IACS. Water quenched. Composition: Al-0.90Mg-0.80Si-0.85Cu-0.50Mn. UNS A96013

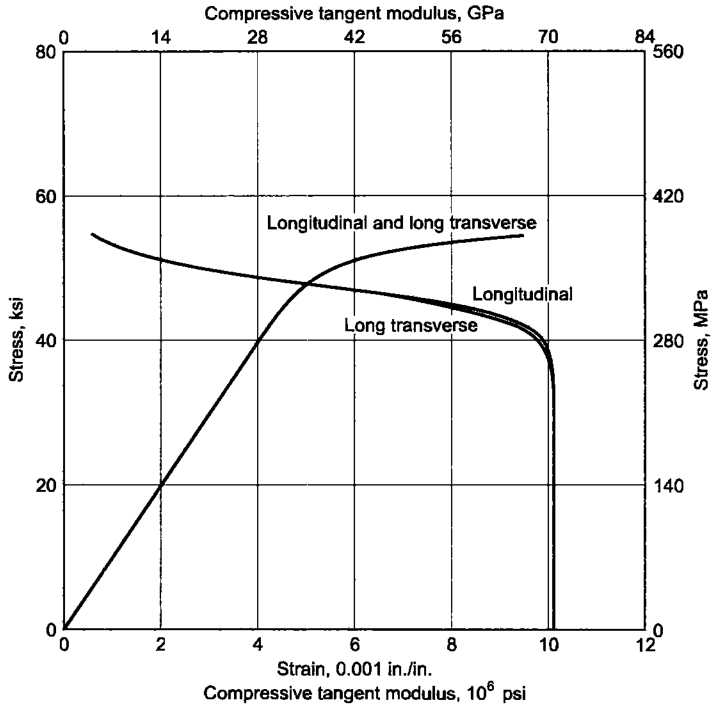
Source: J.T. Gutierrez, B.F. Larson, and J.F. Charles, "Fracture Mechanics Forming and Weld Properties for 6013 Sheet," Report MDC K0818, Douglas Aircraft Co., Dec 1989. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3226, CINDAS/Purdue University, 1995, p 8



WA.169 6013-T6 aluminum alloy sheet, tensile stress-strain curves

Tested at room temperature. Typical for specimen thickness: 0.254–6.325 mm (0.010–0.249 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 21; *n*(long transverse, tension) = 15. UNS A96013

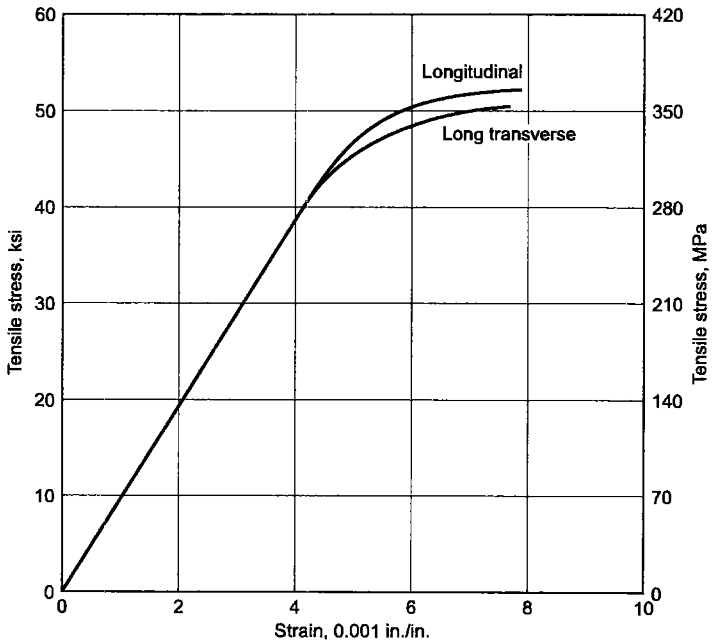
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–248



WA.170 6013-T6 aluminum alloy sheet, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for specimen thickness: 0.254–6.325 mm (0.010–0.249 in.). Ramberg-Osgood parameter, n(longitudinal, compression) = 21; n(long transverse, compression) = 23. UNS A96013

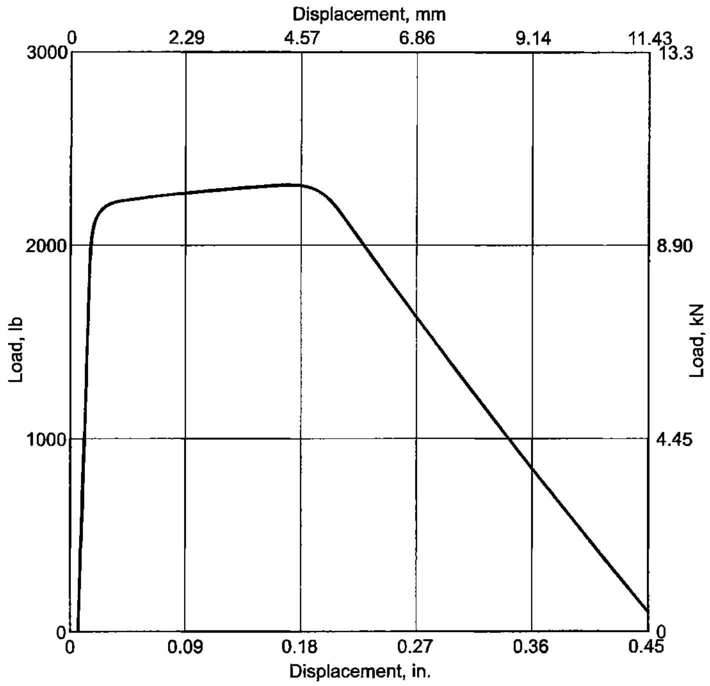
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–249



WA.171 6013-T6 aluminum alloy sheet, tensile stress-strain curves

Composition: Al-0.90Mg-0.80Si-0.85Cu-0.50Mn. UNS A96013

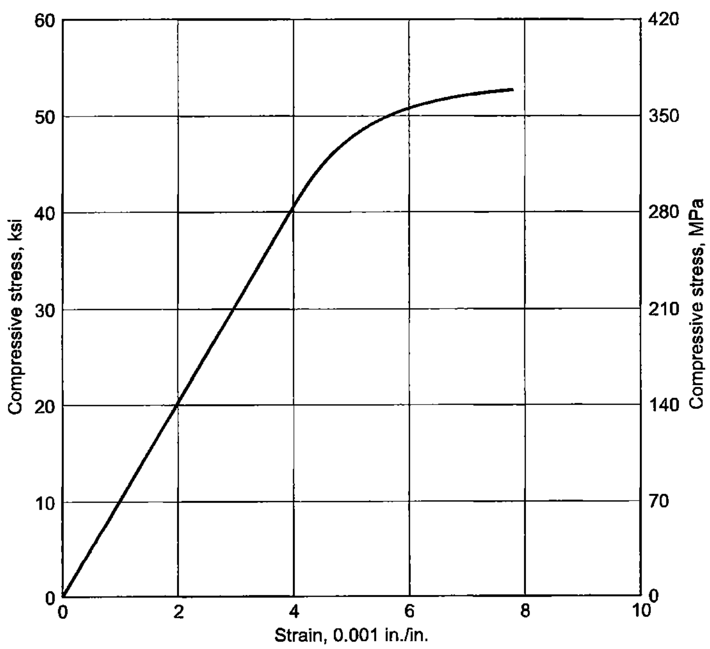
Source: "Alcoa Aluminum Alloy 6013," Alcoa Green Letter No. 225, Dec 1987. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3226, CINDAS/Purdue University, 1995, p 8



WA.172 6013-T6 aluminum alloy sheet, load-displacement curve (tensile test)

Test direction: longitudinal. Specimen width: 12.7 mm (0.5 in.); thickness: 2.032 mm (0.080 in.). Gage length: 50.8 mm (2.0 in.). Ultimate tensile strength (F_{tu}): 398.5 MPa (57.8 ksi). Tensile yield strength (F_{ty}): 368.1 MPa (53.4 ksi). Elongation: 11.0%. Electrical conductivity: 42.9%IACS. Water quenched. Composition: Al-0.90Mg-0.80Si-0.85Cu-0.50Mn. UNS A96013

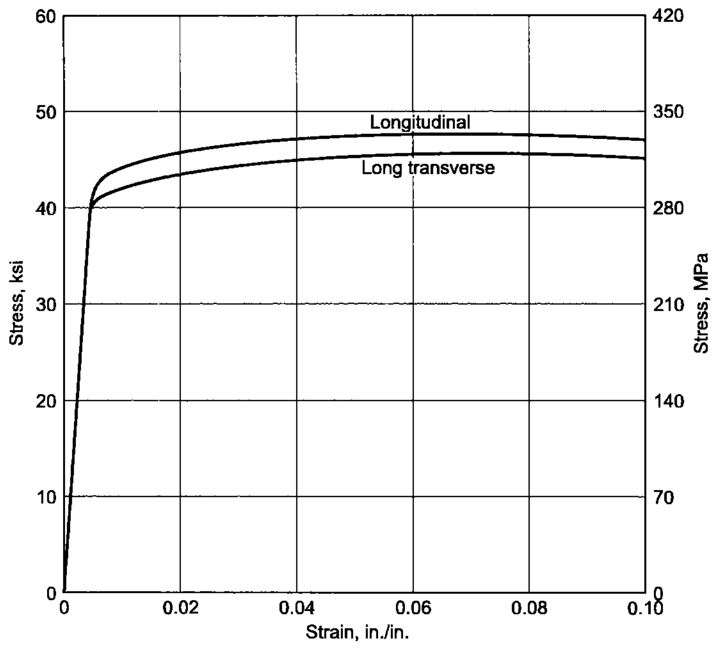
Source: J.T. Gutierrez, B.F. Larson, and J.F. Charles, "Fracture Mechanics Forming and Weld Properties for 6013 Sheet," Report MDC K0818, Douglas Aircraft Co., Dec 1989. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3226, CINDAS/Purdue University, 1995, p 8



WA.173 6013-T6 aluminum alloy sheet, compressive stress-strain curve

Test direction: longitudinal and long transverse. Composition: Al-0.90Mg-0.80Si-0.85Cu-0.50Mn. UNS A96013

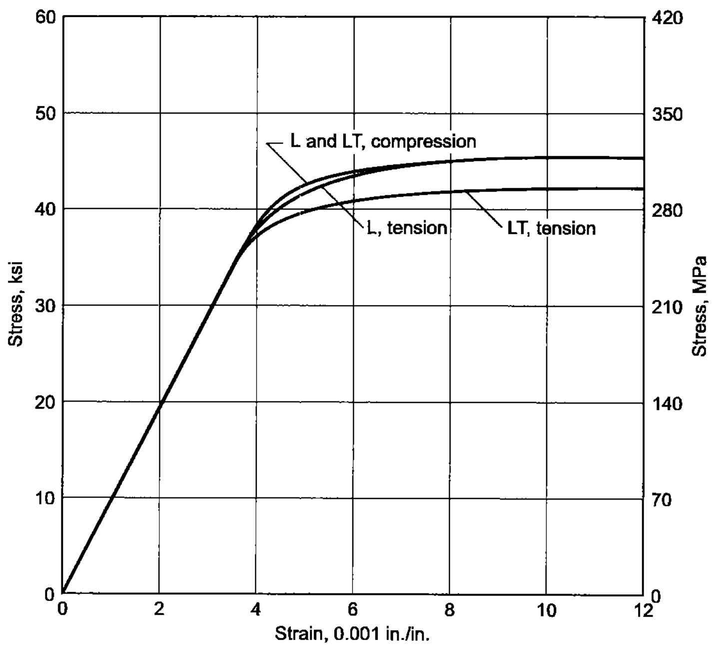
Source: "Alcoa Aluminum Alloy 6013," Alcoa Green Letter No. 225, Dec 1987. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3226, CINDAS/Purdue University, 1995, p 10



WA.174 6061-T62 aluminum alloy extrusion, tensile stress-strain curves (full range)

Specimen thickness: 3.2–41.3 mm (⅛–1⅝ in.).
Composition: Al-1Mg-0.65Si-0.25Cu-0.20Cr.
UNS A96061

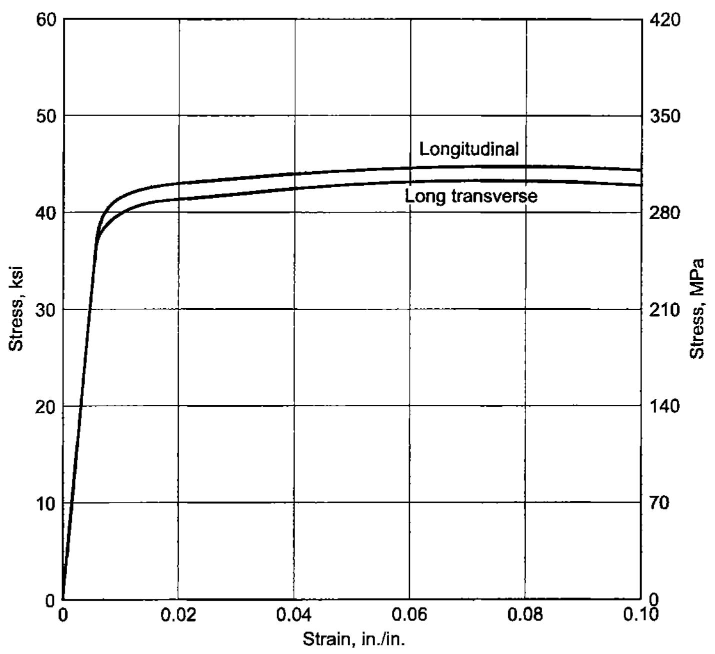
Source: O.J. Brownhill, O.J. Davies, and D.O. Sprowls, "Mechanical Properties, Including Fracture Toughness and Fatigue and Resistance to Stress Corrosion Cracking of Stress Relieved and Stretched Aluminum Alloy Extrusions," AF Contract AF33(615)-3580, AFML TR68-34, Feb 1970. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3206, CINDAS/Purdue University, 1995, p 6



WA.175 6061-T62 aluminum alloy extrusion, tensile and compressive stress-strain curves

Test direction: L, longitudinal; LT, long transverse.
Specimen thickness: 3.2–41.3 mm (⅛–1⅝ in.).
Composition: Al-1Mg-0.65Si-0.25Cu-0.20Cr.
UNS A96061

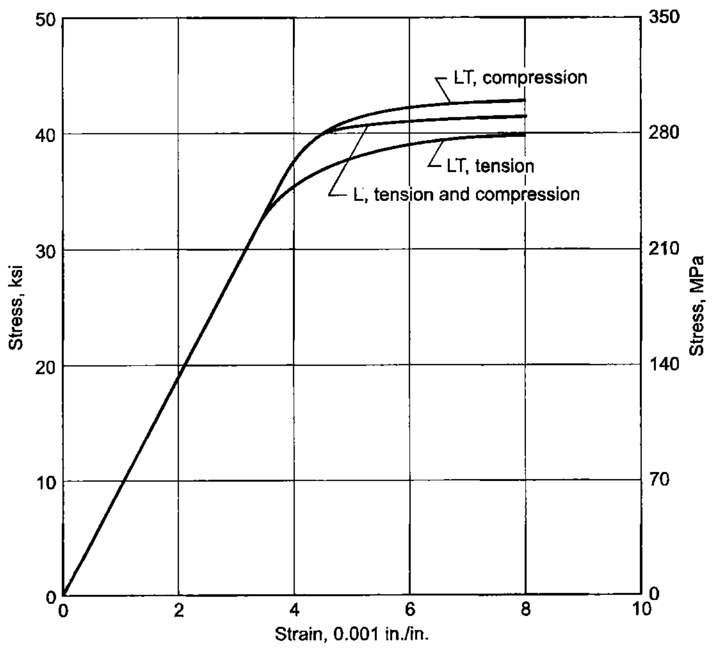
Source: O.J. Brownhill, O.J. Davies, and D.O. Sprowls, "Mechanical Properties, Including Fracture Toughness and Fatigue and Resistance to Stress Corrosion Cracking of Stress Relieved and Stretched Aluminum Alloy Extrusions," AF Contract AF33(615)-3580, AFML TR68-34, Feb 1970. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3206, CINDAS/Purdue University, 1995, p 7



WA.176 6061-T651 aluminum alloy extrusion, tensile stress-strain curves (full range)

Specimen thickness: ≤12.675 mm (≤0.499 in.). Composition: Al-1Mg-0.65Si-0.25Cu-0.20Cr. UNS A96061

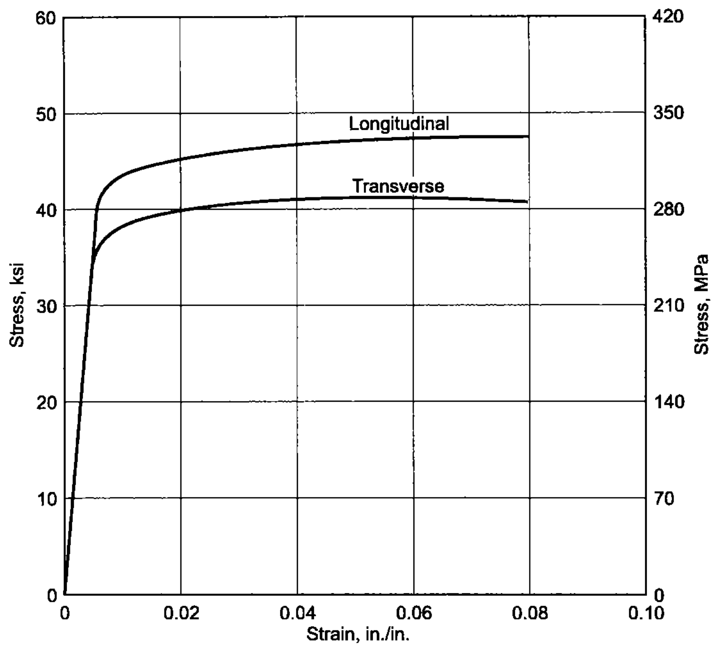
Source: O.J. Brownhill, O.J. Davies, and D.O. Sprowls, "Mechanical Properties, Including Fracture Toughness and Fatigue and Resistance to Stress Corrosion Cracking of Stress Relieved and Stretched Aluminum Alloy Extrusions," AF Contract AF33(615)-3580, AFML TR68-34, Feb 1970. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3206, CINDAS/Purdue University, 1995, p 7



WA.177 6061-T651 aluminum alloy extrusion, tensile and compressive stress-strain curves

Test direction: L, longitudinal; LT, long transverse. Specimen thickness: ≤12.675 mm (≤0.499 in.). Composition: Al-1Mg-0.65Si-0.25Cu-0.20Cr. UNS A96061

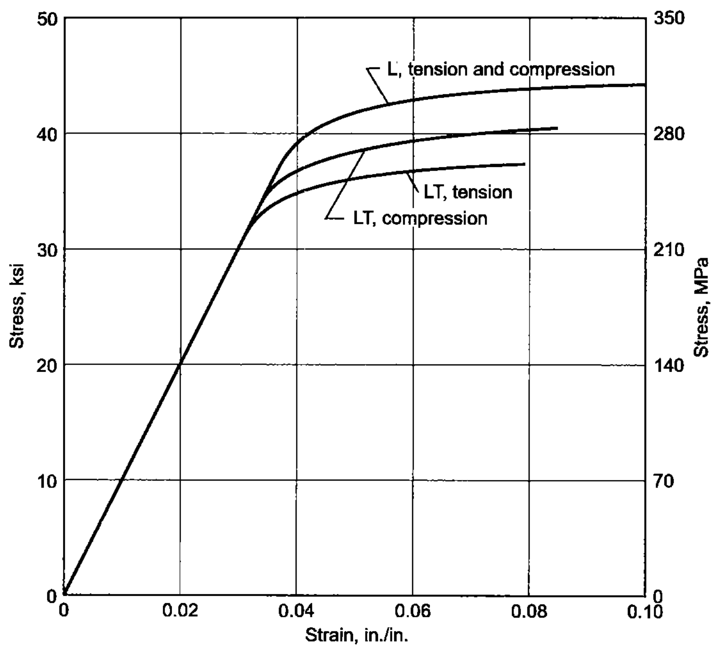
Source: O.J. Brownhill, O.J. Davies, and D.O. Sprowls, "Mechanical Properties, Including Fracture Toughness and Fatigue and Resistance to Stress Corrosion Cracking of Stress Relieved and Stretched Aluminum Alloy Extrusions," AF Contract AF33(615)-3580, AFML TR68-34, Feb 1970. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3206, CINDAS/Purdue University, 1995, p 7



WA.178 6061-T651 aluminum alloy extrusion, tensile stress-strain curves (full range)

Specimen thickness: ≥76.2 mm (≥3.0 in.). Composition: Al-1Mg-0.65Si-0.25Cu-0.20Cr. UNS A96061

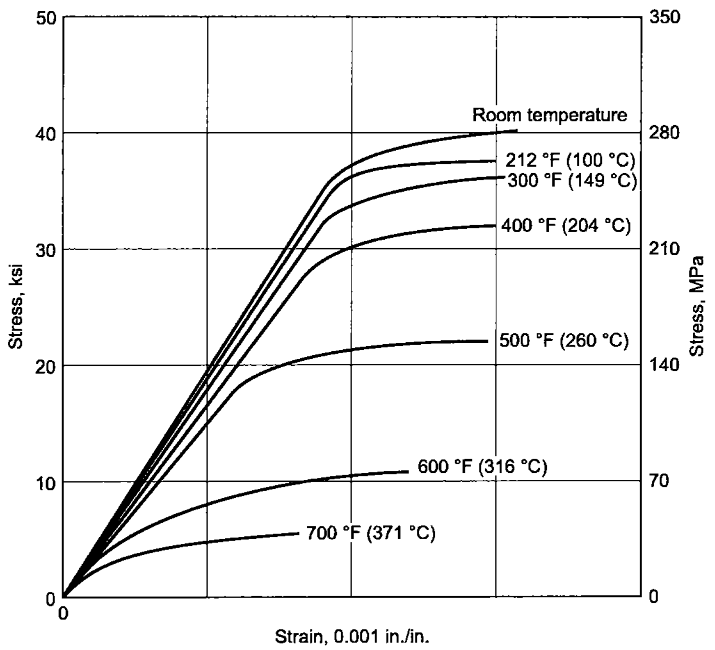
Source: O.J. Brownhill, O.J. Davies, and D.O. Sprowls, "Mechanical Properties, Including Fracture Toughness and Fatigue and Resistance to Stress Corrosion Cracking of Stress Relieved and Stretched Aluminum Alloy Extrusions," AF Contract AF33(615)-3580, AFML TR68-34, Feb 1970. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3206, CINDAS/Purdue University, 1995, p 7



WA.179 6061-T651 aluminum alloy extrusion, tensile and compressive stress-strain curves

Test direction: L, longitudinal; LT, long transverse. Specimen thickness: ≥76.2 mm (≥3.0 in.). Composition: Al-1Mg-0.65Si-0.25Cu-0.20Cr. UNS A96061

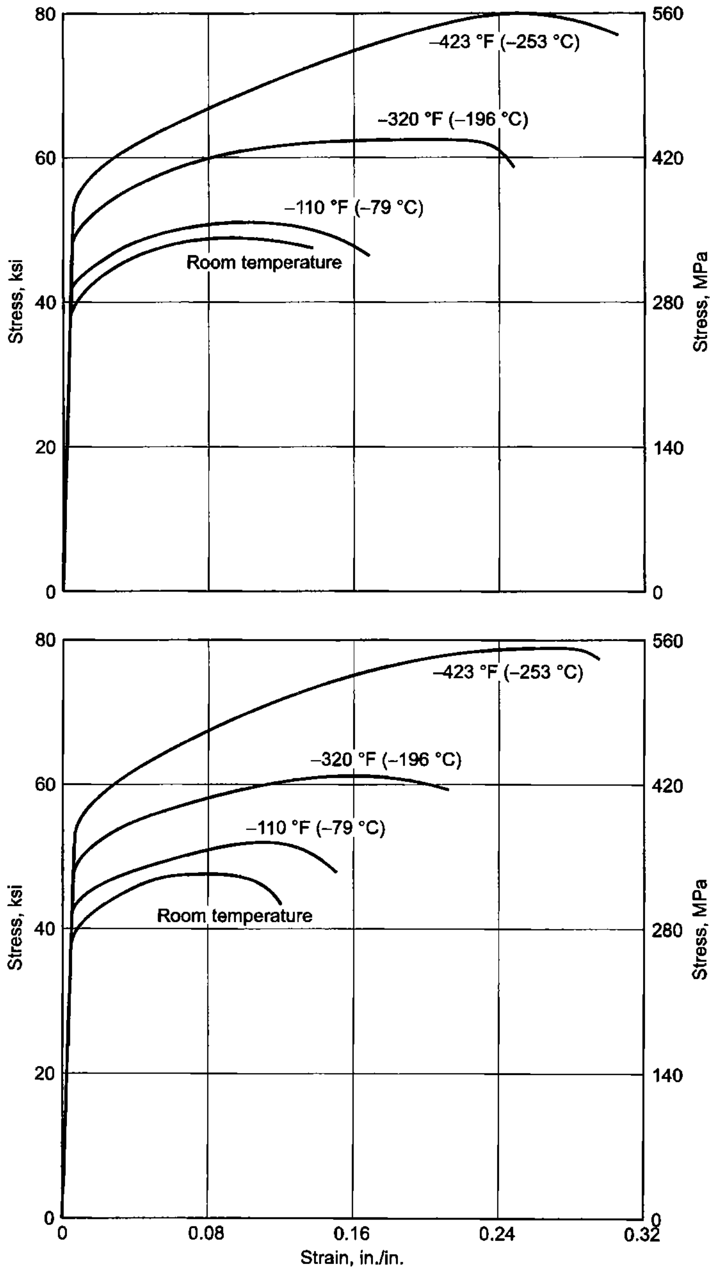
Source: O.J. Brownhill, O.J. Davies, and D.O. Sprowls, "Mechanical Properties, Including Fracture Toughness and Fatigue and Resistance to Stress Corrosion Cracking of Stress Relieved and Stretched Aluminum Alloy Extrusions," AF Contract AF33(615)-3580, AFML TR68-34, Feb 1970. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3206, CINDAS/Purdue University, 1995, p 8



WA.180 6061-T6 aluminum alloy, tensile stress-strain curves at room and elevated temperatures

Composition: Al-1Mg-0.6Si-0.25Cu-0.20Cr.
UNS A96061

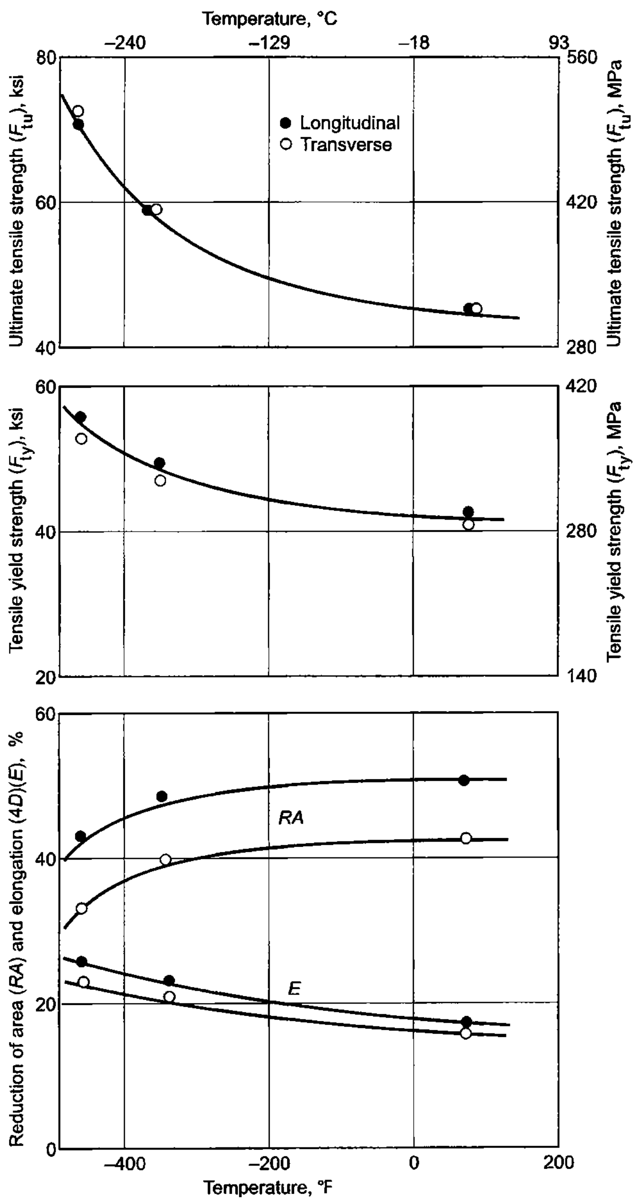
"Typical Tensile Stress-Strain Curves for 6061-T6 at Room Temperature, 212, 300, 400, 500, 600, and 700 F," Physical Test No. 010758-G Data Sheets, 6 and 31 March 1958. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3206, CINDAS/ Purdue University, 1995, p 8



WA.181 6061-T6 aluminum alloy sheet, stress-strain curves at room and elevated temperatures

Tested at low temperature. Test direction: longitudinal (top); transverse (bottom). Sheet thickness: 2.54 mm (0.100 in.). Composition: Al-1Mg-0.6Si-0.25Cu-0.20Cr. UNS A96061

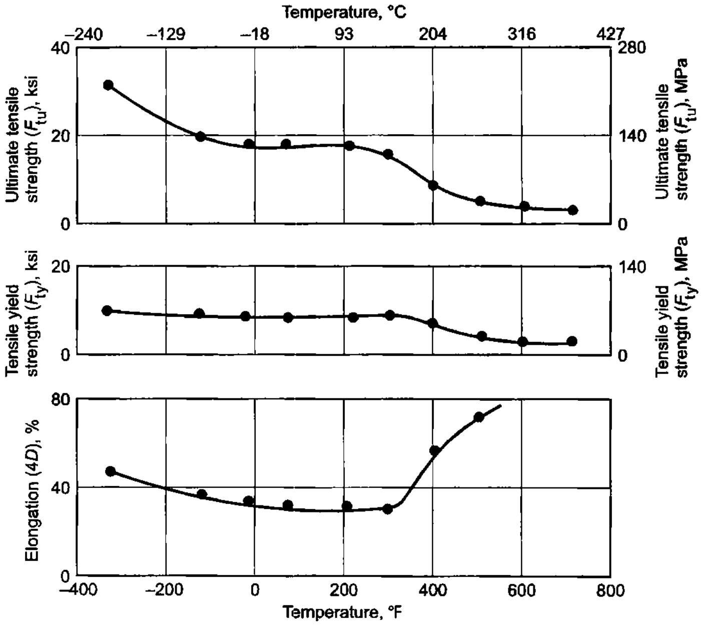
F.R. Schwartzberg et al., *Cryogenic Materials Data Handbook,* ML-TDR-64-280, Aug 1964, Suppl. 1, Feb 1965. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3206, CINDAS/Purdue University, 1995, p 9



WA.182 6061-T651 aluminum alloy plate, effect of cryogenic temperatures on tensile properties

Tested to −269 °C (−452 °F). Plate thickness: 31.75 mm (1¼ in.). Composition: Al-1Mg-0.65Si-0.25Cu-0.20Cr. UNS A96061

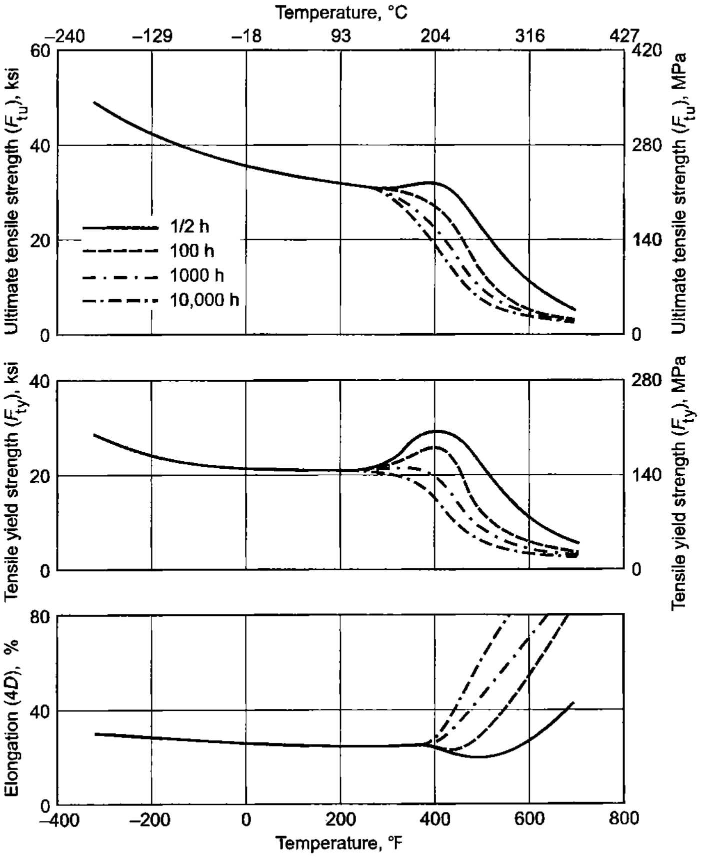
Source: J.G. Kaufman, K.O. Bogardus, and E.T. Wanderer, Tensile Properties and Notch Toughness of Aluminum Alloys at −452F in Liquid He, *Adv. Cryogenic Eng.*, Vol 13, 1968, p 294. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3206, CINDAS/Purdue University, 1995, p 9



WA.183 6061-O aluminum alloy, effect of exposure and test temperature on tensile properties

Exposure up to 10,000 h. Composition: Al-1Mg-0.6Si-0.25Cu-0.20Cr. UNS A96061

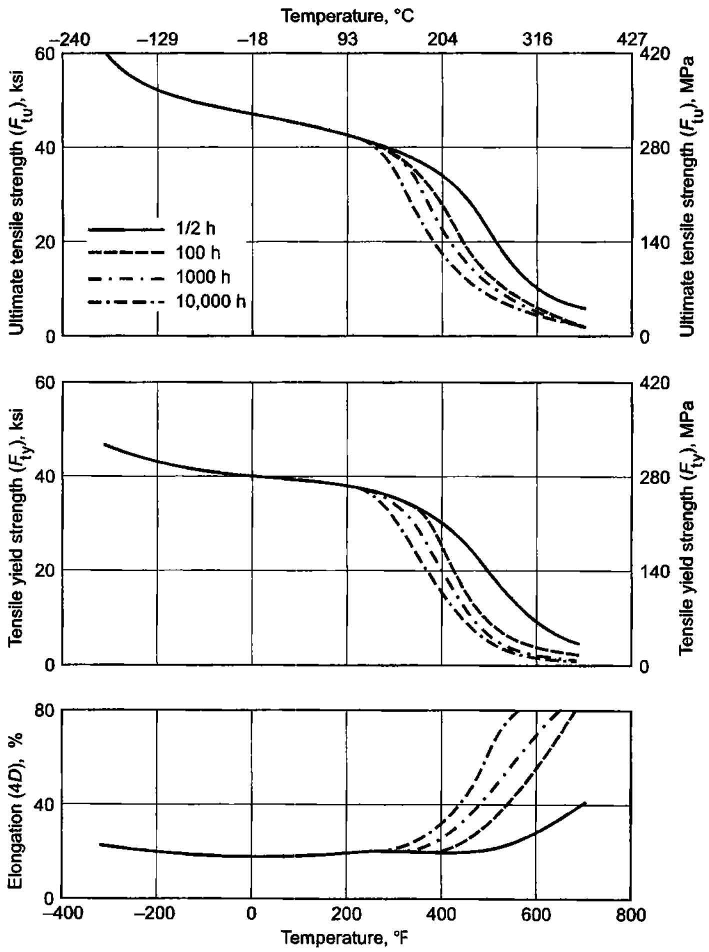
Source: "Mechanical Properties at Various Temperatures of 6061-O," Data sheet, Alcoa Research Laboratories, 1 Feb 1956. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3206, CINDAS/ Purdue University, 1995, p 9



WA.184 6061-T4 aluminum alloy sheet, effect of exposure and test temperature on tensile properties

Composition: Al-1Mg-0.6Si-0.25Cu-0.20Cr.
UNS A96061

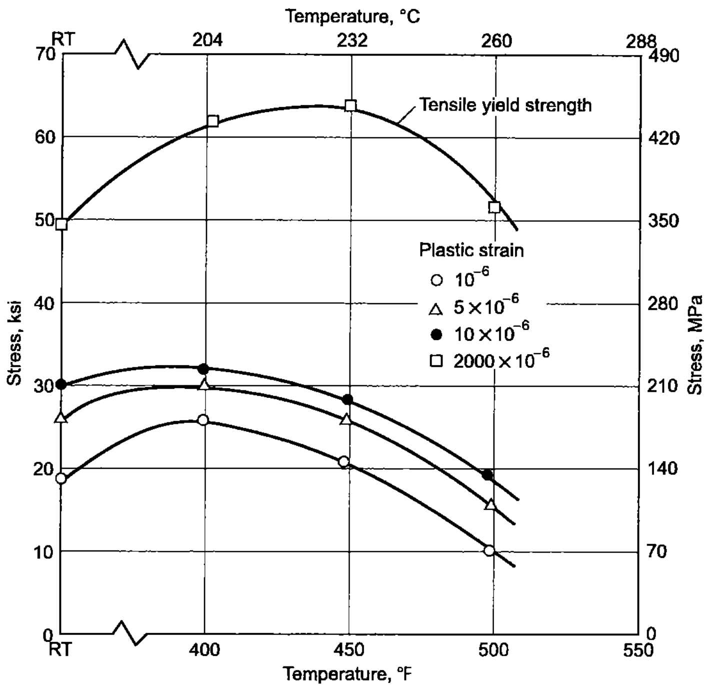
Source: "Mechanical Properties at Various Temperatures of 6061-T4 and 6062-T4," Data sheet, Alcoa Research Laboratories, 23 Feb 1956. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3206, CINDAS/Purdue University, 1995, p 10



WA.185 6061-T6 aluminum alloy, effect of exposure and test temperature on tensile properties

Composition: Al-1Mg-0.6Si-0.25Cu-0.20Cr.
UNS A96061

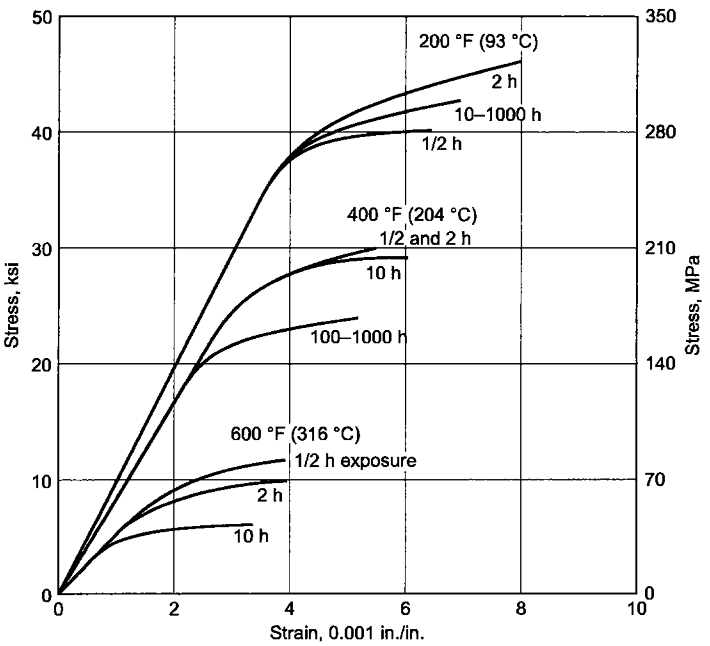
Source: "Mechanical Properties at Various Temperatures of 6061-T6 Products," Data table, Alcoa Research Laboratories, 6 Dec 1960. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3206, CINDAS/Purdue University, 1995, p 10



WA.186 6061-T6 aluminum alloy sheet, effect of test temperature on stress to produce various amounts of small plastic strain in tension

Sheet thickness: 3.17 mm (1/8 in.). RT, room temperature. Composition: Al-1Mg-0.6Si-0.25Cu-0.20Cr. UNS A96061

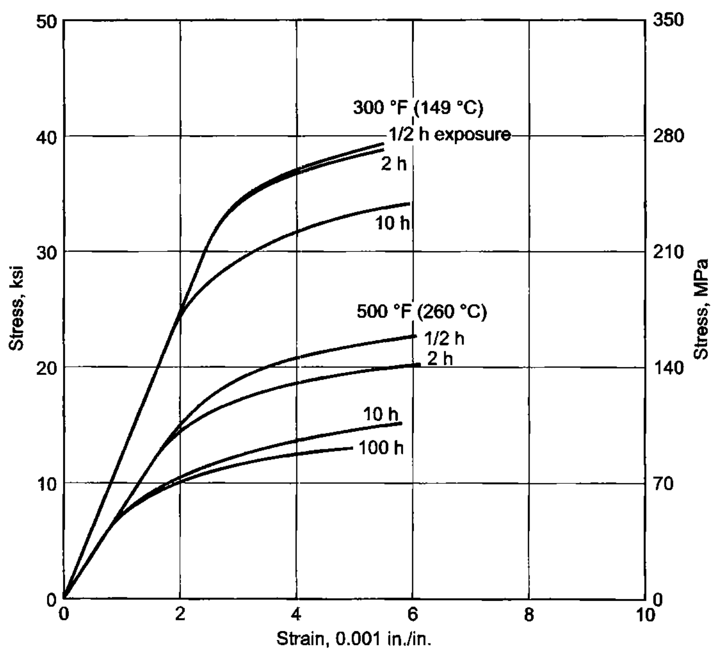
Source: R.E. Maringer and M.M. Cho, "Stability of Structural Materials for Space Craft Application," NASA CR 97844, National Aeronautics and Space Administration, April 1968. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3206, CINDAS/Purdue University, 1995, p 10



WA.187 6061-T6 aluminum alloy clad sheet, compressive stress-strain curves

Tested at 93, 204, and 316 °C (200, 400, and 600 °F) in long transverse direction. Composition: Al-1Mg-0.6Si-0.25Cu-0.20Cr. UNS A96061

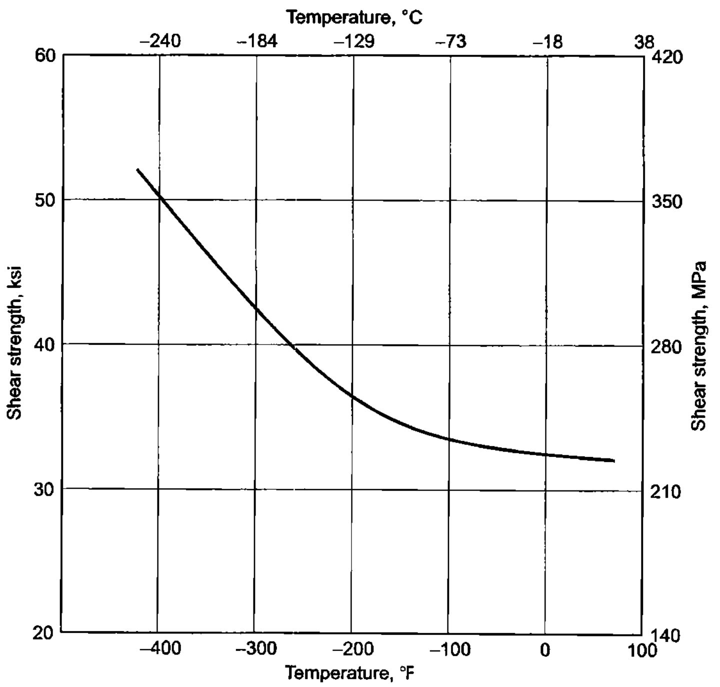
Source: *Metallic Materials and Elements for Aerospace Vehicle Structures, MIL-HDBK-5B,* FSC 1500, Sept 1971. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3206, CINDAS/Purdue University, 1995, p 10



WA.188 6061-T6 aluminum alloy sheet, compressive stress-strain curves

Tested at 149 and 260 °C (300 and 500 °F) in long transverse direction. Composition: Al-1Mg-0.6Si-0.25Cu-0.20Cr. UNS A96061

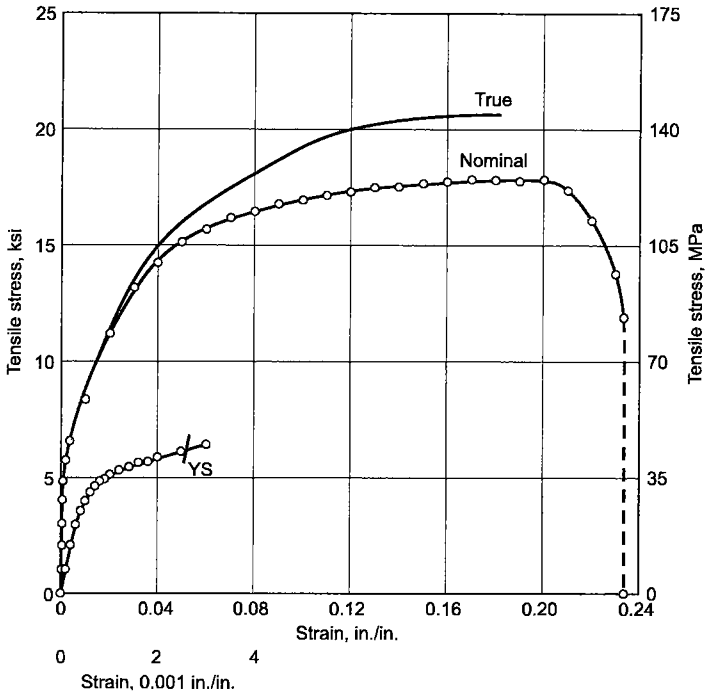
Source: *Metallic Materials and Elements for Aerospace Vehicle Structures, MIL-HDBK-5B,* FSC 1500, Sept 1971. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3206, CINDAS/Purdue University, 1995, p 11



WA.189 6061-T6 aluminum alloy sheet, effect of low temperature on shear strength

Test direction: Longitudinal and transverse. Sheet thickness: 2.54 mm (0.100 in.). Composition: Al-1.0Mg-0.6Si-0.25Cu-0.20Cr. UNS A96061

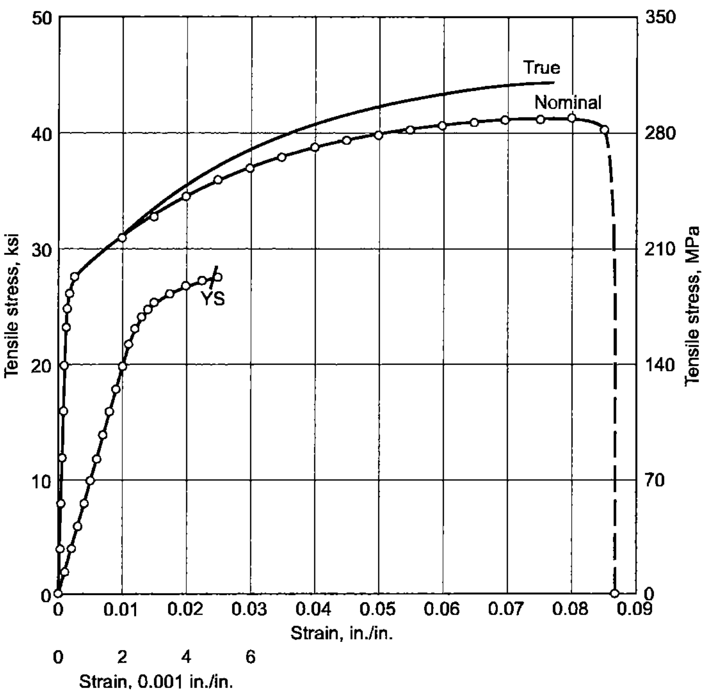
F.R Schwartzberg et al., *Cryogenic Materials Data Handbook,* MIL-TDR-64-280, Aug 1964, and Suppl. No. 1, Feb 1965. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3206, CINDAS/Purdue University, 1995, p 11



WA.190 6061-O aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test specimen diam, 12.7 mm (1/2 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 123 MPa (17.8 ksi). True tensile strength, 143 MPa (20.7 ksi). Nominal yield strength (0.2% offset), 43 MPa (6.2 ksi). Elongation (in 50.8 mm, or 2 in.), 23.4%. Reduction of area, 75%. True strain at maximum load, 18.2%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.22 in the area of uniform plastic deformation. UNS A96061

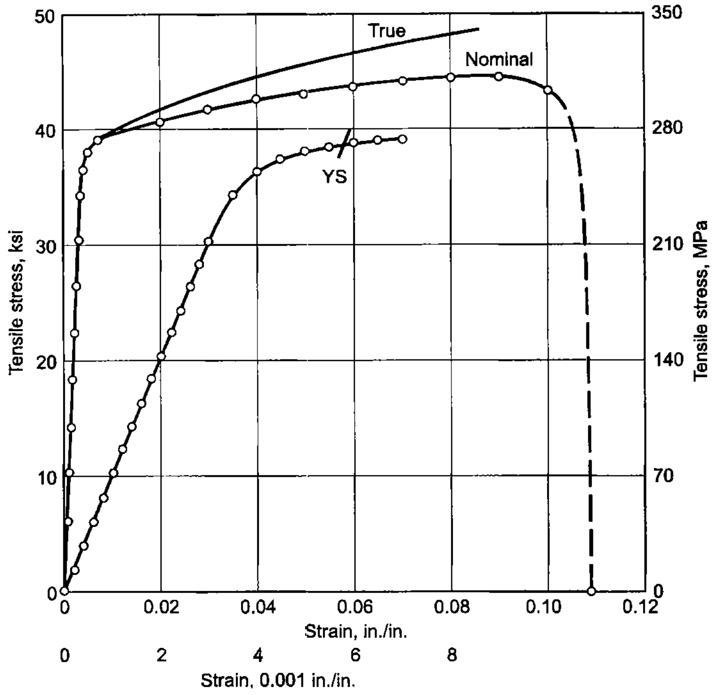
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, July 1954



WA.191 6061-T4 aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test specimen diam, 12.7 mm (1/2 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 285 MPa (41.4 ksi). True tensile strength, 307 MPa (44.5 ksi). Nominal yield strength (0.2% offset), 190 MPa (27.6 ksi). Elongation (in 50.8 mm, or 2 in.), 17.2%. Reduction of area, 54%. True strain at maximum load, 7.7%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.11 in the area of uniform plastic deformation. UNS A96061

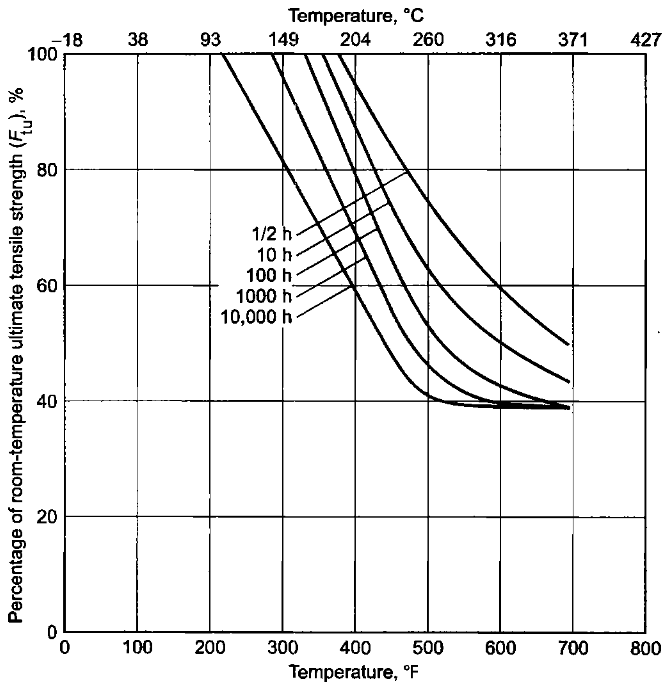
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, July 1954



WA.192 6061-T6 aluminum alloy rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test specimen diam, 12.7 mm (1/2 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 307 MPa (44.5 ksi). True tensile strength, 334 MPa (48.5 ksi). Nominal yield strength (0.2% offset), 266 MPa (38.6 ksi). Elongation (in 50.8 mm, or 2 in.), 10.8%. Reduction of area, 49%. True strain at maximum load, 8.6%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.13 in the area of uniform plastic deformation. UNS A96061

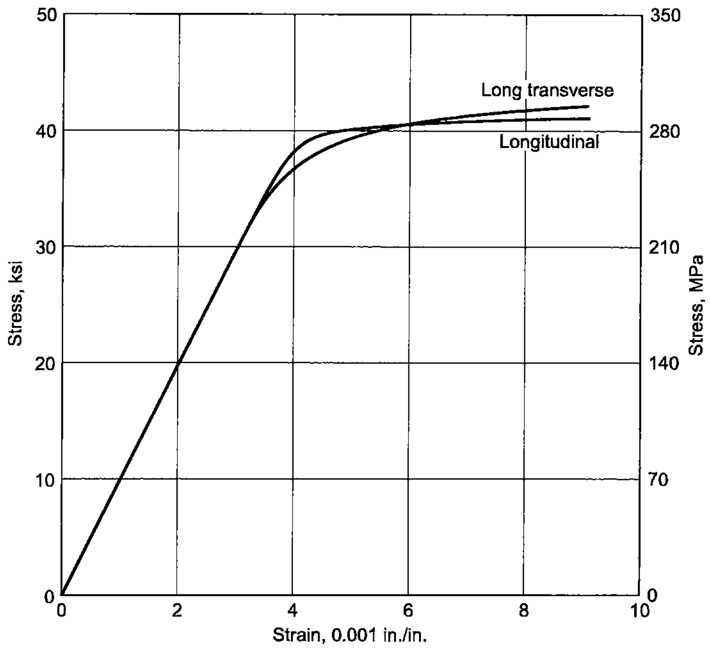
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, July 1954



WA.193 6061-T6 aluminum alloy, all products, effect of exposure at elevated temperature on room temperature tensile ultimate strength

Exposure up to 10,000 h, as indicated. All products. UNS A96061

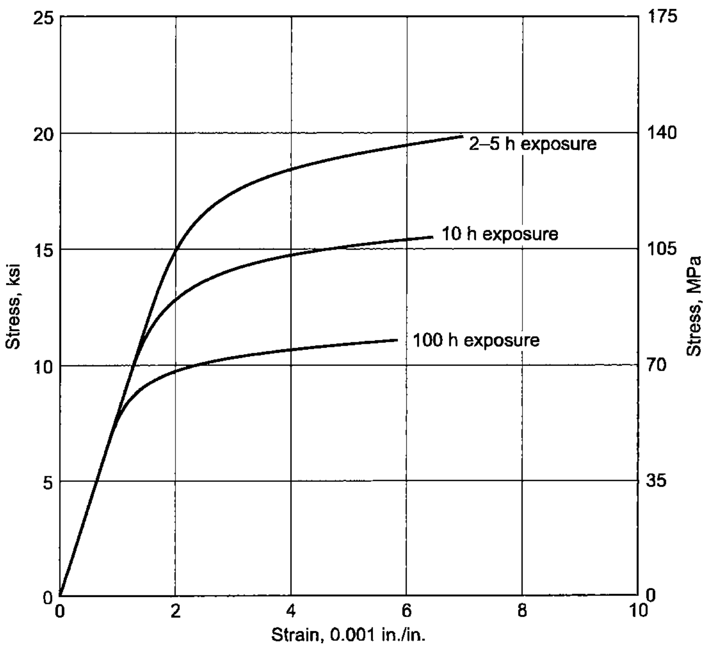
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3-264



WA.194 6061-T6 aluminum alloy sheet, tensile stress-strain curves

Tested at room temperature. Typical for sheet thickness ≤6.325 mm (≤0.249 in.). Ramberg-Osgood parameter, n(longitudinal, tension) = 50; n(long transverse, tension) = 21. UNS A96061

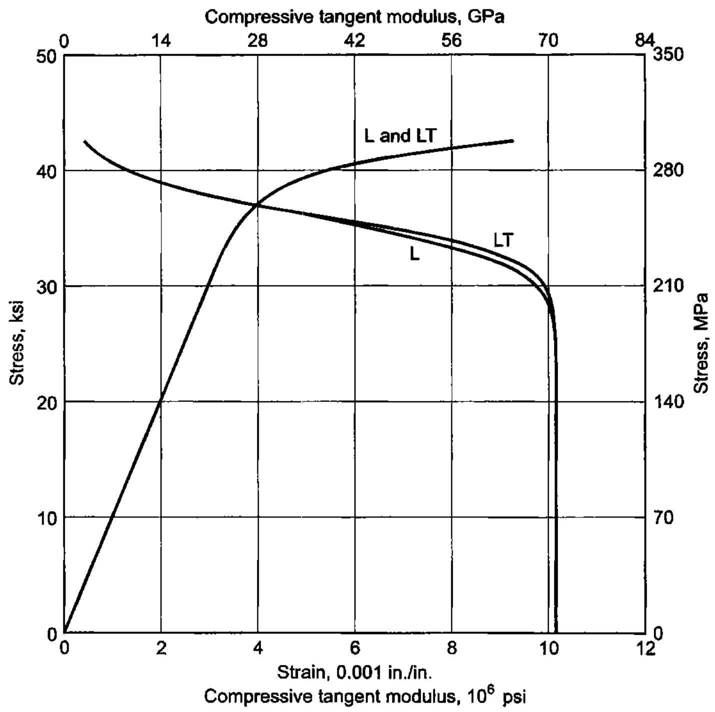
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–267



WA.195 6061-T6 aluminum alloy sheet, tensile stress-strain curves

Tested at 260 °C (500 °F). Test direction: longitudinal. Typical for sheet thickness ≤3.175 mm (≤0.125 in.). Ramberg-Osgood parameter, n(2–5 h exposure) = 13; n(10 h exposure) = 13); n(100 h exposure) = 13. UNS A96061

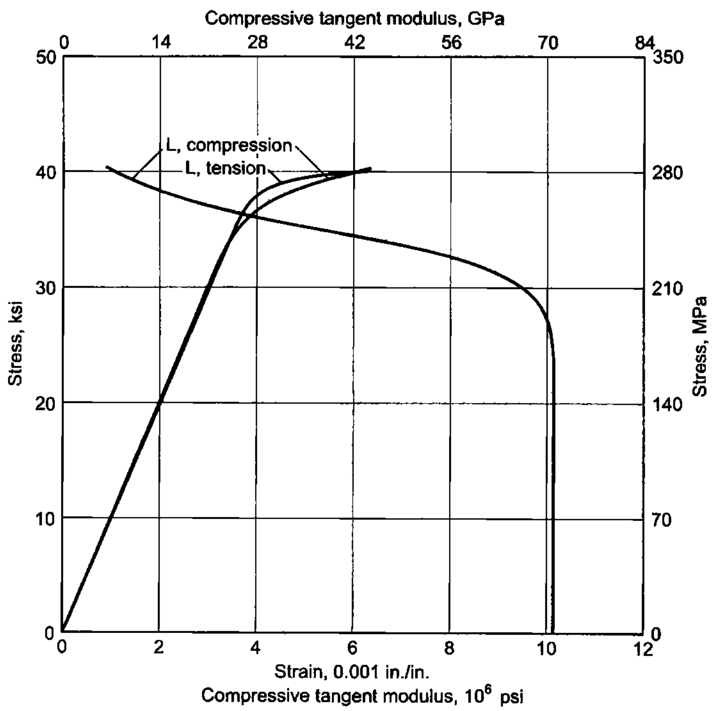
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–269



WA.196 6061-T6 aluminum alloy sheet, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for sheet thickness ≤6.325 mm (≤0.249 in.). Ramberg-Osgood parameter, n (L, compression) = 19; n(LT, compression) = 21. UNS A96061

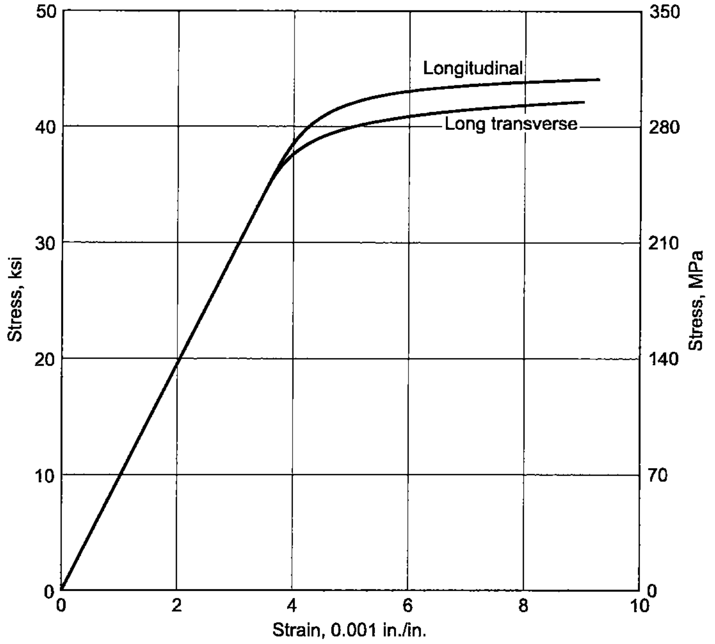
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–269



WA.197 6061-T6 aluminum alloy sheet, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal. Typical. Ramberg-Osgood parameter, n(L, tension) = 50; n(L, compression) = 18. UNS A96061

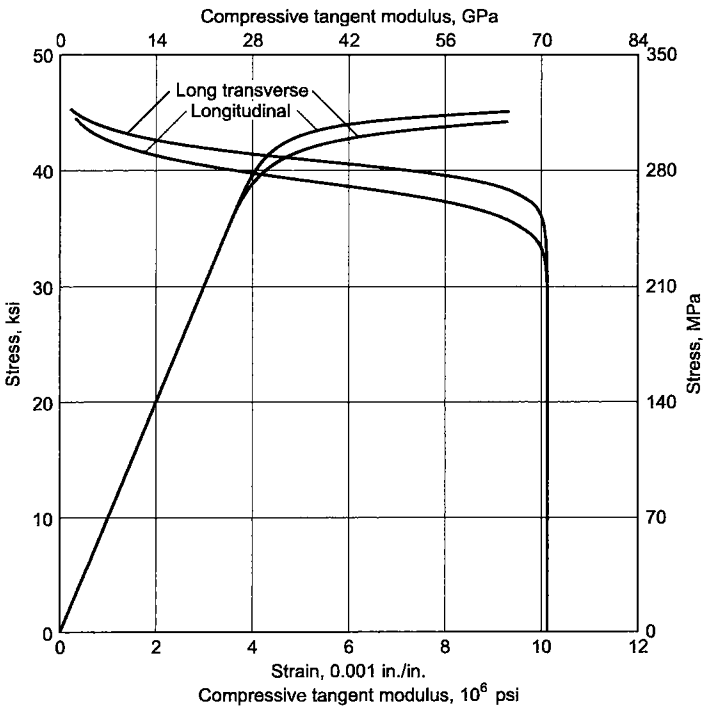
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–270



WA.198 6061-T6 aluminum alloy extrusion, tensile stress-strain curves

Tested at room temperature. Typical for all thicknesses. Ramberg-Osgood parameter, n(longitudinal, tension) = 34; n(long transverse, tension) = 29. UNS A96061

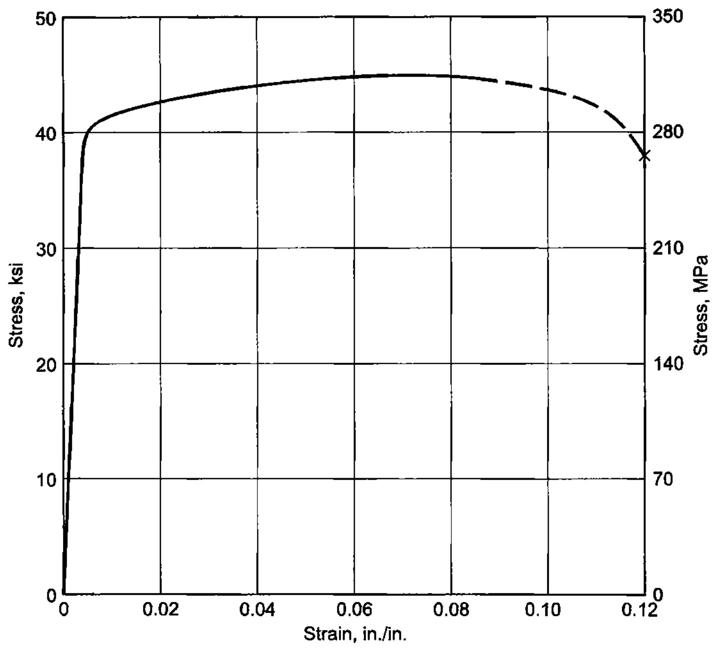
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–271



WA.199 6061-T6 aluminum alloy extrusion, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for all thicknesses. Ramberg-Osgood parameter, n(longitudinal, compression) = 38; n(long transverse, compression) = 28. UNS A96061

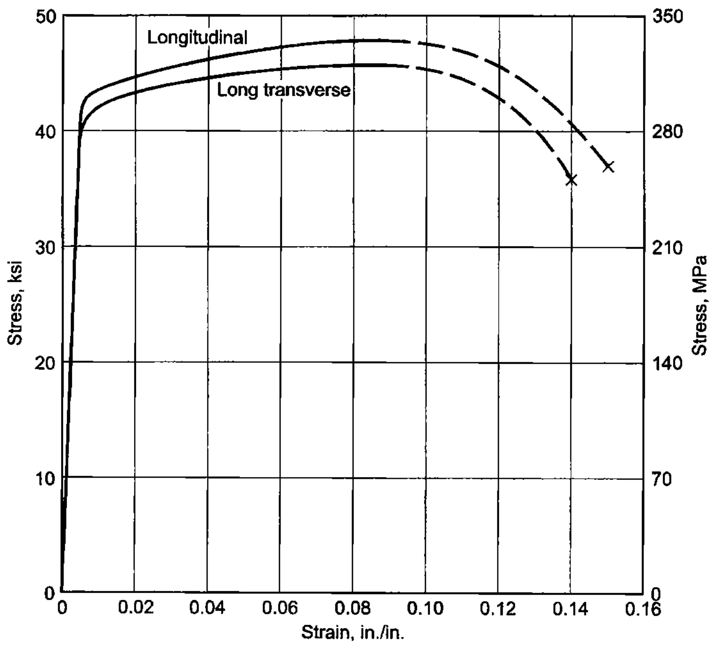
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–271



WA.200 6061-T6 aluminum alloy sheet, tensile stress-strain curve (full range)

Tested at room temperature. Test direction: longitudinal. Typical. UNS A96061

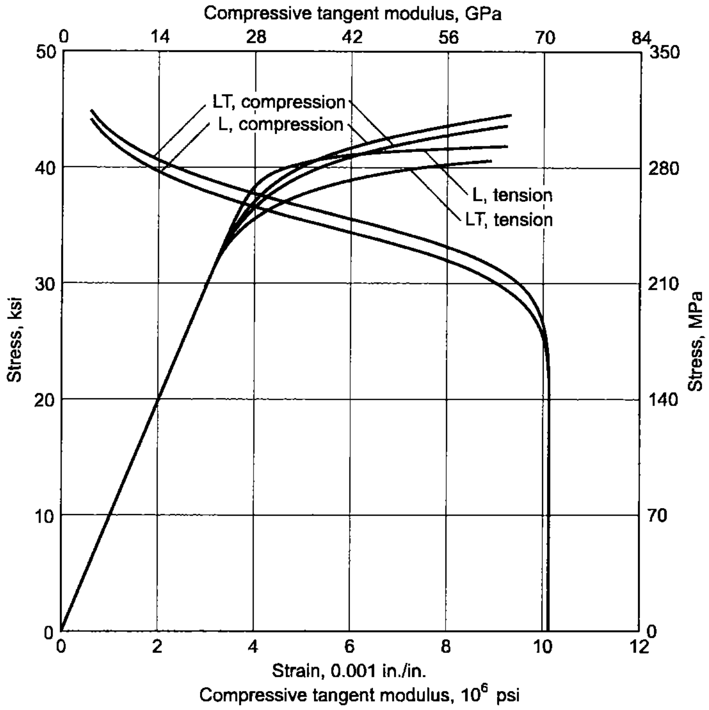
Source: *MIL-HDBK-5H,* 1 Dec 1998. p 3–273



WA.201 6061-T62 aluminum alloy extrusion, tensile stress-strain curves (full range)

Tested at room temperature. Typical for all thicknesses. UNS A96061

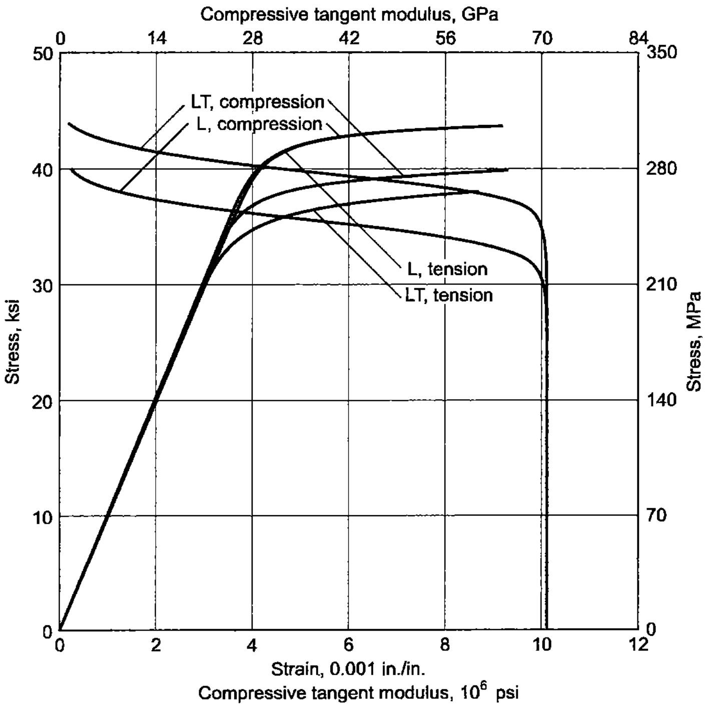
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–274



WA.202 6061-T651X, aluminum alloy extrusion, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for extrusion thickness ≤12.67 mm (≤0.499 in.). Ramberg-Osgood parameter, *n*(L, tension) = 40; *n*(LT, tension) = 19; *n*(L, compression) = 15; *n*(LT, compression) = 14. UNS A96061

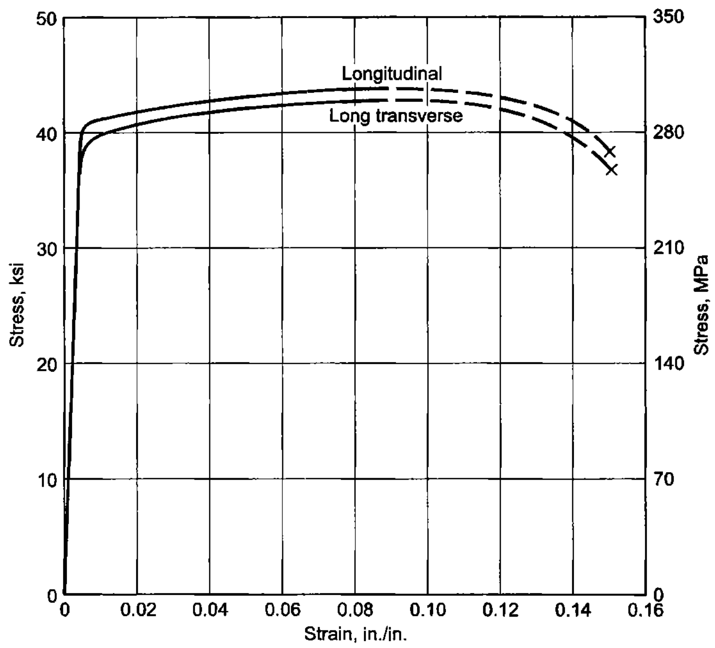
Source: *MIL-HDBK-5H,* 1 Dec 1998



WA.203 6061-T651X aluminum alloy extrusion, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for extrusion thickness ≥76.20 mm (≥3.000 in.). Ramberg-Osgood parameter, *n*(L, tension) = 45; *n*(LT, tension) = 24; *n*(L, compression) = 40; *n*(LT, compression) = 32. UNS A96061

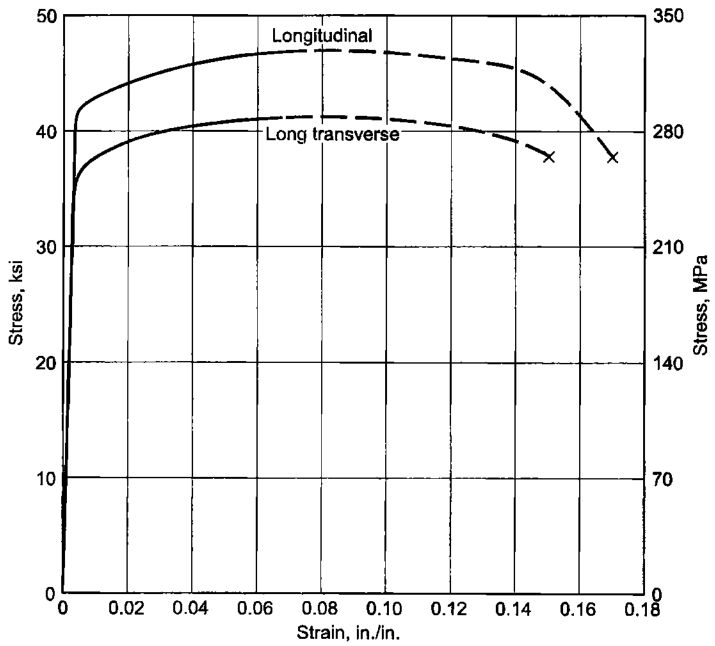
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–272



WA.204 6061-T651X aluminum alloy extrusion, tensile stress-strain curves (full range)

Tested at room temperature. Typical for extrusion thickness ≤12.675 mm (≤0.499 in.). UNS A96061

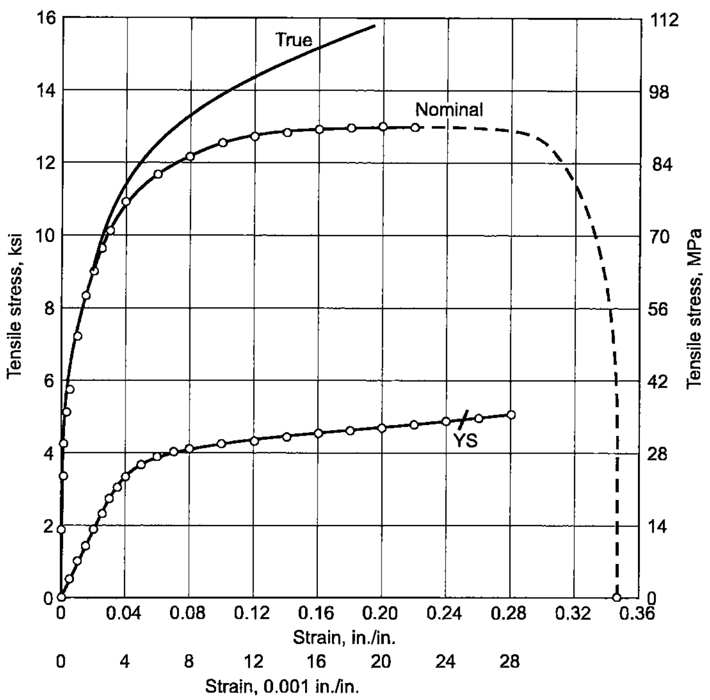
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–275



WA.205 6061-T651X aluminum alloy extrusion, tensile stress-strain curves (full range)

Tested at room temperature. Typical for extrusion thickness 76.20 mm (3.000 in.). UNS A96061

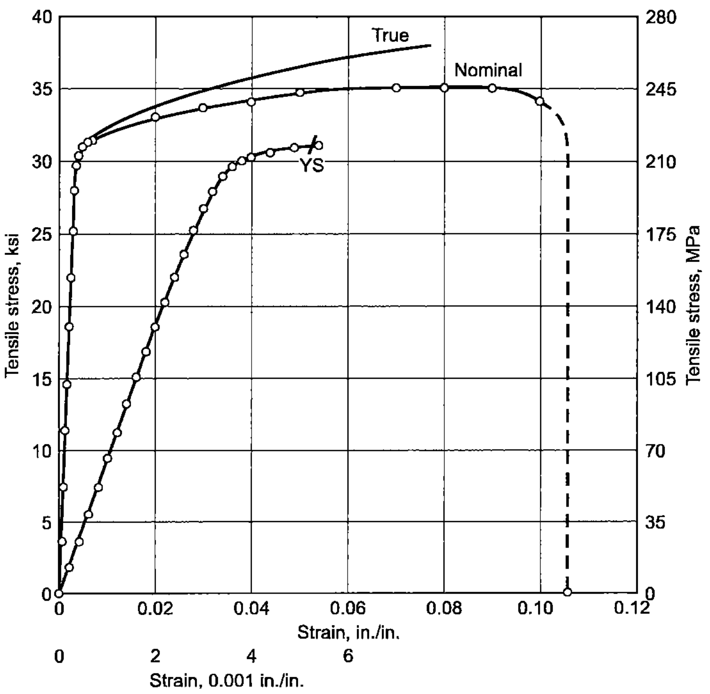
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–276



WA.206 6063-O aluminum alloy extruded rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Full specimen size. Test specimen diam, 19 mm (3/4 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 89.6 MPa (13.0 ksi). True tensile strength, 109 MPa (15.8 ksi). Nominal yield strength (0.2% offset), 34 MPa (4.9 ksi). Elongation (in 50.8 mm, or 2 in.), 34.5%. Reduction of area, 85%. True strain at maximum load, 19.0%. A log-log plot of the stress-strain curve would yield a slope of (*n*) of 0.20 in the area of uniform plastic deformation. UNS A96063

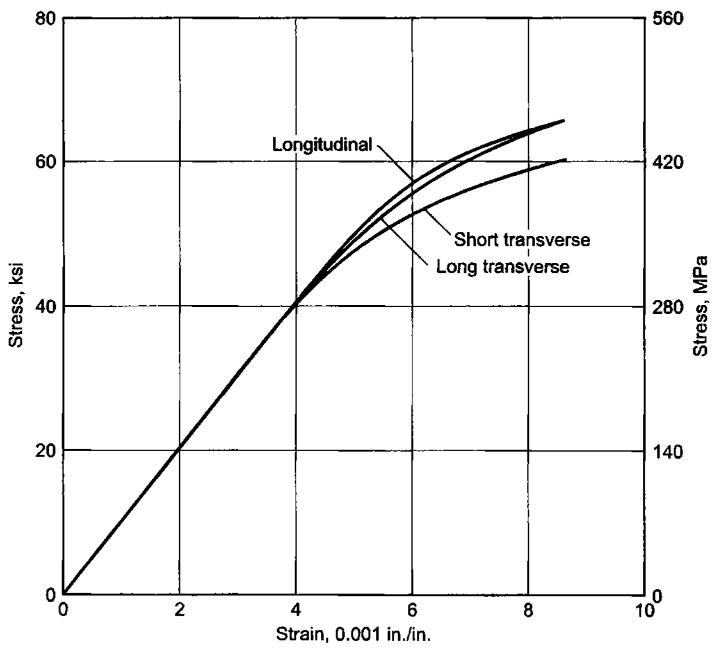
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA



WA.207 6063-T6 aluminum alloy extruded rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Rod diam, 19 mm (3/4 in.). Specimen diam, 12.7 mm (1/2 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 243 MPa (35.3 ksi). True tensile strength, 252 MPa (36.5 ksi). Nominal yield strength (0.2% offset), 214 MPa (31.0 ksi). Elongation (in 50.8 mm, or 2 in.), 10.6%. Reduction of area, 44%. True strain at maximum load, 7.7%. A log-log plot of the stress-strain curve would yield a slope of (*n*) of 0.08 in the area of uniform plastic deformation. UNS A96063

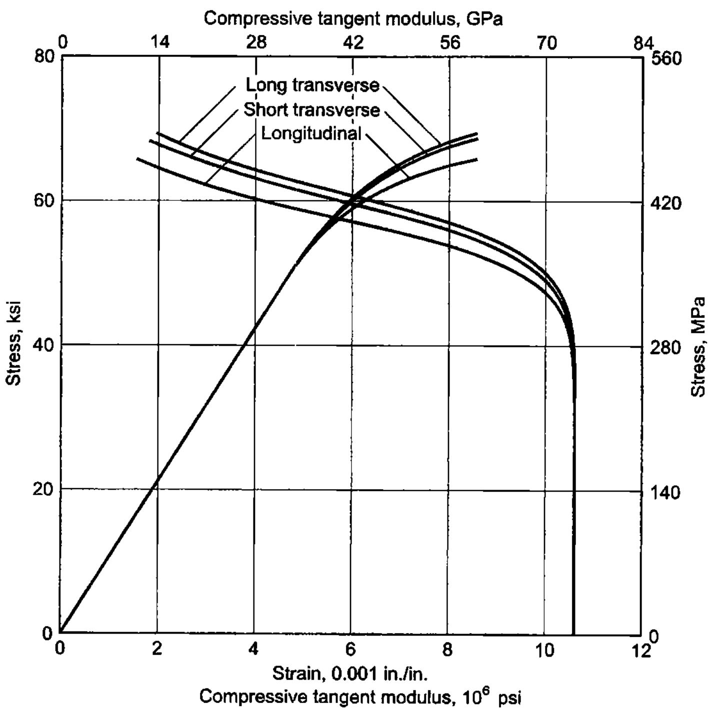
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, March 1953



WA.208 7010-T7451 aluminum alloy plate, tensile stress-strain curves

Tested at room temperature. Typical for sheet thickness 50.82–139.7 mm (2.001–5.50 in.). Ramberg-Osgood parameter, n(longitudinal, tension) = 13; n(long transverse, tension) = 8.8; n(short transverse, tension) = 8.7. UNS A97010

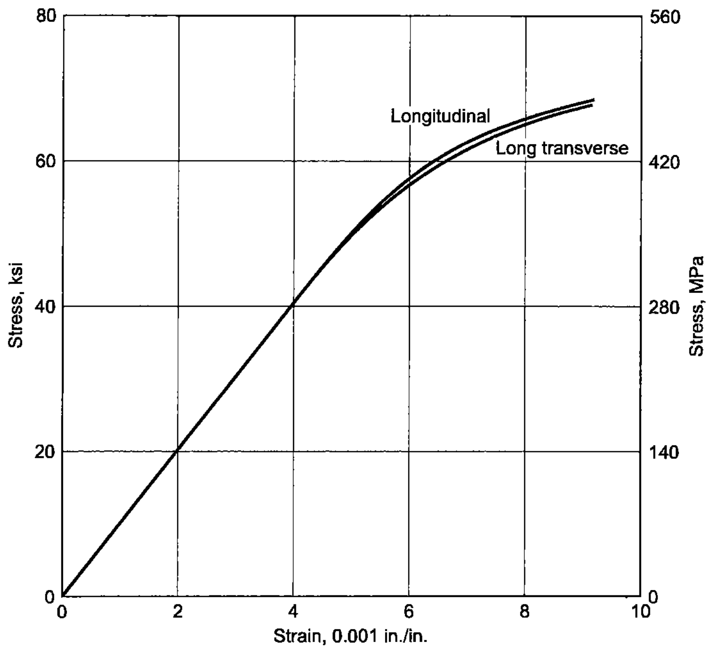
Source: *MIL-HDBK-5H*, 1 Dec 1998, p 3–285



WA.209 7010-T7451 aluminum alloy plate, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for sheet thickness 50.82–139.7 mm (2.001–5.50 in.). Ramberg-Osgood parameter, n(longitudinal, compression) = 15; n(long transverse, compression) = 14; n(short transverse, compression) = 14. UNS A97010

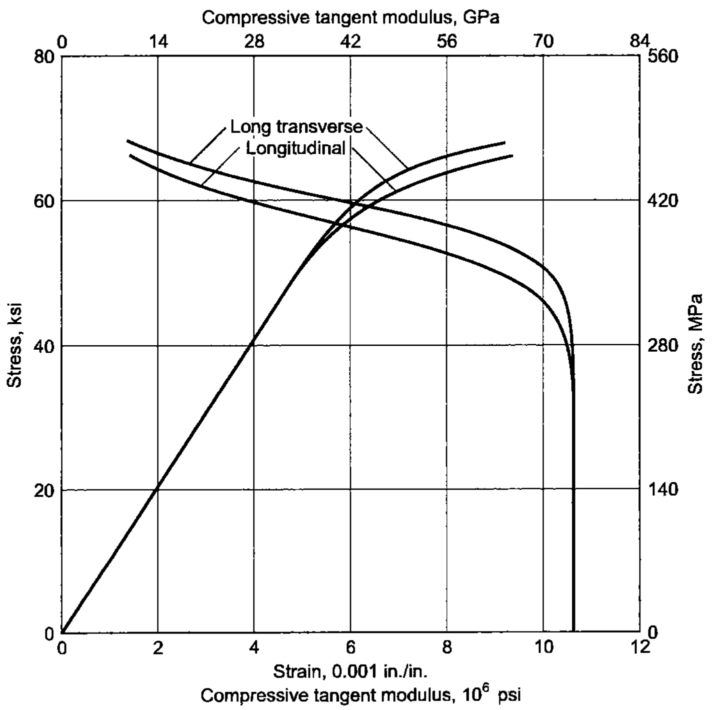
Source: *MIL-HDBK-5H*, 1 Dec 1998, p 3–285



WA.210 7010-T7451 aluminum alloy plate, tensile stress-strain curves

Tested at room temperature. Typical for sheet thickness 12.7–38.1 mm (0.50–1.50 in.). Ramberg-Osgood parameter, n(longitudinal, tension) = 12; n(long transverse, tension) = 10. UNS A97010

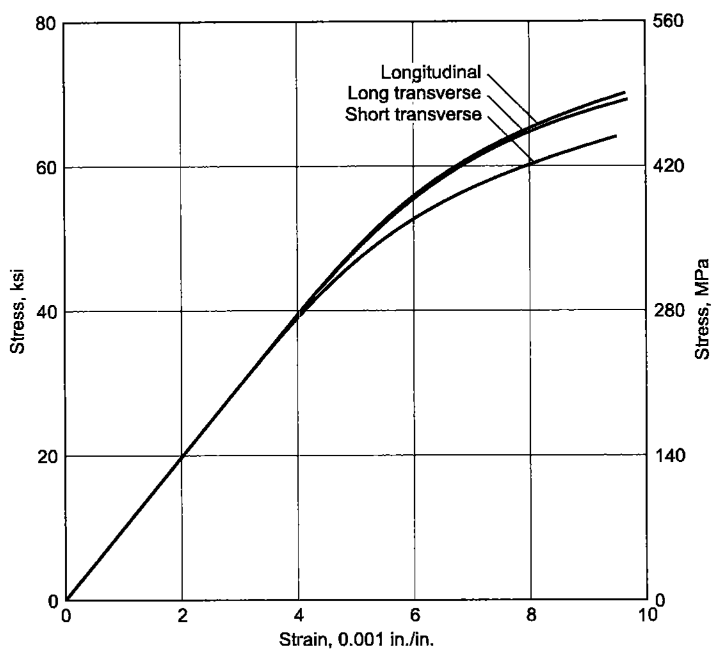
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–286



WA.211 7010-T7451 aluminum alloy plate, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for sheet thickness 12.7–38.1 mm (0.50–1.50 in.). Ramberg-Osgood parameter, n(longitudinal, compression) = 14; n(long transverse, compression) = 17. UNS A97010

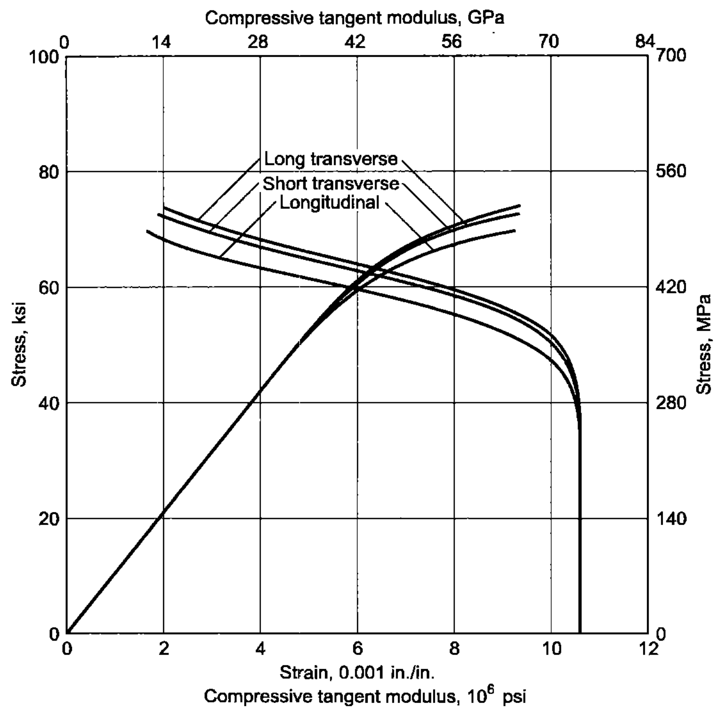
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–286



WA.212 7010-T7651 aluminum alloy plate, tensile stress-strain curves

Tested at room temperature. Typical for sheet thickness 50.82–139.7 mm (2.001–5.50 in.). Ramberg-Osgood parameter, n(longitudinal, tension) = 9.2; n(long transverse, tension) = 9.7; n(short transverse, tension) = 8.2. UNS A97010

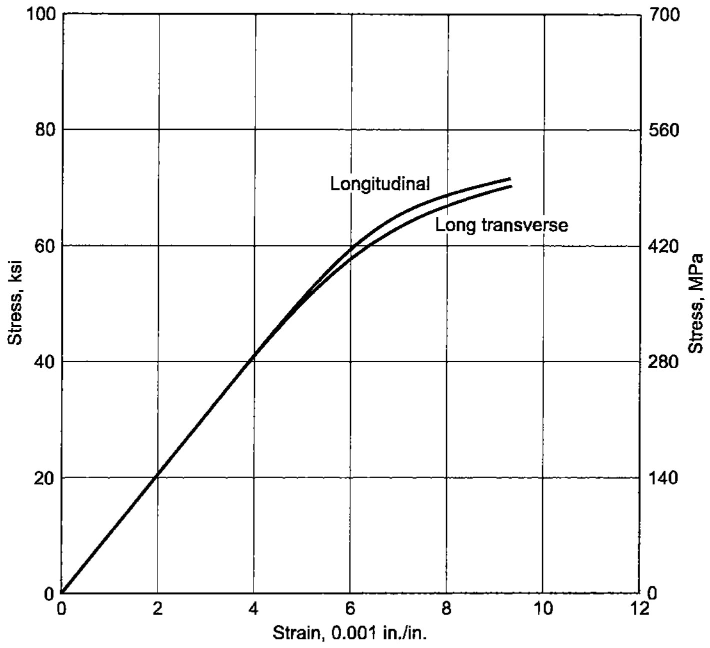
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–287



WA.213 7010-T7651 aluminum alloy plate, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for sheet thickness 50.82–139.7 mm (2.001–5.50 in.). Ramberg-Osgood parameter, n(longitudinal, compression) = 13; n(long transverse, compression) = 13; n(short transverse, compression) = 12. UNS A97010

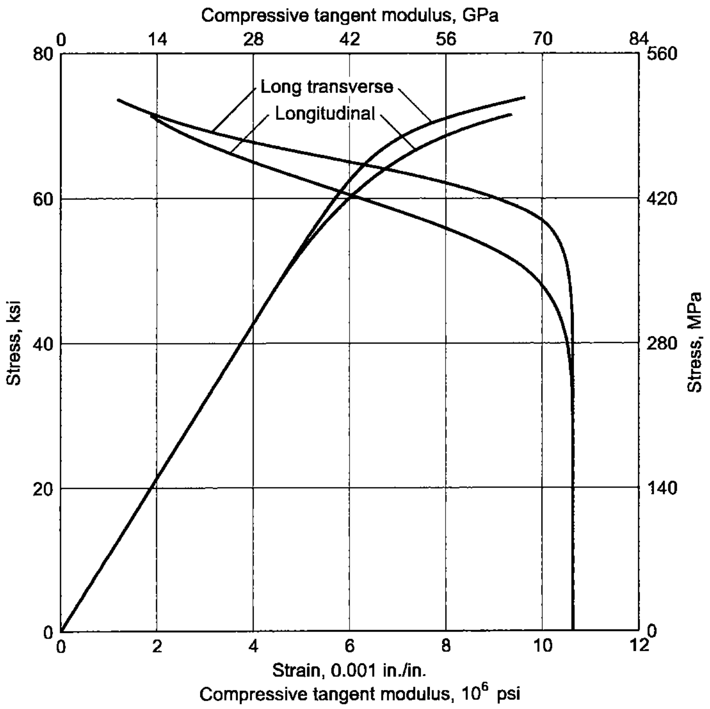
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–287



WA.214 7010-T7651 aluminum alloy plate, tensile stress-strain curves

Tested at room temperature. Typical for plate thickness 12.7–38.10 mm (0.500–1.500 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 14; *n*(long transverse, tension) = 9.9. UNS A97010

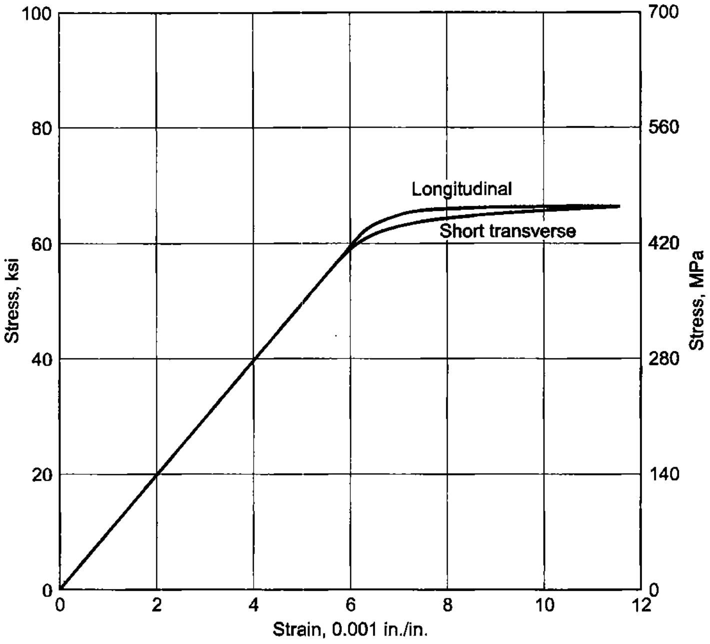
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–288



WA.215 7010-T7651 aluminum alloy plate, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for plate thickness 12.7–38.10 mm (0.500–1.500 in.). Ramberg-Osgood parameter, *n*(longitudinal, compression) = 12; *n*(long transverse, compression) = 20. UNS A97010

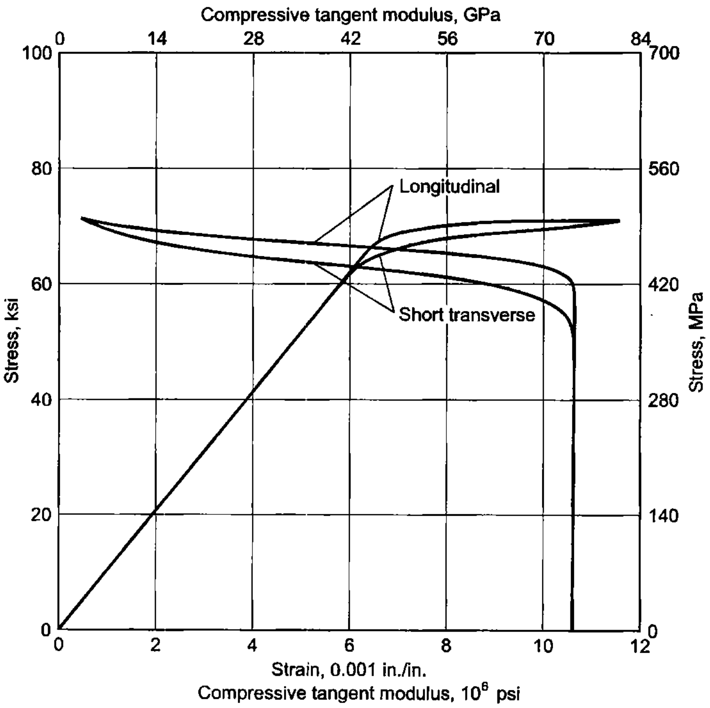
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–288



WA.216 7049/7149-T73 aluminum alloy die forging, tensile stress-strain curves

Tested at room temperature. Typical for forging thickness ≤101.60 mm (≤4.000 in.). Ramberg-Osgood parameter, n(longitudinal, tension) = 54; n(short transverse, tension) = 29. UNS A97049, A97149

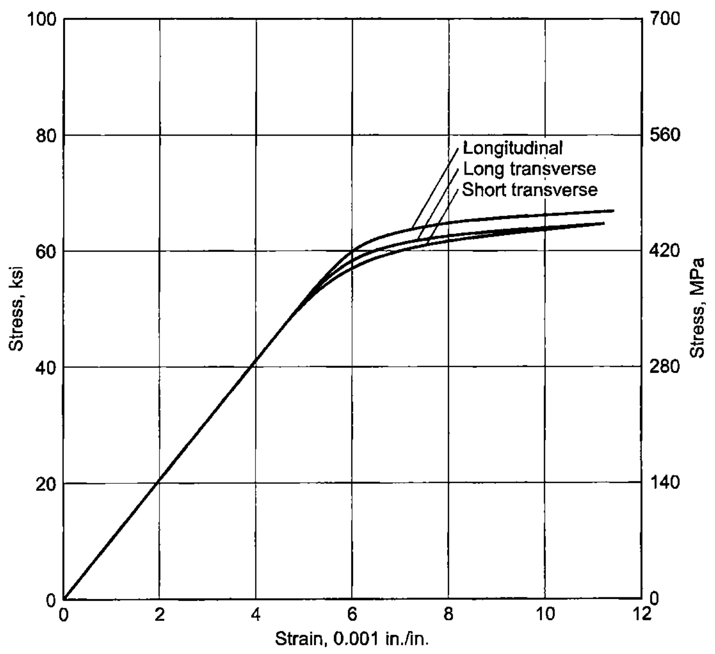
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–295



WA.217 7049/7149-T73 aluminum alloy die forging, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for forging thickness ≤101.60 mm (≤4.000 in.). Ramberg-Osgood parameter, n(longitudinal, compression) = 54; n(short transverse, compression) = 29. UNS A97049, A97149

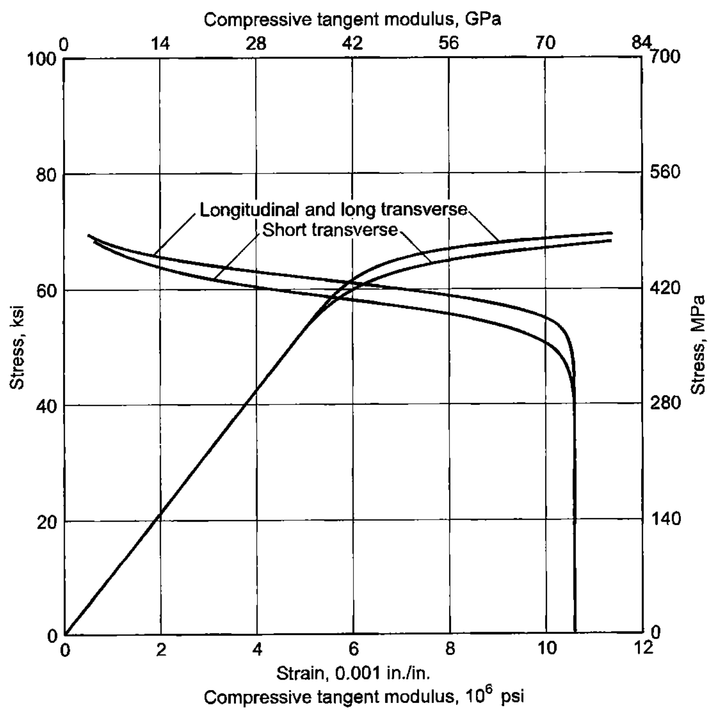
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–295



WA.218 7049/7149-T73 aluminum alloy hand forging, tensile stress-strain curves

Tested at room temperature. Typical for forging thickness 50.083–127.0 mm (2.001–5.000 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 29; *n*(long transverse, tension) = 24; *n*(short transverse, tension) = 18. UNS A97049, A97149

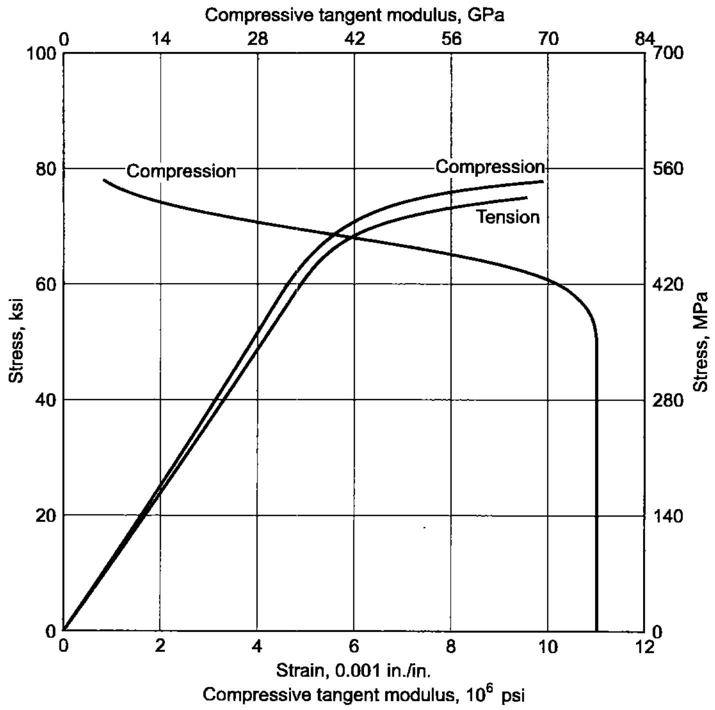
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–296



WA.219 7049/7149-T73 aluminum alloy hand forging, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for forging thickness 50.08–127.0 mm (2.001–5.000 in.). Ramberg-Osgood parameter, *n*(longitudinal, compression) = 26; *n*(long transverse, compression) = 24; *n*(short transverse, compression) = 20. UNS A97049, A97149

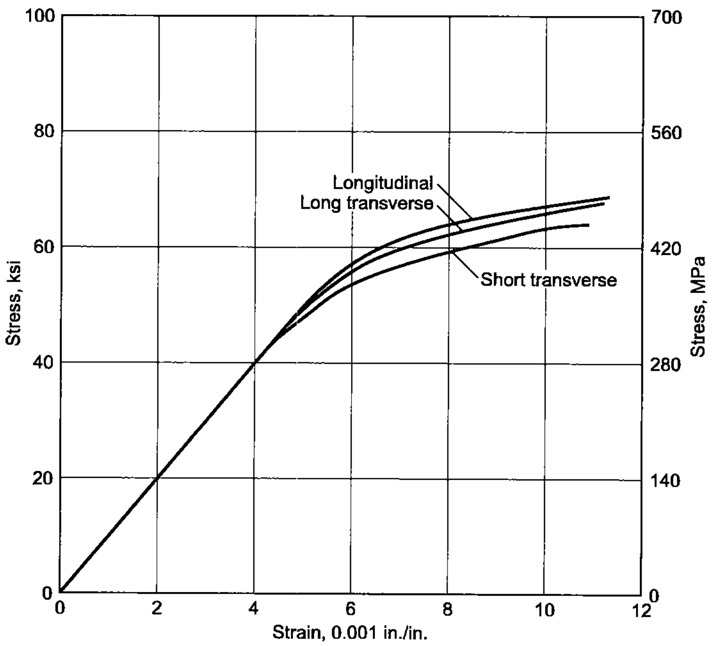
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–296



WA.220 7049/7149-T73511 aluminum alloy extrusion, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: longitudinal. Typical for extrusion thickness ≤127.0 mm (≤5.00 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 22; *n*(longitudinal, compression) = 20. UNS A97049, A97149

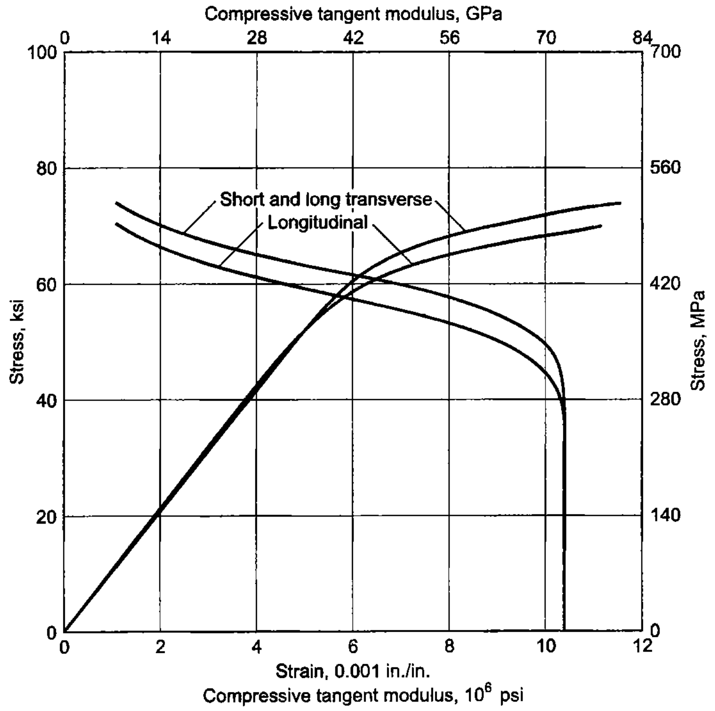
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–298



WA.221 7049-T7351 aluminum alloy plate, tensile stress-strain curves

Tested at room temperature. Typical for plate thickness 38.12–114.3 mm (1.501–4.500 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 13; *n*(long transverse, tension) = 12; *n*(short transverse, tension) = 10. UNS A97049

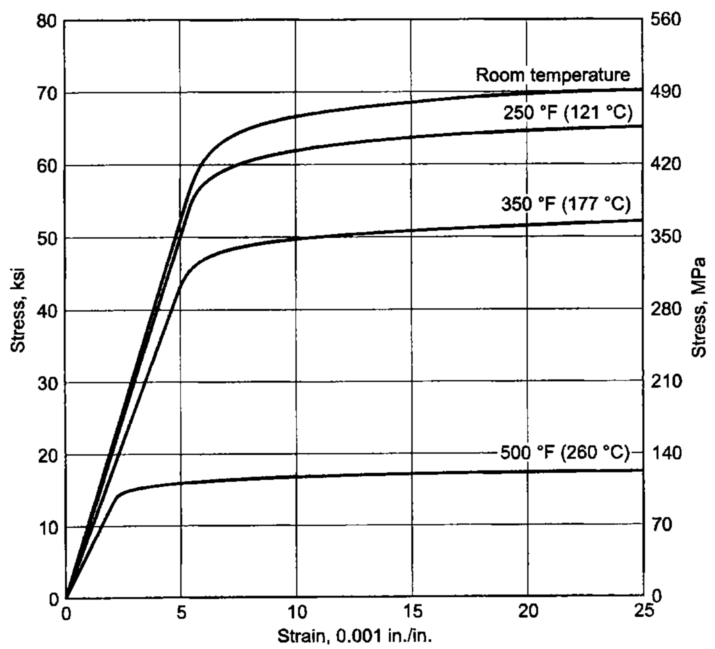
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–297



WA.222 7049-T7351 aluminum alloy plate, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for plate thickness 38.125–114.30 mm (1.501–4.500 in.). Ramberg-Osgood parameter, *n*(longitudinal, compression) = 13; *n*(long transverse, compression) = 15; *n*(short transverse, compression) = 14. UNS A97049

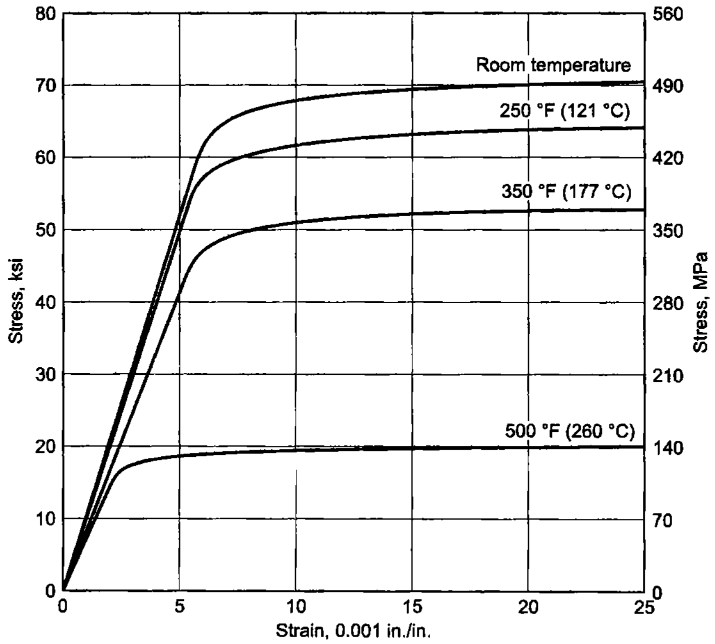
Source: *MIL-HDBK-5H*, 1 Dec 1998, p 3–297



WA.223 7049-T73 aluminum alloy forging, tensile stress-strain curves

Tested at room and elevated temperatures. Test direction: longitudinal. Typical for forging thickness 127 mm (5 in.). Composition: Al-7.6Zn-2.5Mg-1.5Cu-0.15Cr. UNS A97049

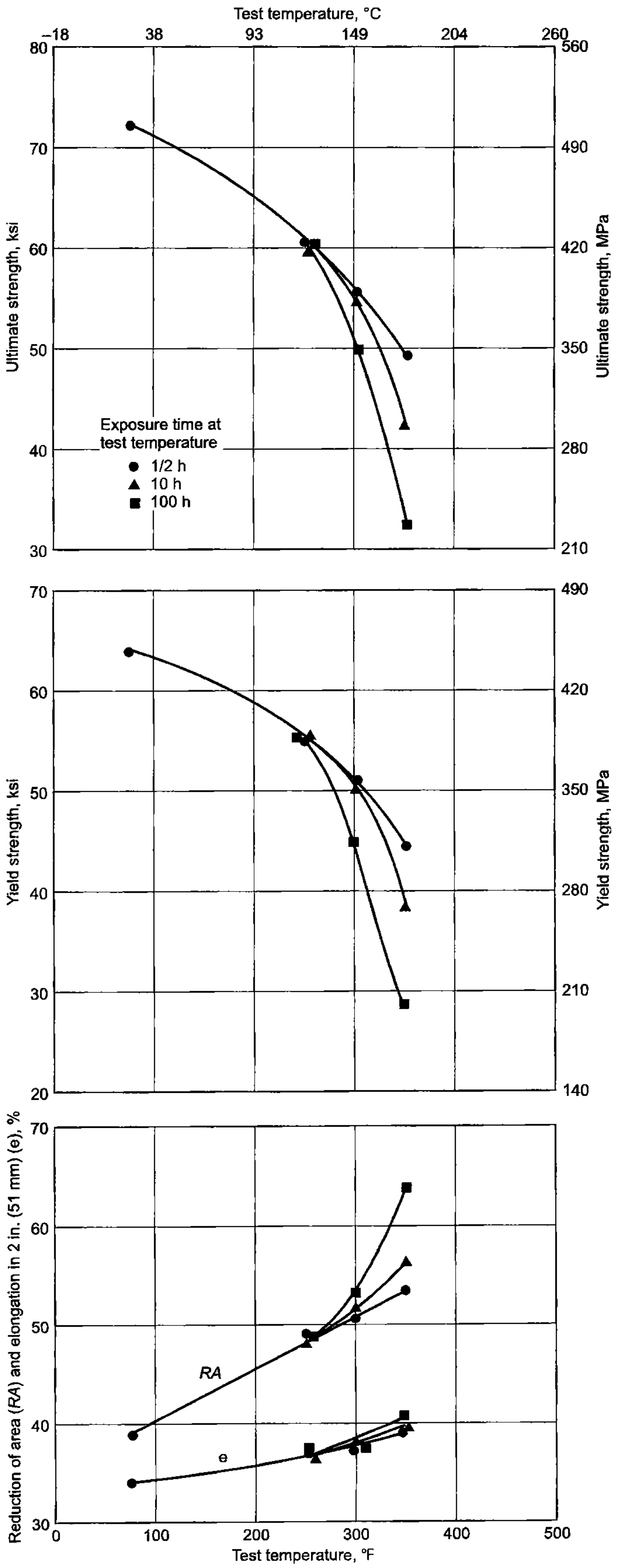
Source: Private communication between O. Deel (Battelle Memorial Institute) and L.J. Barker (Kaiser Aluminum and Chemical Corp.), Dec 1969. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3217, CINDAS/Purdue University, 1995, p 17



WA.224 7049-T73 aluminum alloy forging, tensile stress-strain curves

Tested at room and elevated temperatures. Test direction: transverse. Typical for forging thickness 127 mm (5 in.). Composition: Al-7.6Zn-2.5Mg-1.5Cu-0.15Cr.
UNS A97049

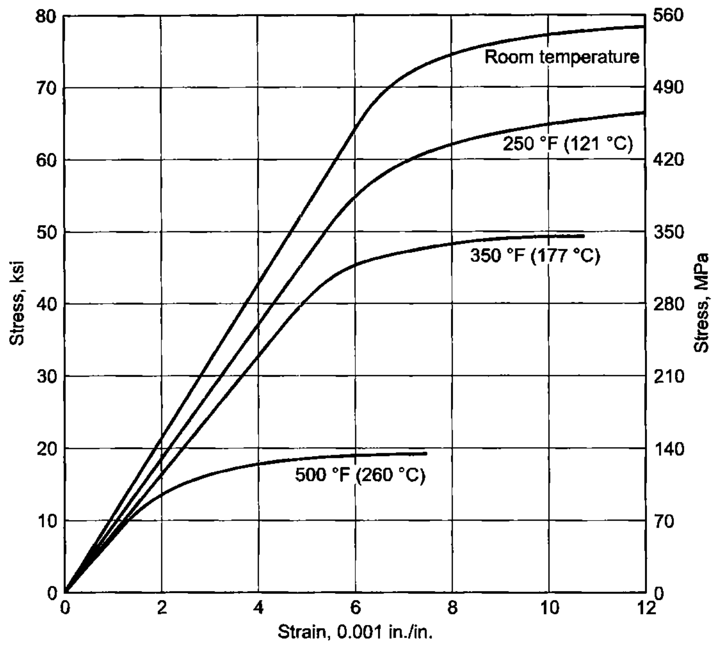
Source: O.L. Deel and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," Technical Report AFML-TR-72-196, Vol II, Air Force Materials Laboratory, Wright-Patterson AFB, OH, Sept 1972. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3217, CINDAS/Purdue University, 1995, p 17



WA.225 7049-T73 aluminum alloy forging, effect of exposure and test temperature on tensile properties

Forging thickness: 127 mm (5 in.). Each point average of three tests. Composition: Al-7.6Zn-2.5Mg-1.5Cu-0.15Cr. UNS A97049

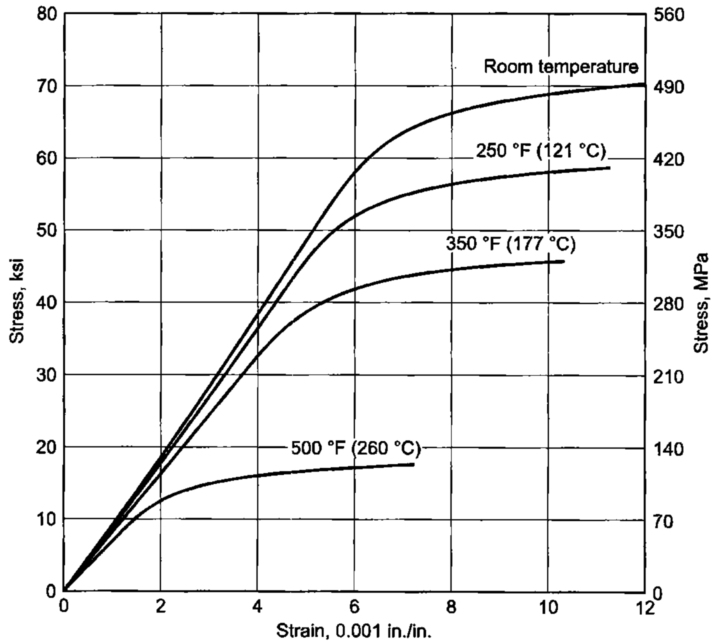
Source: W.M. Pratt, "Material-Kaiser Aluminum Alloy X7049-T73, Effect of Elevated Temperature on Mechanical Properties," Report FGT-5541, General Dynamics, Fort Worth Div., Dec 1969. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3217, CINDAS/ Purdue University, 1995, p 18



WA.226 7049-T76 aluminum alloy extrusion, tensile stress-strain curves

Tested at room and elevated temperatures.
Test direction: longitudinal.
Composition: Al-7.6Zn-2.5Mg-1.5Cu-0.15Cr.
UNS A97049

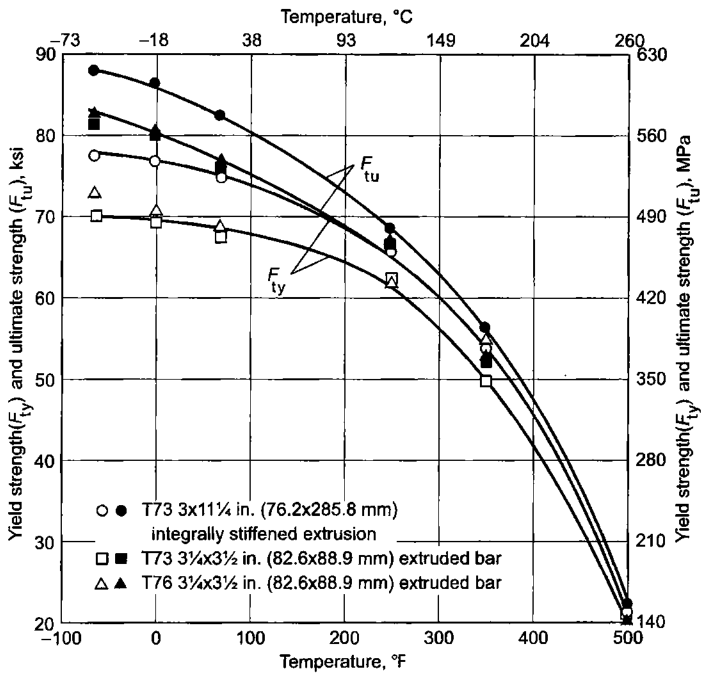
Source: O.L. Deel and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," Technical Report AFML-TR-72-196, Vol II, Air Force Materials Laboratory, Wright-Patterson AFB, OH, Sept 1972. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3217, CINDAS/Purdue University, 1995, p 18



WA.227 7049-T76 aluminum alloy extrusion, tensile stress-strain curves

Tested at room and elevated temperatures. Test direction: transverse. Composition: Al-7.6Zn-2.5Mg-1.5Cu-0.15Cr. UNS A97049

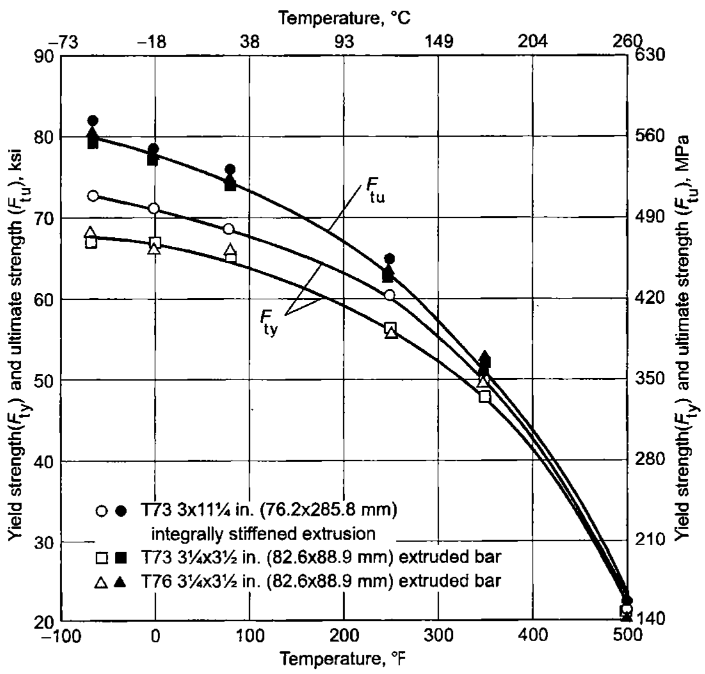
Source: O.L. Deel and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," Technical Report AFML-TR-72-196, Vol II, Air Force Materials Laboratory, Wright-Patterson AFB, OH, Sept 1972. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3217, CINDAS/Purdue University, 1995, p 18



WA.228 7049-T73 aluminum alloy extrusion and bar, 7049-T76 bar, effect of temperature on tensile properties data

Test direction: transverse. Composition: Al-7.6Zn-2.5Mg-1.5Cu-0.15Cr. UNS A97049

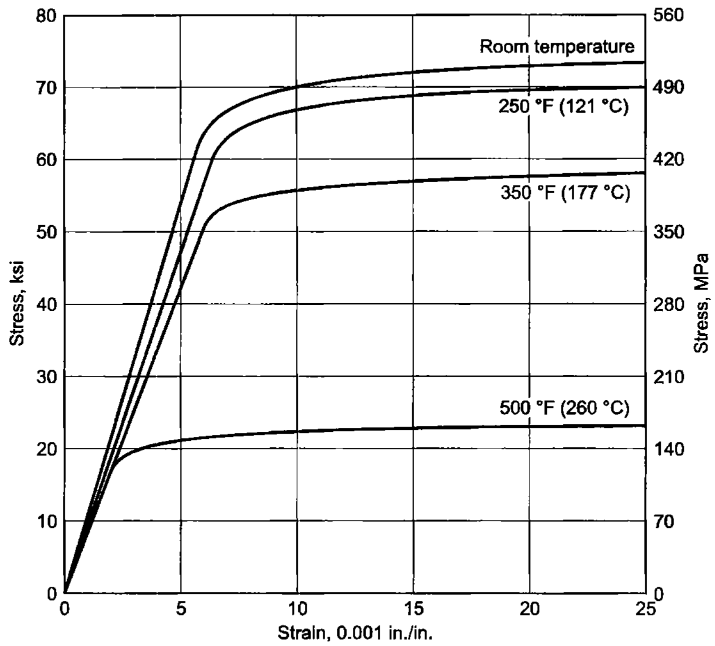
Source: R.E. Jones, "Mechanical Properties of 7049-T73 and 7049-T76 Aluminum Alloy Extrusions at Several Temperatures," AFML-TR-72-2, Air Force Materials Laboratory, Wright-Patterson AFB, OH, Feb 1972. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3217, CINDAS/Purdue University, 1995, p 20



WA.229 7049-T73 aluminum alloy extrusion and bar, 7049-T76 bar, tensile property data

Test direction: short transverse. Composition: Al-7.6Zn-2.5Mg-1.5Cu-0.15Cr. UNS A97049

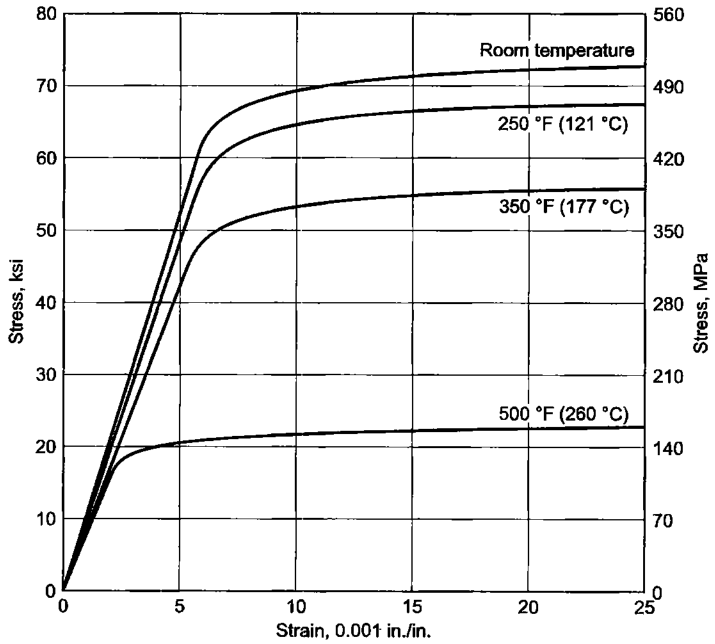
Source: R.E. Jones, "Mechanical Properties of 7049-T73 and 7049-T76 Aluminum Alloy Extrusions at Several Temperatures," AFML-TR-72-2, Air Force Materials Laboratory, Wright-Patterson AFB, OH, Feb 1972. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3217, CINDAS/Purdue University, 1995, p 20



WA.230 7049-T73 aluminum alloy forging, compressive stress-strain curves

Tested at room and elevated temperatures. Test direction: longitudinal. Typical for forging thickness 127 mm (5 in.). Composition: Al-7.6Zn-2.5Mg-1.5Cu-0.15Cr. UNS A97049

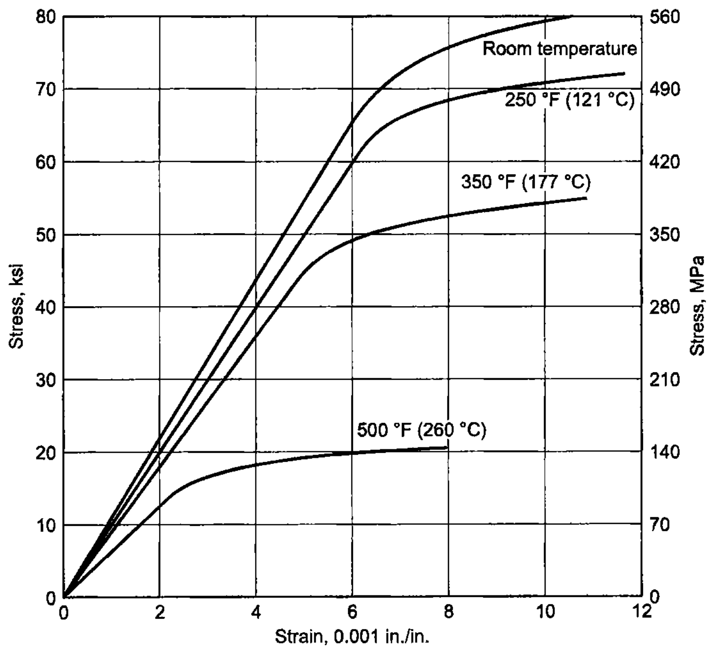
Source: Private communication between O. Deel (Battelle Memorial Institute) and L.J. Barker (Kaiser Aluminum and Chemical Corp.), Dec 1969. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3217, CINDAS/Purdue University, 1995, p 20



WA.231 7049-T73 aluminum alloy forging, compressive stress-strain curves

Tested at room and elevated temperatures. Test direction: transverse. Typical for forging thickness 127 mm (5 in.). Composition: Al-7.6Zn-2.5Mg-1.5Cu-0.15Cr. UNS A97049

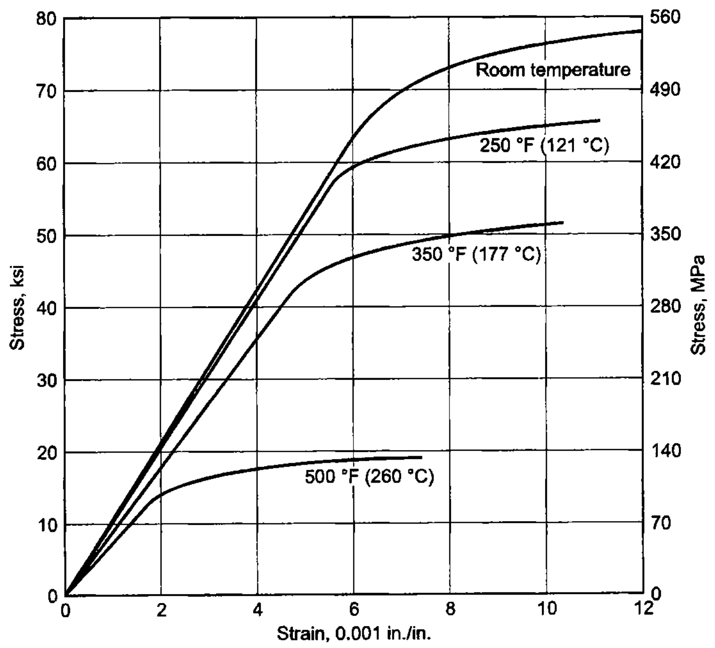
Source: Private communication between O. Deel (Battelle Memorial Institute) and L.J. Barker (Kaiser Aluminum and Chemical Corp.), Dec 1969. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3217, CINDAS/Purdue University, 1995, p 20



WA.232 7049-T76 aluminum alloy extrusion, compressive stress-strain curves

Tested at room and elevated temperatures. Test direction: longitudinal. Composition: Al-7.6Zn-2.5Mg-1.5Cu-0.15Cr. UNS A97049

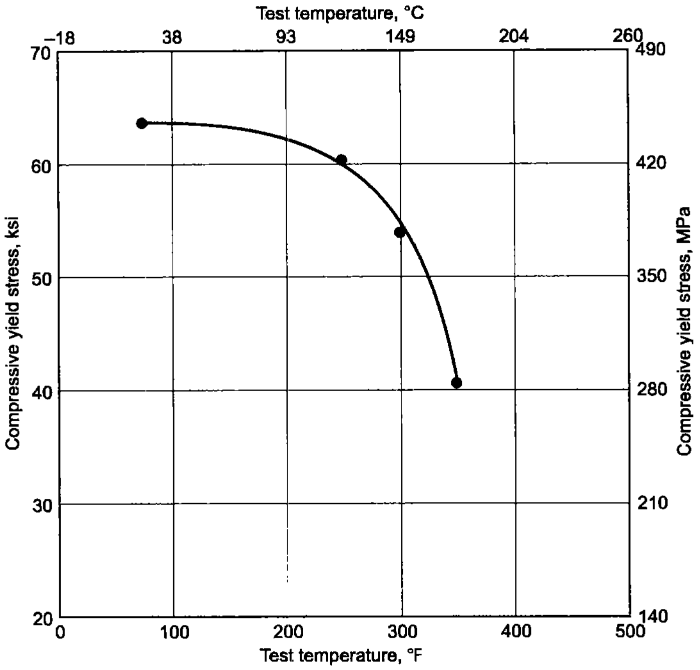
Source: O.L. Deel and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," Technical Report AFML-TR-72-196, Vol II, Air Force Materials Laboratory, Wright-Patterson AFB, OH, Sept 1972. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3217, CINDAS/Purdue University, 1995, p 21



WA.233 7049-T76 aluminum alloy extrusion, compressive stress-strain curves

Tested at room and elevated temperatures. Test direction: transverse. Composition: Al-7.6Zn-2.5Mg-1.5Cu-0.15Cr. UNS A97049

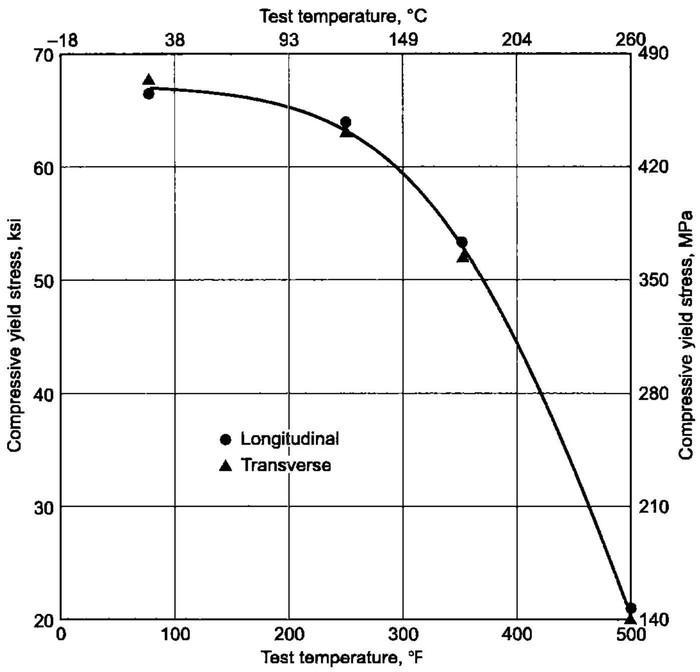
Source: O.L. Deel and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," Technical Report AFML-TR-72-196, Vol II, Air Force Materials Laboratory, Wright-Patterson AFB, OH, Sept 1972. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3217, CINDAS/Purdue University, 1995, p 21



WA.234 7049-T73 aluminum alloy forging, effect of 10 h exposure and test temperature on compressive properties

Test direction: transverse. Forging thickness: 127 mm (5 in.). Each point average of three tests. Composition: Al-7.6Zn-2.5Mg-1.5Cu-0.15Cr. UNS A97049

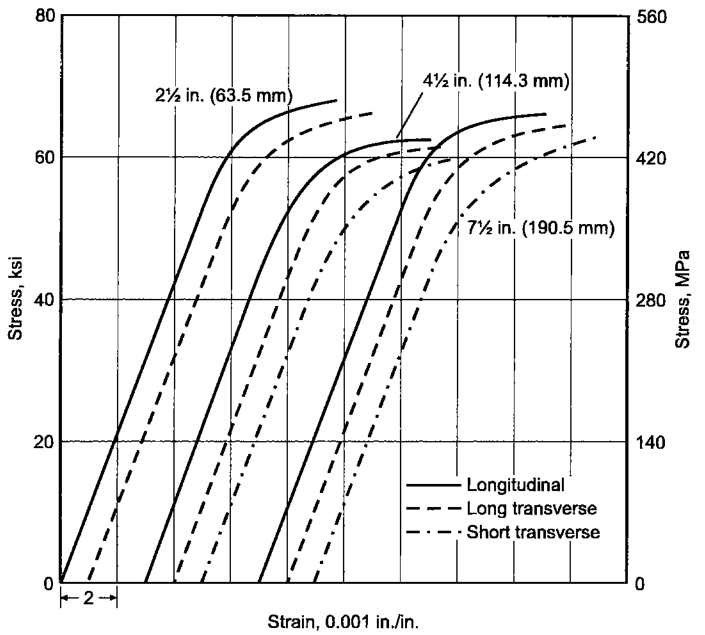
Source: W.M. Pratt, "Material-Kaiser Aluminum Alloy X7049-T73, Effect of Elevated Temperature on Mechanical Properties," Report FGT-5541, General Dynamics, Fort Worth Div., Dec 1969. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3217, CINDAS/Purdue University, 1995, p 21



WA.235 7049-T73 aluminum alloy forging, effect of temperature on compressive yield strength

Forging thickness: 127 mm (5 in.). Composition: Al-7.6Zn-2.5Mg-1.5Cu-0.15Cr. UNS A97049

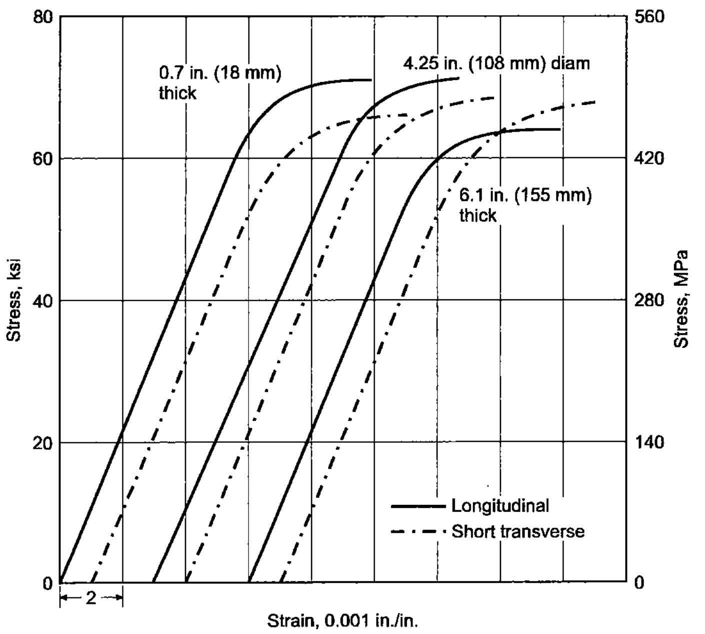
Source: "Mechanical Property Data 7049 Aluminum-T73 Forgings," prepared by Batelle Memorial Institute, Columbus Laboratories, issued by Air Force Materials Laboratory, Wright-Patterson AFB, OH, Dec 1969. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3217, CINDAS/Purdue University, 1995, p 21



WA.236 7050-T7451 aluminum alloy hand forging, tensile stress-strain curves

Various thicknesses and test directions as indicated for 7050-T7451 (-T73651). Composition: Al-6.2Zn-2.25Mg-2.3Cu-0.12Zr. UNS A97050

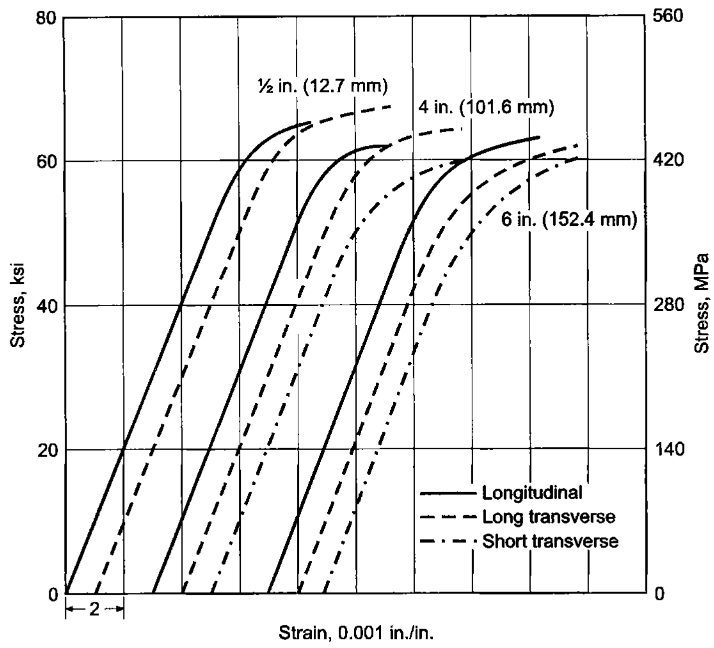
Source: R.E. Davies, G.E. Nordmark, and J.D. Walsh, "Design Mechanical Properties, Fracture Toughness, Fatigue Properties, Exfoliation, and Stress-Corrosion Resistance of 7050 Sheet, Plate, Hand Forgings, Die Forgings, and Extrusions," Report N00019-72-C-0512 to Naval Air Systems Command from Alcoa Laboratories, July 1975. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3222, CINDAS/Purdue University, 1995, p 20



WA.237 7050-T74 aluminum alloy die forging, tensile stress-strain curves

Various thicknesses and test directions for 7050-T74 (-T736). Composition: Al-6.2Zn-2.25Mg-2.3Cu-0.12Zr. UNS A97050

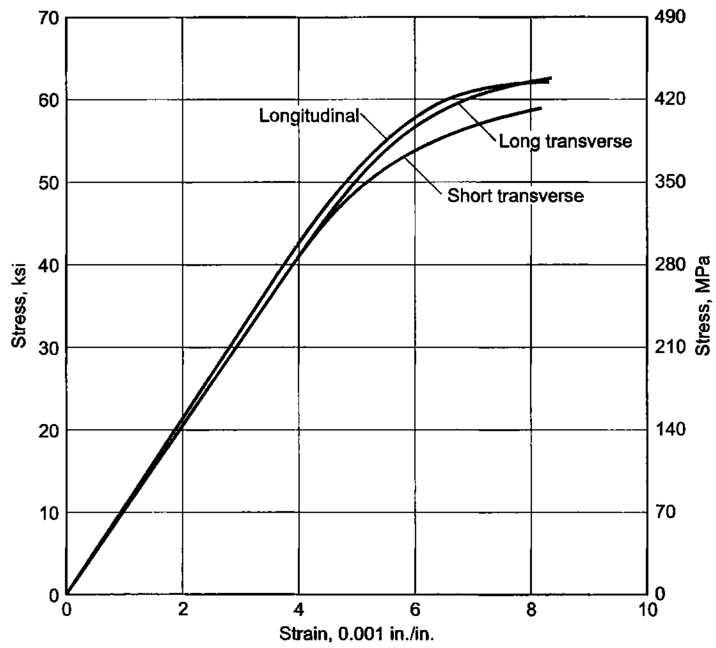
Source: R.E. Davies, G.E. Nordmark, and J.D. Walsh, "Design Mechanical Properties, Fracture Toughness, Fatigue Properties, Exfoliation, and Stress-Corrosion Resistance of 7050 Sheet, Plate, Hand Forgings, Die Forgings, and Extrusions," Report N00019-72-C-0512 to Naval Air Systems Command from Alcoa Laboratories, July 1975. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3222, CINDAS/Purdue University, 1995, p 20



WA.238 7050-T7451 aluminum alloy plate, tensile stress-strain curves

Various thicknesses and test directions for 7050-T7451 (-T73651). Composition: Al-6.2Zn-2.25Mg-2.3Cu-0.12Zr. UNS A97050

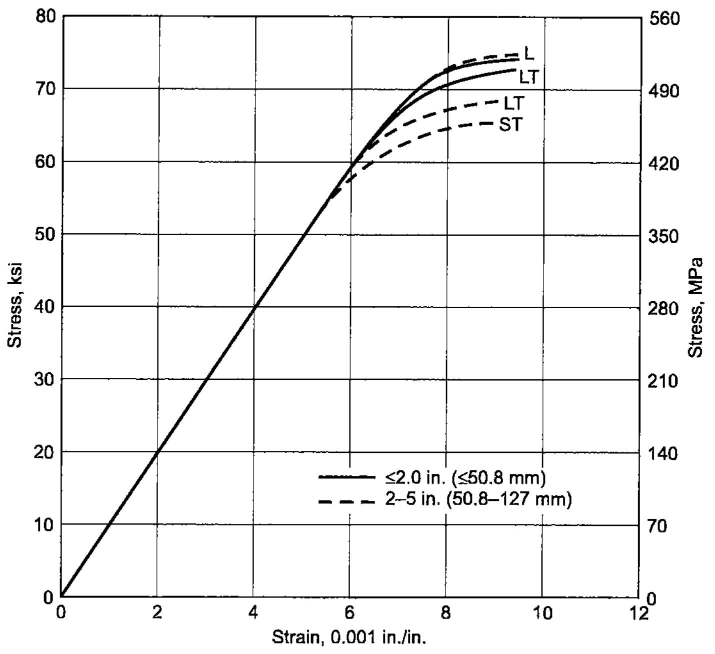
Source: R.E. Davies, G.E. Nordmark, and J.D. Walsh, "Design Mechanical Properties, Fracture Toughness, Fatigue Properties, Exfoliation, and Stress-Corrosion Resistance of 7050 Sheet, Plate, Hand Forgings, Die Forgings, and Extrusions," Report N00019-72-C-0512 to Naval Air Systems Command from Alcoa Laboratories, July 1975. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3222, CINDAS/Purdue University, 1995, p 20



WA.239 7050-T7351 aluminum alloy plate, tensile stress-strain curves

Plate thickness: 50.8–152.4 mm (2–6 in.). Composition: Al-6.2Zn-2.25Mg-2.3Cu-0.12Zr. UNS A97050

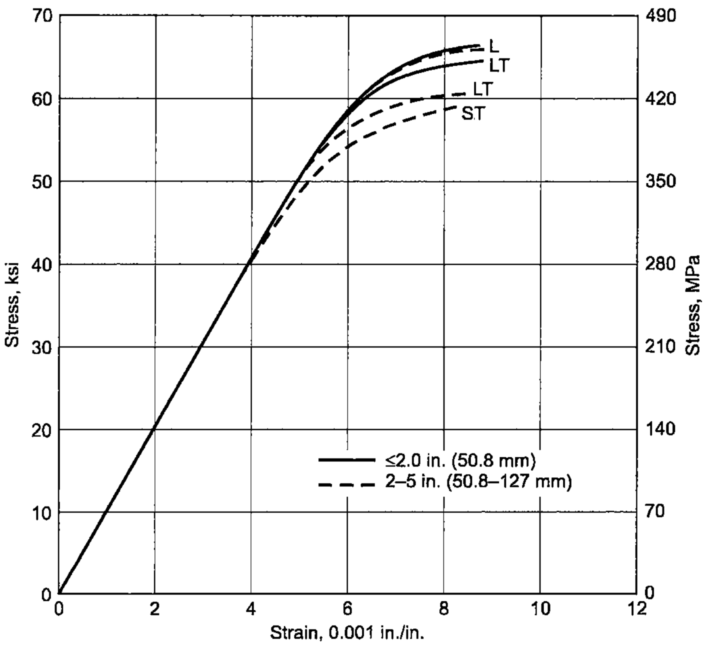
Source: D.J. Brownhill, R.E. Davies, G.E. Nordmark, and B.M. Ponchel, "Exploratory Development for Design Data on Structural Aluminum Alloys in Representative Aircraft Environments," AF contract 33615-74-C-5089, Alcoa Laboratories, AFML TR 77-102, July 1977. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3222, CINDAS/Purdue University, 1995, p 21



WA.240 7050-T7651 aluminum alloy extrusion, tensile stress-strain curves

Various thicknesses. Test direction: L, longitudinal; LT, long transverse; ST, short transverse. Cross-sectional area: ≤277.4 cm^2 (≤43 in.^{2}). Composition: Al-6.2Zn-2.25Mg-2.3Cu-0.12Zr. UNS A97050

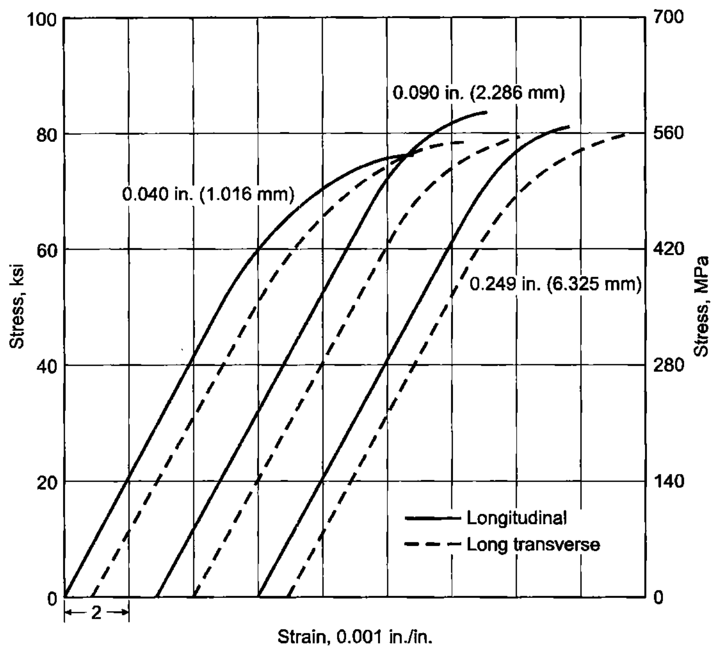
Source: J.T. Staley, J.E. Jacoby, R.E. Davies, G.E. Nordmark, J.D. Walsh, and F.R. Rudolph, "Aluminum Alloy 7050 Extrusions," AF contract 33615-73-C-5015, Alcoa Laboratories, AFML-TR-76-129, March 1977. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3222, CINDAS/Purdue University, 1995, p 21



WA.241 7050-T7351 aluminum alloy extrusion, tensile stress-strain curves

Various thicknesses. Test direction: L, longitudinal; LT, long transverse; ST, short transverse. Cross-sectional area: ≤277.4 cm^2 (≤43 in.^{2}). Composition: Al-6.2Zn-2.25Mg-2.3Cu-0.12Zr. UNS A97050

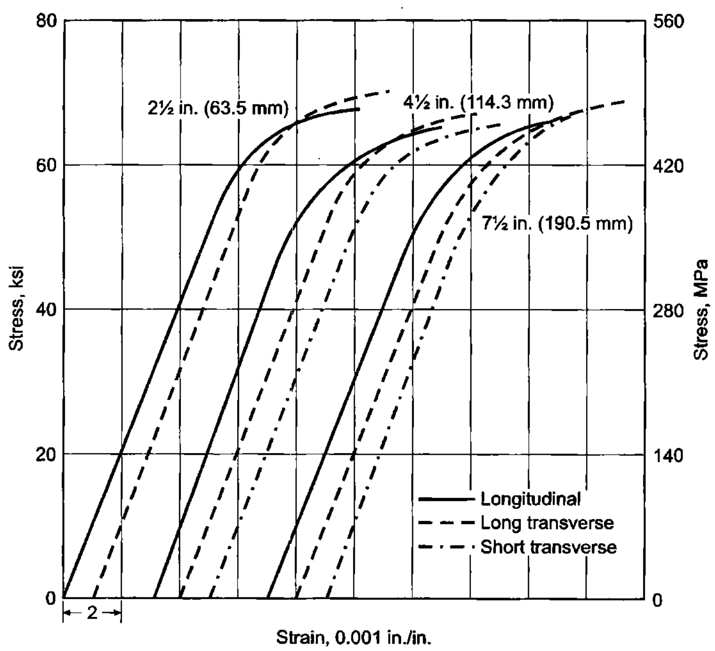
Source: J.T. Staley, J.E. Jacoby, R.E. Davies, G.E. Nordmark, J.D. Walsh, and F.R. Rudolph, "Aluminum Alloy 7050 Extrusions," AF contract 33615-73-C-5015, Alcoa Laboratories, AFML-TR-76-129, March 1977. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3222, CINDAS/Purdue University, 1995, p 21



WA.242 7050-T76 aluminum alloy sheet, tensile stress-strain curves

Various thicknesses and test directions. Composition: Al-6.2Zn-2.25Mg-2.3Cu-0.12Zr. UNS A97050

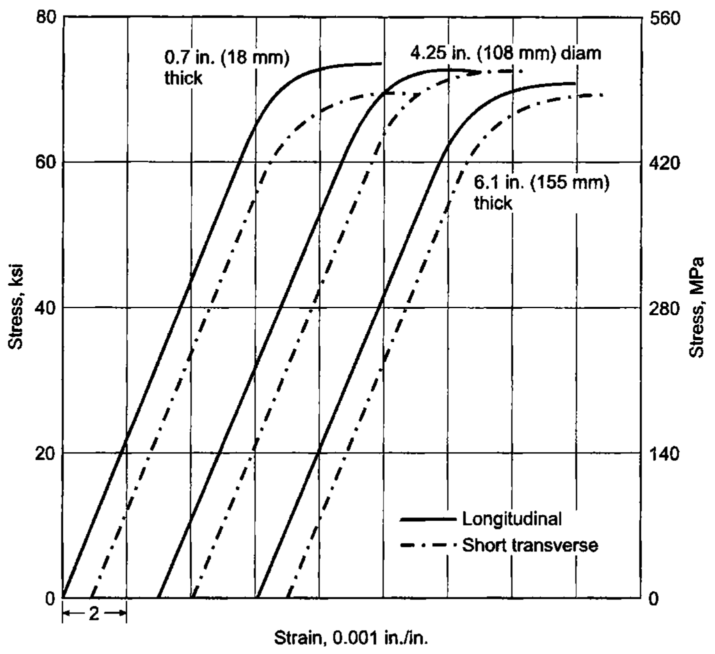
Source: R.E. Davies, G.E. Nordmark, and J.D. Walsh, "Design Mechanical Properties, Fracture Toughness, Fatigue Properties, Exfoliation, and Stress-Corrosion Resistance of 7050 Sheet, Plate, Hand Forgings, Die Forgings, and Extrusions," Report N00019-72-C-0512 to Naval Air Systems Command from Alcoa Laboratories, July 1975. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3222, CINDAS/Purdue University, 1995, p 21



WA.243 7050-T7452 aluminum alloy hand forgings, compressive stress-strain curves

Various thicknesses. Composition: Al-6.2Zn-2.25Mg-2.3Cu-0.12Zr. UNS A97050

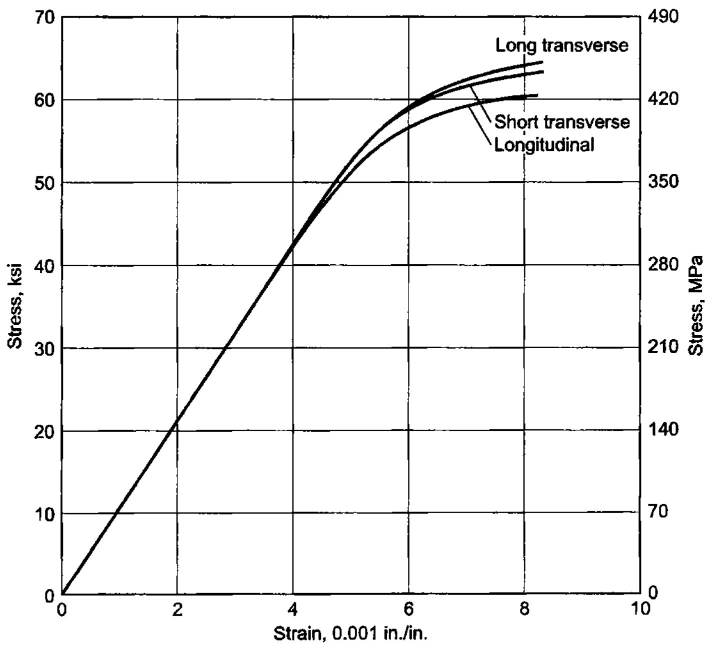
Source: R.E. Davies, G.E. Nordmark, and J.D. Walsh, "Design Mechanical Properties, Fracture Toughness, Fatigue Properties, Exfoliation, and Stress-Corrosion Resistance of 7050 Sheet, Plate, Hand Forgings, Die Forgings, and Extrusions," Report N00019-72-C-0512 to Naval Air Systems Command from Alcoa Laboratories, July 1975. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3222, CINDAS/Purdue University, 1995, p 24



WA.244 7050-T74 aluminum alloy die forgings, compressive stress-strain curves

Composition: Al-6.2Zn-2.25Mg-2.3Cu-0.12Zr. UNS A97050

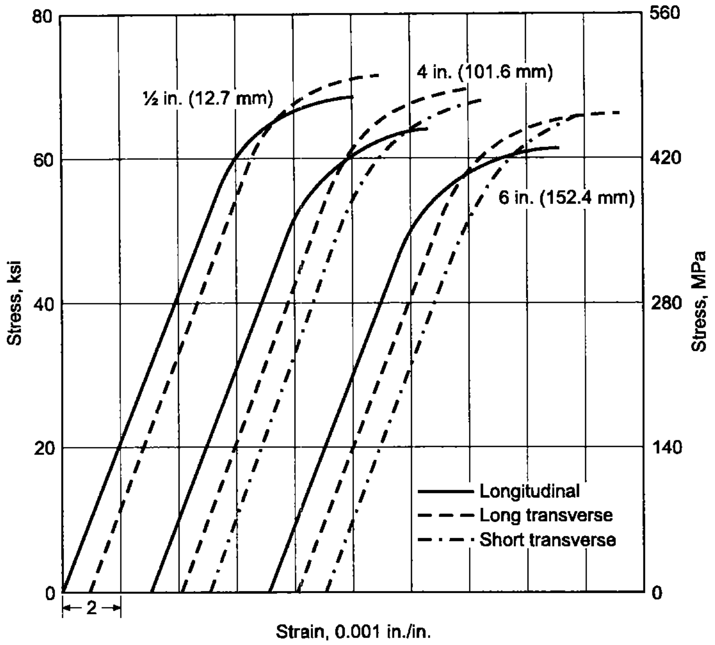
Source: R.E. Davies, G.E. Nordmark, and J.D. Walsh, "Design Mechanical Properties, Fracture Toughness, Fatigue Properties, Exfoliation, and Stress-Corrosion Resistance of 7050 Sheet, Plate, Hand Forgings, Die Forgings, and Extrusions," Report N00019-72-C-0512 to Naval Air Systems Command from Alcoa Laboratories, July 1975. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3222, CINDAS/Purdue University, 1995, p 24



WA.245 7050-T7351 aluminum alloy plate, compressive stress-strain curves

Plate thickness: 50.8–152.4 mm (2–6 in.). Composition: Al-6.2Zn-2.25Mg-2.3Cu-0.12Zr. UNS A97050

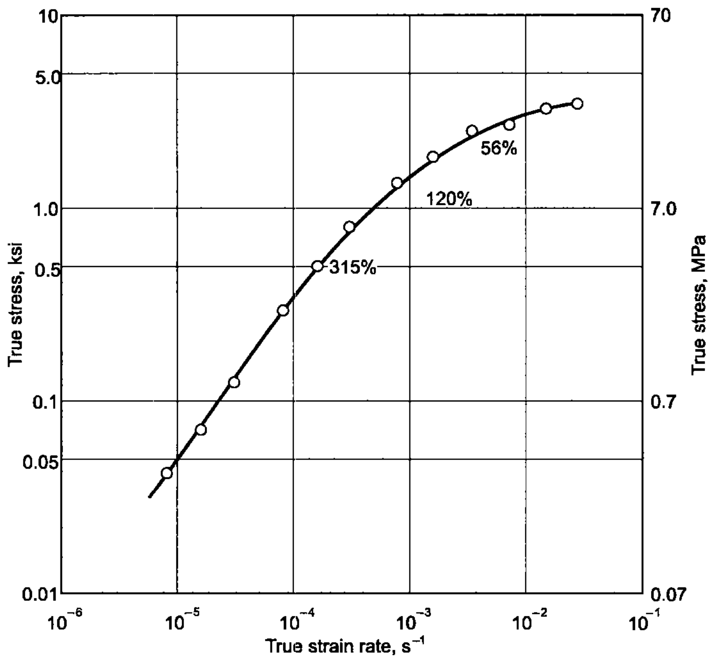
Source: D.J. Brownhill, R.E. Davies, G.E. Nordmark, and B.M. Ponchel, "Exploratory Development for Design Data on Structural Aluminum Alloys in Representative Aircraft Environments," AF contract 33615-74-C-5089, Alcoa Laboratories, AFML TR 77-102, July 1977. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3222, CINDAS/Purdue University, 1995, p 24



WA.246 7050-T7451 aluminum alloy plate, compressive stress-strain curves

Various thicknesses. Composition: Al-6.2Zn-2.25Mg-2.3Cu-0.12Zr. UNS A97050

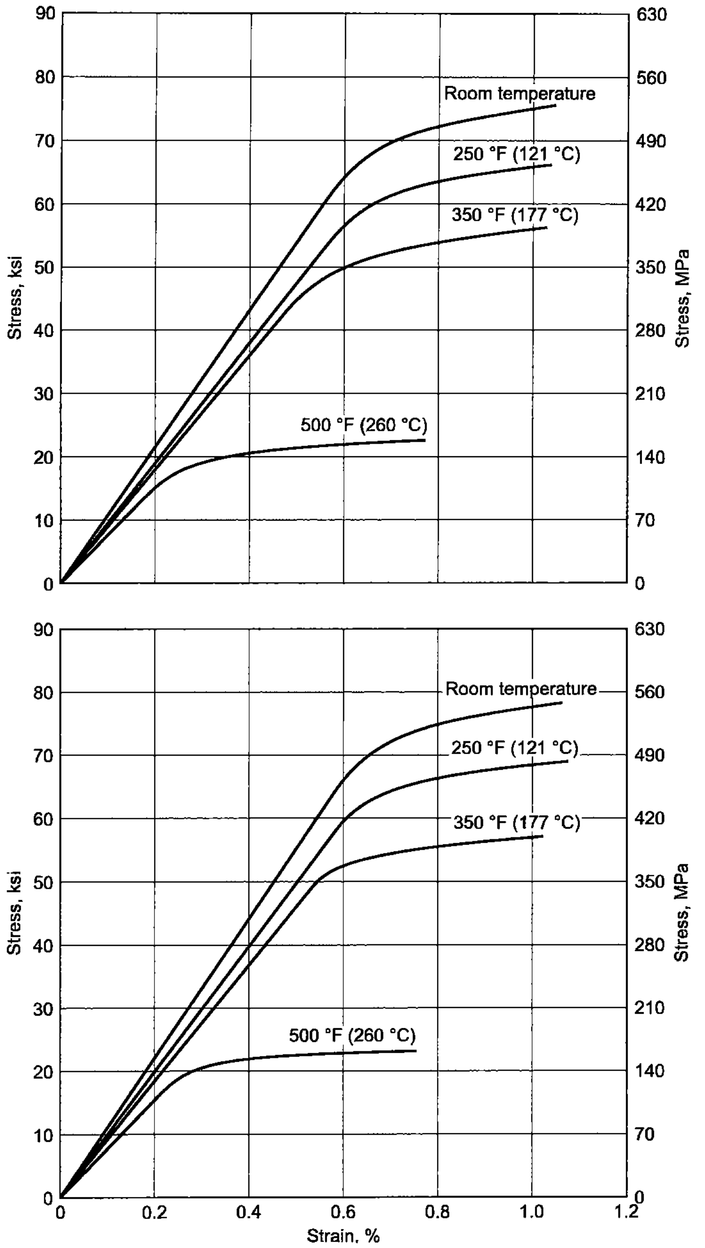
Source: R.E. Davies, G.E. Nordmark, and J.D. Walsh, "Design Mechanical Properties, Fracture Toughness, Fatigue Properties, Exfoliation, and Stress-Corrosion Resistance of 7050 Sheet, Plate, Hand Forgings, Die Forgings, and Extrusions," Report N00019-72-C-0512 to Naval Air Systems Command from Alcoa Laboratories, July 1975. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3222, CINDAS/Purdue University, 1995, p 24



WA.247 7050 aluminum alloy sheet, true stress as a function of strain rate

Tested at 482 °C (900 °F). Grain size: 14 µm (0.55 mil). Total elongation shown in percent. Composition: Al-6.2Zn-2.25Mg-2.3Cu-0.12Zr. UNS A97050

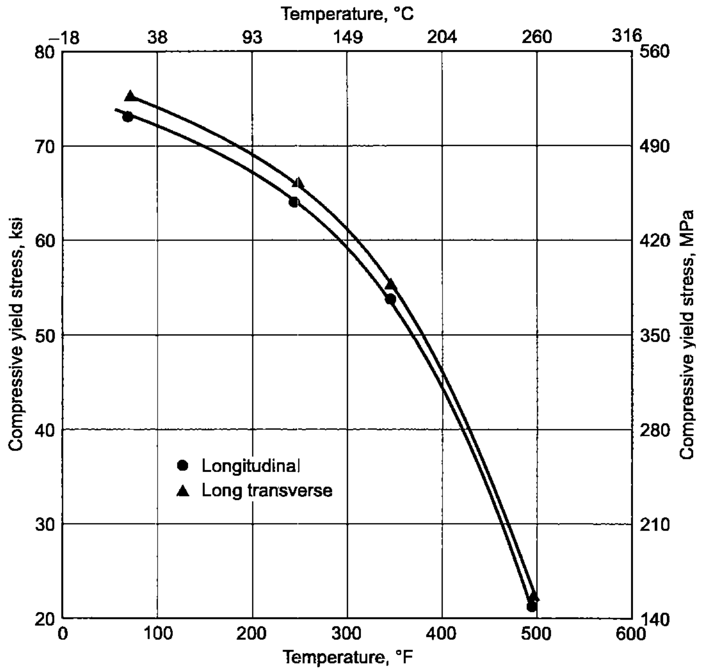
Source: A.K. Ghosh and C.H. Hamilton, Deformation and Fracture in Al-Zn-Mg Alloys at Elevated Temperature, *Strength of Metals and Alloys,* Proc. Fifth International Conference, Vol 2 (Aachen, Germany), 27-31 Aug 1979. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3222, CINDAS/Purdue University, 1995, p 32



WA.248 7050-T7451 aluminum alloy plate, compressive stress-strain curves at room and elevated temperatures

Tested at room and elevated temperatures. Test direction: (top) longitudinal; (bottom) long transverse. Plate thickness: 25.4 mm (1.0 in.). Composition: Al-6.2Zn-2.25Mg-2.3Cu-0.12Zr. UNS A97050

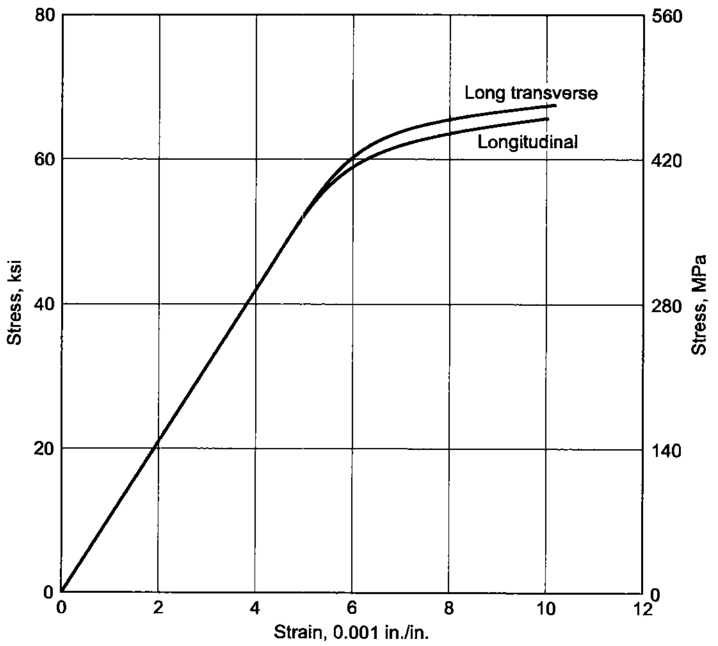
Source: O.L. Deel, P.E. Ruff, and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," AFML-TR-73-114, Battelle's Columbus Laboratories, June 1973. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3222, CINDAS/Purdue University, 1995, p 32



WA.249 7050-T7451 aluminum alloy plate, effect of temperature on compressive yield strength

Plate thickness: 25.4 mm (1.0 in.). Composition: Al-6.2Zn-2.25Mg-2.3Cu-0.12Zr. UNS A97050

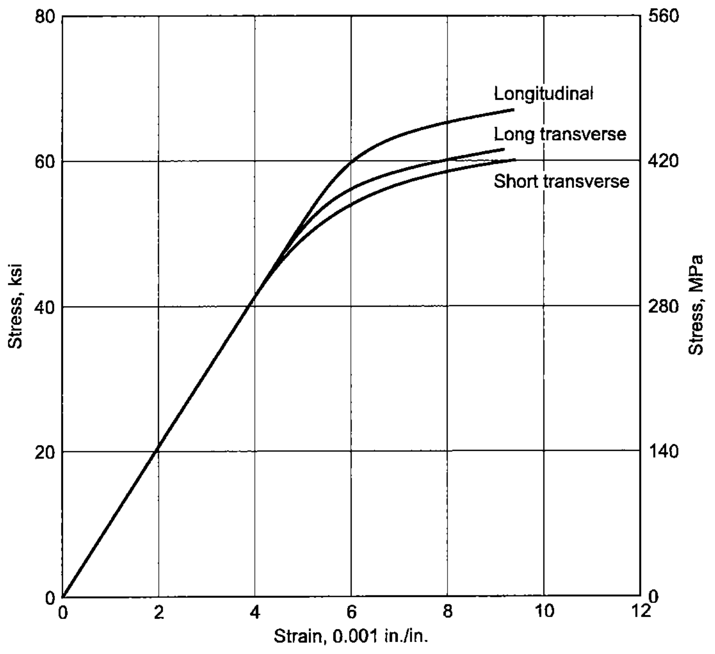
Source: O.L. Deel, P.E. Ruff, and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," AFML-TR-73-114, Battelle's Columbus Laboratories, June 1973. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3222, CINDAS/Purdue University, 1995, p 32



WA.250 7050-T7351X aluminum alloy extrusion, tensile stress-strain curves

Tested at room temperature. Typical for extrusion thickness ≤50.775 mm (≤1.999 in.). Cross-sectional area: ≤206 cm^2 (≤32 in.^{2}). Ramberg-Osgood parameter, n(longitudinal, tension) = 25; n(long transverse, tension) = 21. UNS A97050

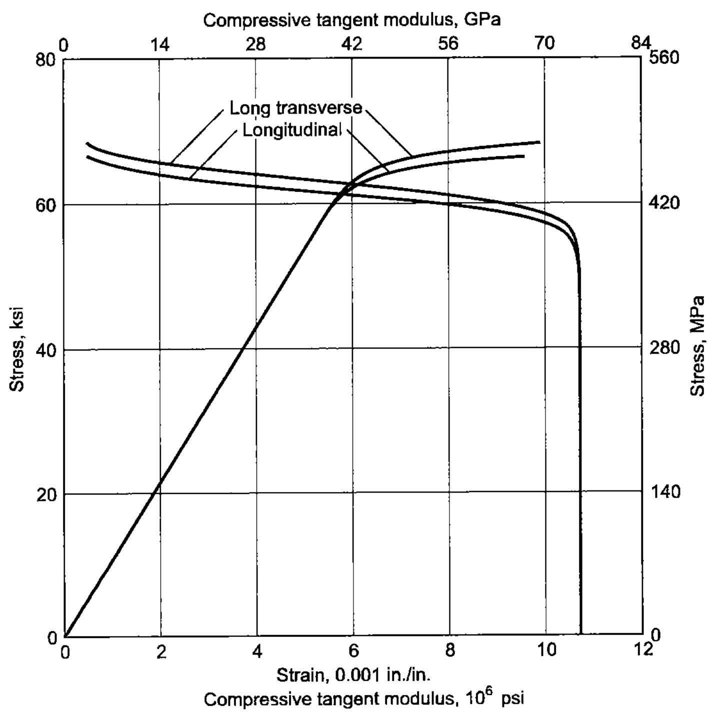
Source: *MIL-HDBK-5H*, 1 Dec 1998, p 3–317



WA.251 7050-T7351X aluminum alloy extrusion, tensile stress-strain curves

Tested at room temperature. Typical for extrusion thickness 50.80–127.0 mm (2.000–5.000 in.). Cross-sectional area: ≤277 cm^2 (≤43 $in.^2$). Ramberg-Osgood parameter, n(longitudinal, tension) = 22; n(long transverse, tension) = 19, n(short transverse, tension) = 14. UNS A97050

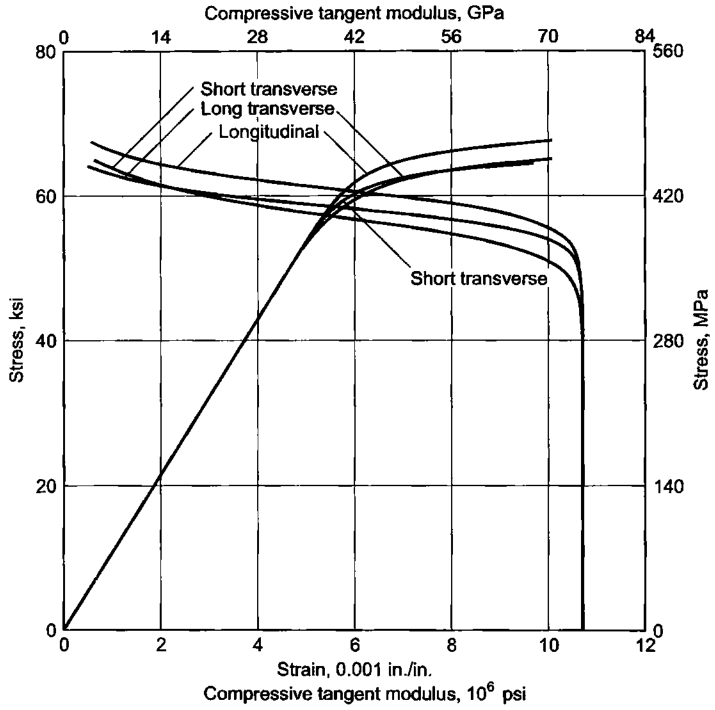
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–317



WA.252 7050-T7351X aluminum alloy extrusion, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for extrusion thickness ≤50.775 mm (≤1.999 in.). Cross-sectional area: ≤206 cm^2 (≤32 $in.^2$). Ramberg-Osgood parameter, n(longitudinal, compression) = 39; n(long transverse, compression) = 38. UNS A97050

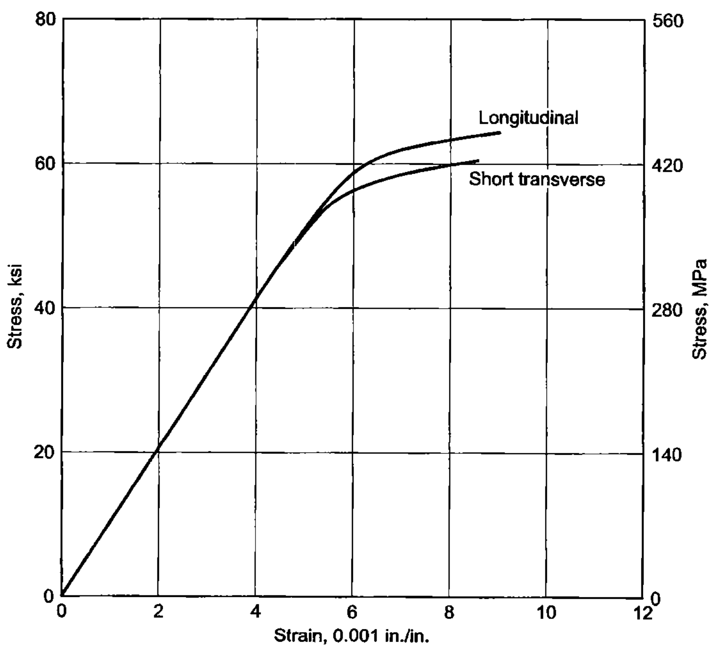
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–318



WA.253 7050-T7351X aluminum alloy extrusion, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for extrusion thickness 50.80–127.0 mm (2.000–5.000 in.). Cross-sectional area: ≤277 cm^2 (≤43 $in.^2$). Ramberg-Osgood parameter, *n*(longitudinal, compression) = 29; *n*(long transverse, compression) = 33; *n*(short transverse, compression) = 23. UNS A97050

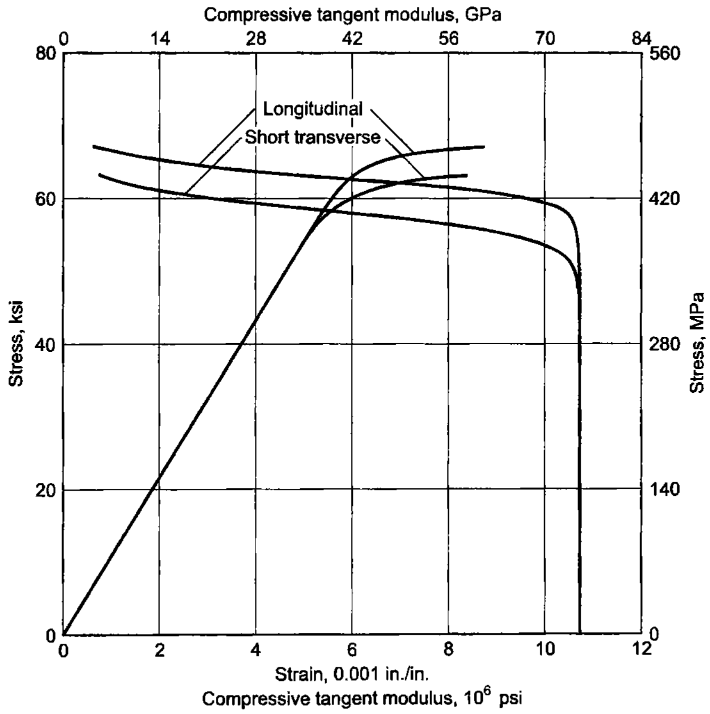
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–318



WA.254 7050-T74 aluminum alloy die forging, tensile stress-strain curves

Tested at room temperature. Typical for forging thickness ≤76.20 mm (≤3.000 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 27; *n*(short transverse, tension) = 24. UNS A97050

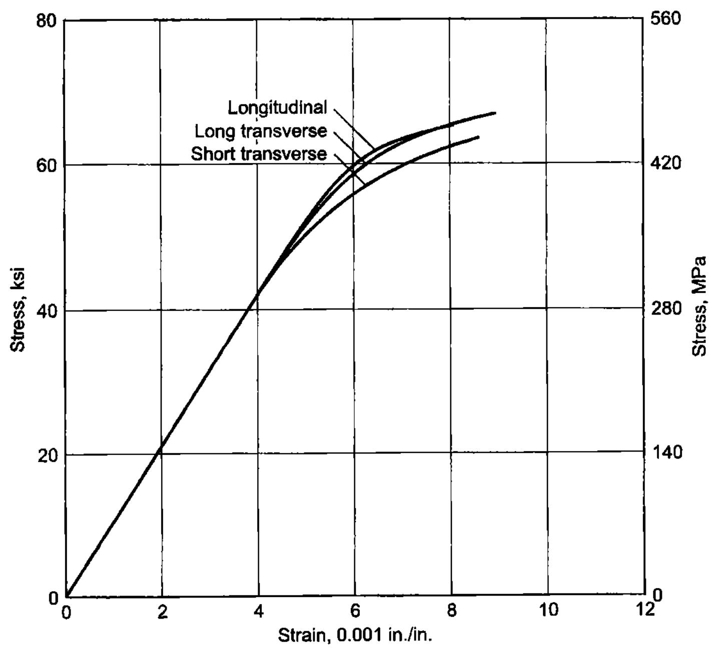
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–324



WA.255 7050-T74 aluminum alloy die forging, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for forging thickness ≤76.20 mm (≤3.000 in.). Ramberg-Osgood parameter, n(longitudinal, compression) = 44; n(short transverse, compression) = 32. UNS A97050

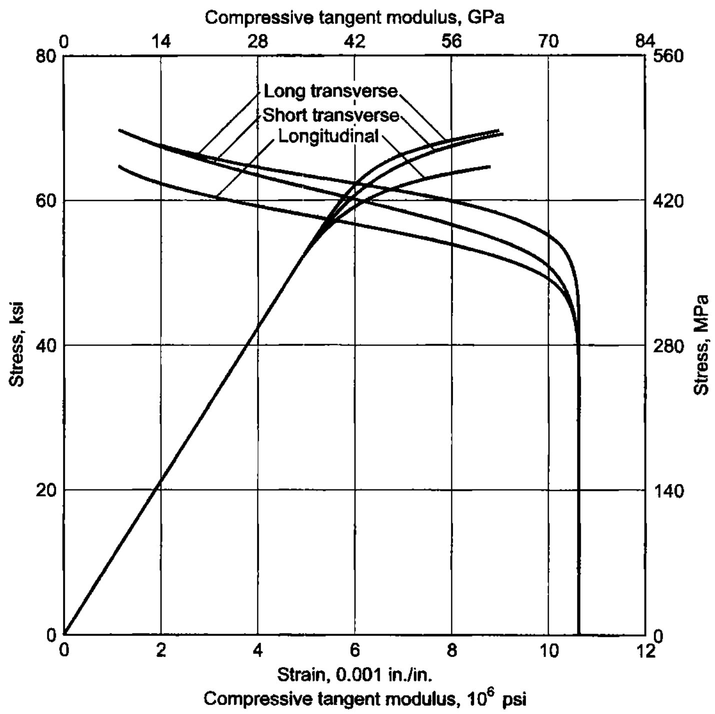
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–324



WA.256 7050-T7451 aluminum alloy plate, tensile stress-strain curves

Tested at room temperature. Typical for plate thickness 12.70–101.60 mm (0.500–4.000 in.). Ramberg-Osgood parameter, n(longitudinal, tension) = 19; n(long transverse, tension) = 13; n(short transverse, tension) = 10. UNS A97050

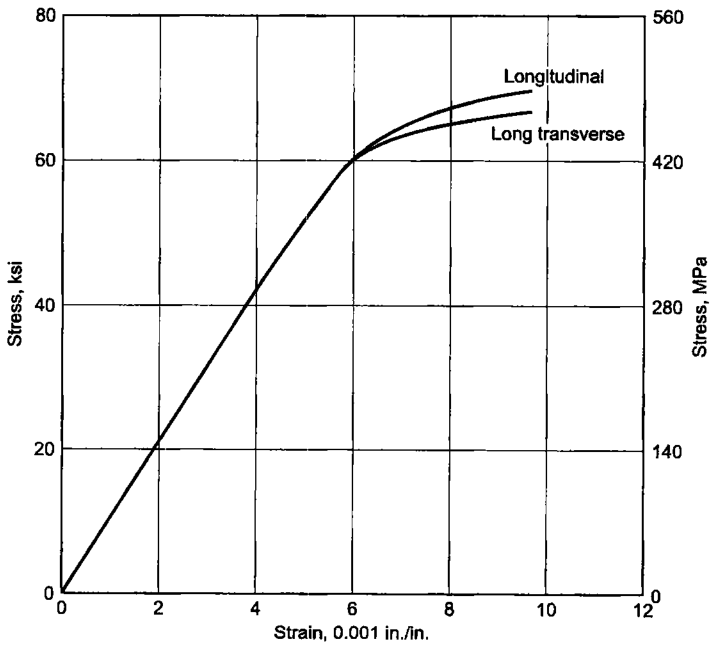
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–322



WA.257 7050-T7451 aluminum alloy plate, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for plate thickness 12.70–101.60 mm (0.500–4.000 in.). Ramberg-Osgood parameter, *n*(longitudinal, compression) = 19; *n*(long transverse, compression) = 22; *n*(short transverse, compression) = 16. UNS A97050

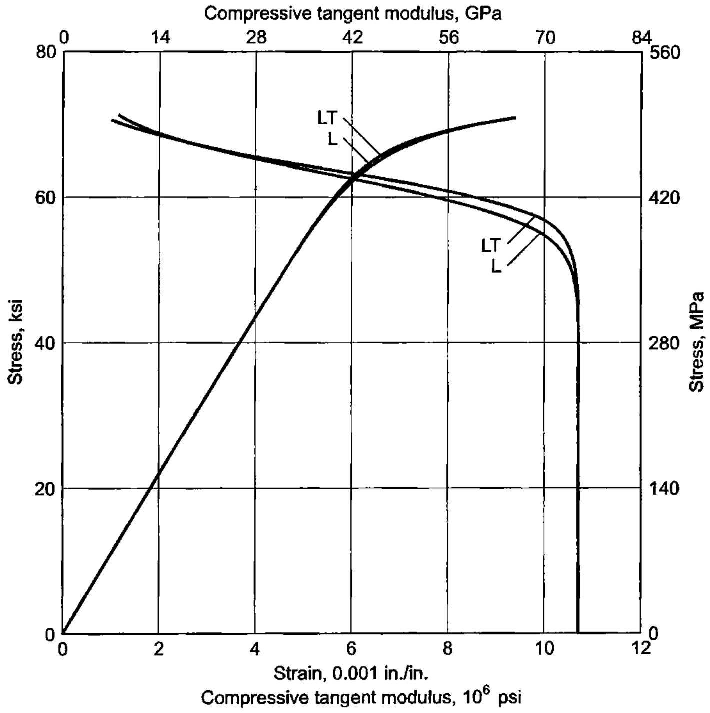
Source: *MIL-HDBK-5H*, 1 Dec 1998, p 3–322



WA.258 7050-T74511 aluminum alloy extrusion, tensile stress-strain curves

Tested at room temperature. Typical for extrusion thickness ≤44.450 mm (≤1.750 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 19; *n*(long transverse, tension) = 26. UNS A97050

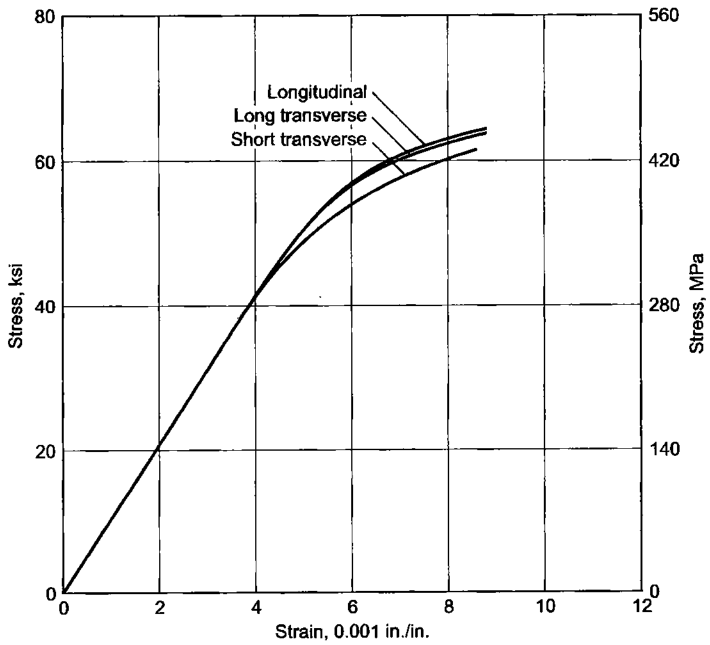
Source: *MIL-HDBK-5H*, 1 Dec 1998, p 3–325



WA.259 7050-T74511 aluminum alloy extrusion, compressive and tangent modulus stress-strain curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for extrusion thickness ≤44.450 mm (≤1.750 in.). Ramberg-Osgood parameter, n(L, compression) = 19; n(LT, compression) = 23. UNS A97050

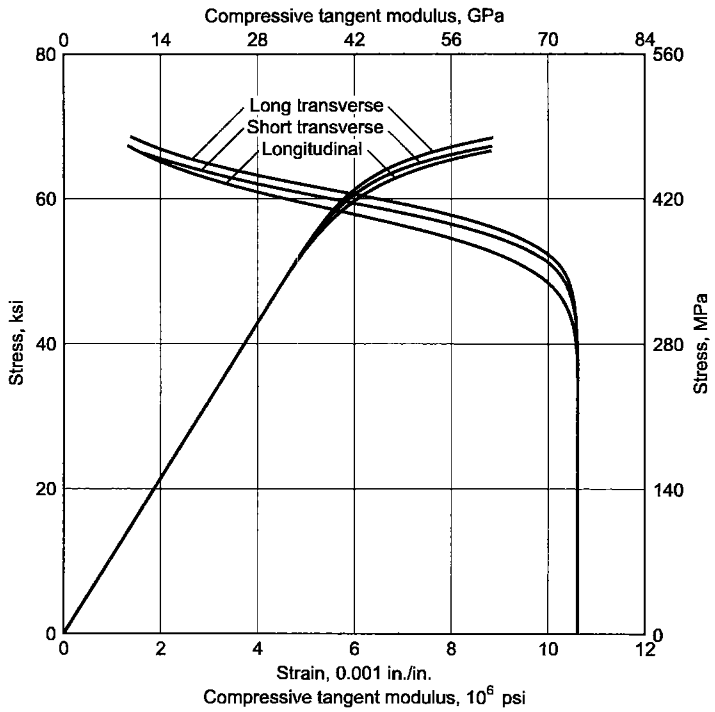
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–325



WA.260 7050-T7452 aluminum alloy hand forging, tensile stress-strain curves

Tested at room temperature. Typical for forging thickness ≤177.8 mm (≤7.000 in.). Ramberg-Osgood parameter, n(longitudinal, tension) = 14; n(long transverse, tension) = 14; n(short transverse, tension) = 9.3. UNS A97050

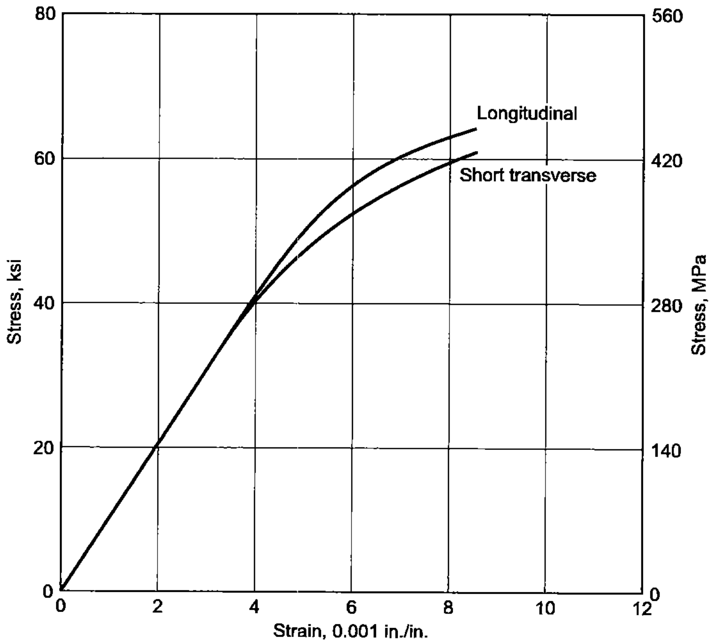
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–323



WA.261 7050-T7452 aluminum alloy hand forging, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse; ST, short transverse. Typical for forging thickness ≤177.8 mm (≤7.000 in.). Ramberg-Osgood parameter, n(L, compression) = 15; n(LT, compression) = 18; n(ST, compression) = 20. UNS A97050

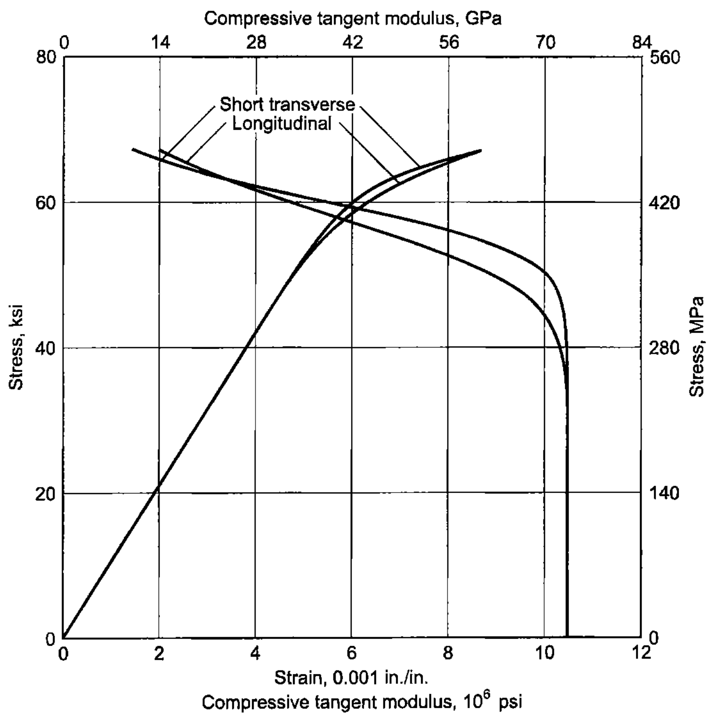
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–323



WA.262 7050-T7452 aluminum alloy die forging, tensile stress-strain curves

Tested at room temperature. Typical for forging thickness ≤152.4 mm (≤6.000 in.). Ramberg-Osgood parameter, n(longitudinal, tension) = 11; n(short transverse, tension) = 7.3. UNS A97050

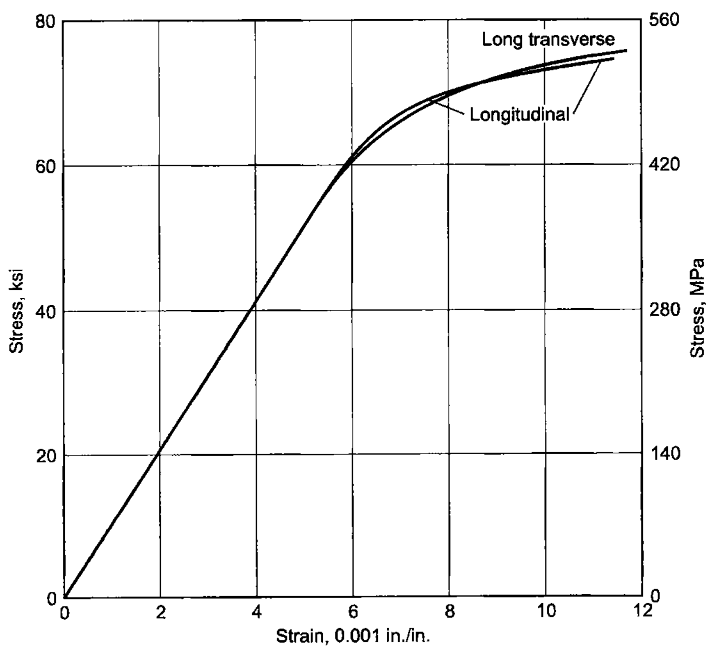
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–326



WA.263 7050-T7452 aluminum alloy die forging, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for forging thickness ≤152.4 mm (≤6.000 in.). Ramberg-Osgood parameter, *n*(longitudinal, compression) = 12; *n*(short transverse, compression) = 18. UNS A97050

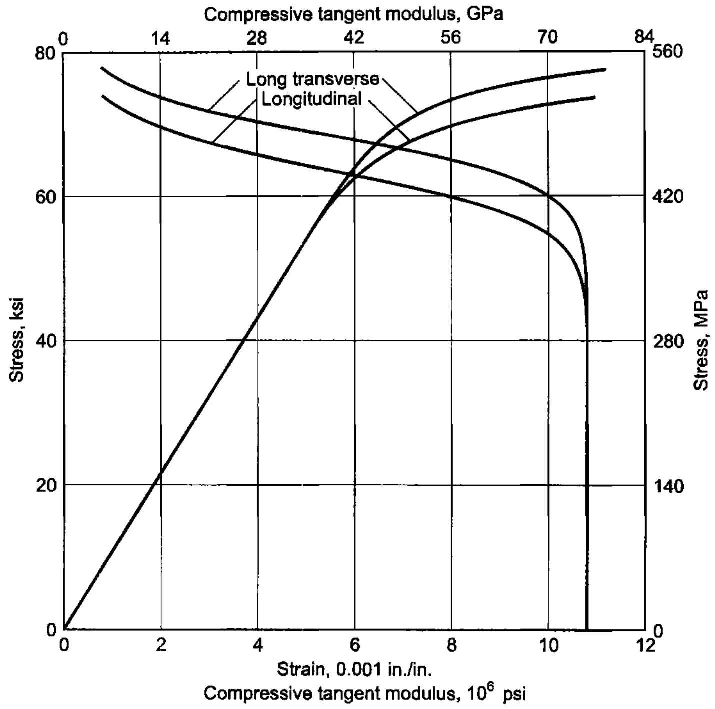
Source: *MIL-HDBK-5H*, 1 Dec 1998, p 3–326



WA.264 7050-T7651 aluminum alloy plate, tensile stress-strain curves

Tested at room temperature. Typical for plate thickness ≤50.8 mm (≤2.000 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 19; *n*(long transverse, tension) = 14. UNS A97050

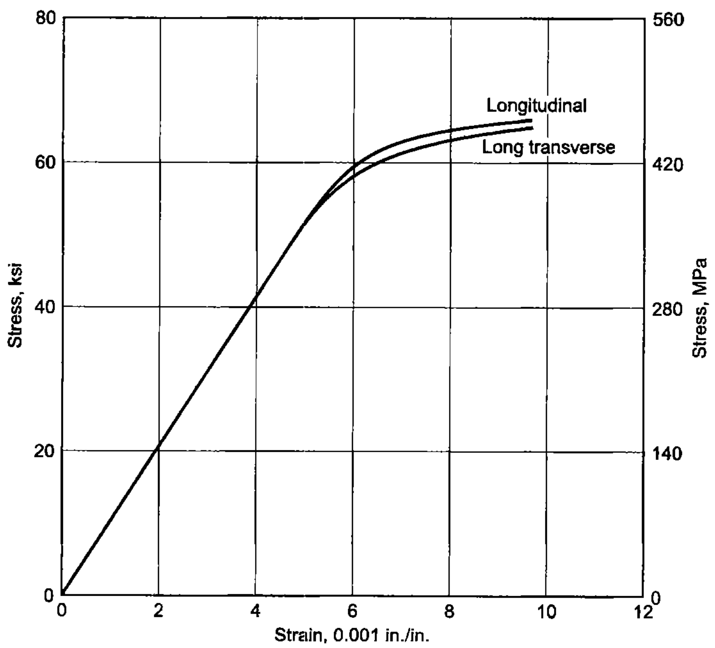
Source: *MIL-HDBK-5H*, 1 Dec 1998, p 3–341



WA.265 7050-T7651 aluminum alloy plate, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for plate thickness ≤50.8 mm (≤2.000 in.). Ramberg-Osgood parameter, n(longitudinal, compression) = 18; n(long transverse, compression) = 21. UNS A97050

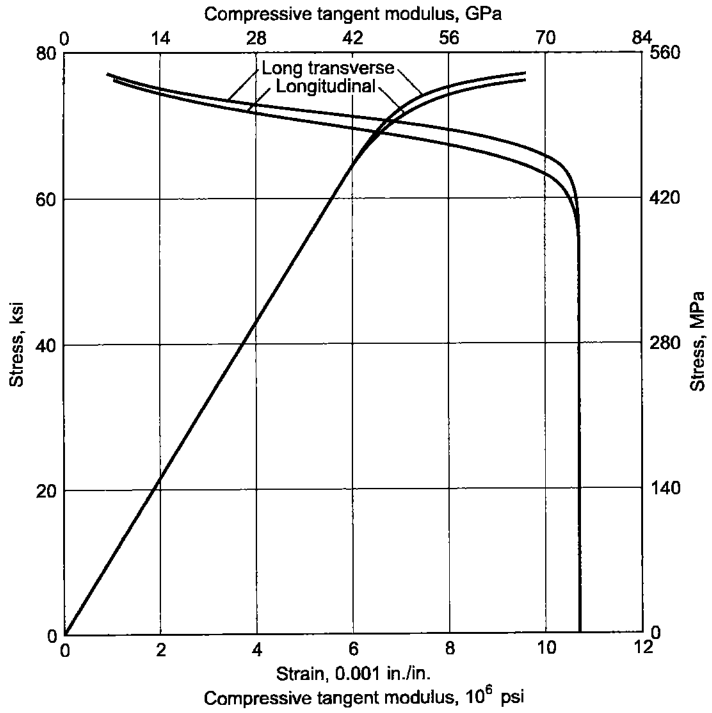
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–341



WA.266 7050-T7651X aluminum alloy extrusion, tensile stress-strain curves

Tested at room temperature. Typical for extrusion thickness ≤50.775 mm (≤1.999 in.). Cross-sectional area: ≤206 cm^2 (≤32 $in.^2$). Ramberg-Osgood parameter, n(longitudinal, tension) = 25; n(long transverse, tension) = 20. UNS A97050

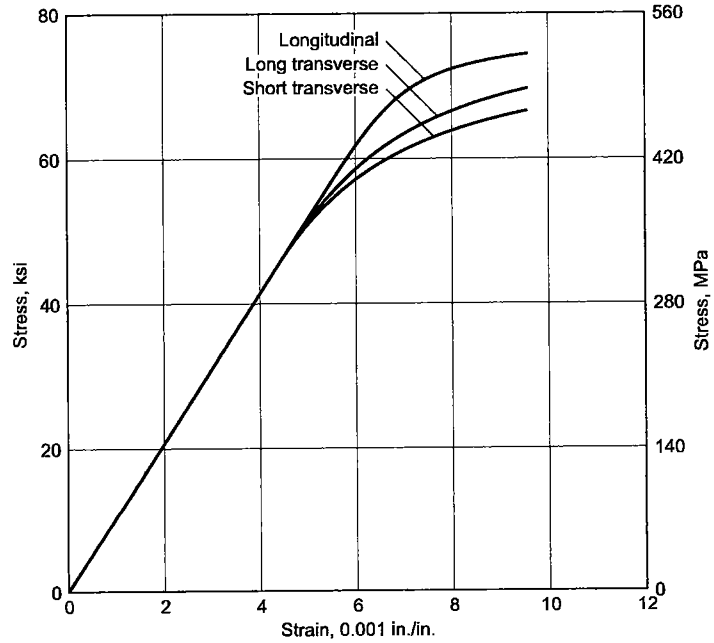
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–339



WA.267 7050-T7651X aluminum alloy extrusion, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for extrusion thickness ≤50.77 mm (≤1.999 in.). Cross-sectional area: ≤206 cm^2 (≤32 $in.^2$). Ramberg-Osgood parameter, n(longitudinal, compression) = 27; n(long transverse, compression) = 33. UNS A97050

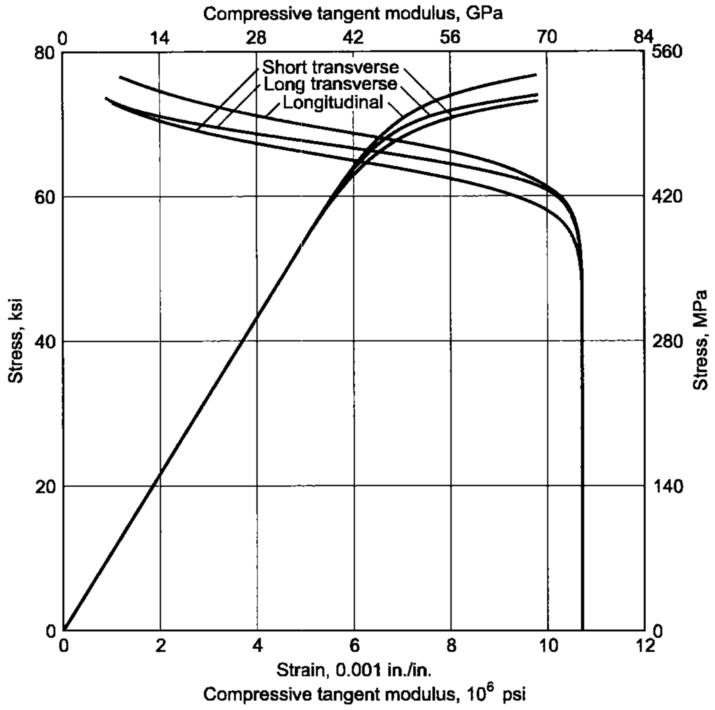
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–340



WA.268 7050-T7651X aluminum alloy extrusion, tensile stress-strain curves

Tested at room temperature. Typical for extrusion thickness 50.80–127.0 mm (2.000–5.000 in.). Cross-sectional area: ≤277 cm^2 (≤43 $in.^2$). Ramberg-Osgood parameter, n(longitudinal, tension) = 28; n(long transverse, tension) = 13; n(short transverse, tension) = 13. UNS A97050

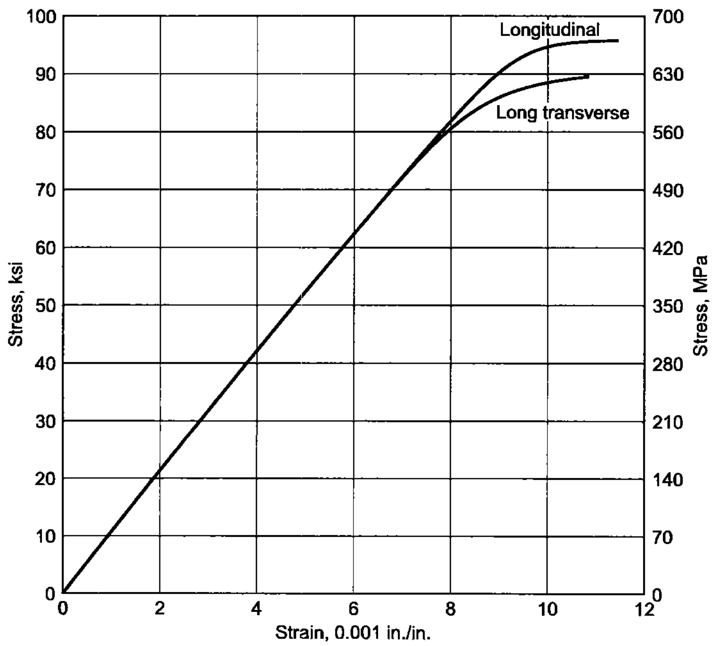
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–339



WA.269 7050-T7651X aluminum alloy extrusion, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for extrusion thickness 50.80–127.0 mm (2.000–5.000 in.). Cross-sectional area: ≤277 cm^2 (≤43 $in.^2$). Ramberg-Osgood parameter, *n*(longitudinal, compression) = 22; *n*(long transverse, compression) = 27; *n*(short transverse, compression) = 22. UNS A97050

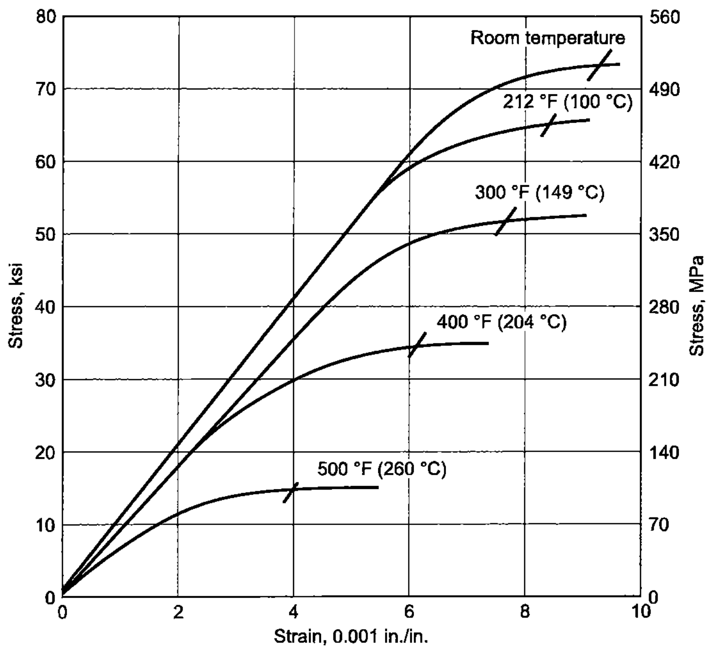
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–340



WA.270 7055-T77511 aluminum alloy extrusion, tensile stress-strain curves

Tested at room temperature. Typical for extrusion thickness 50.80–61.468 mm (0.500–2.420 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 8.9; *n*(long transverse, tension) = 10. UNS A97055

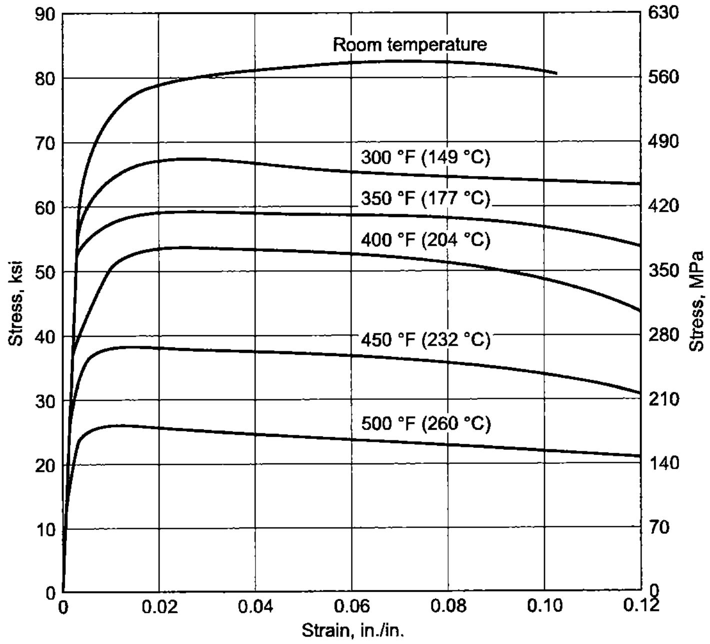
Source: J. Gilbert Kaufman



WA.271 7075-T6 aluminum alloy, tensile stress-strain curves at room and elevated temperatures

Composition: Al-5.6Zn-2.5Mg-1.6Cu-0.3Cr. UNS A97075

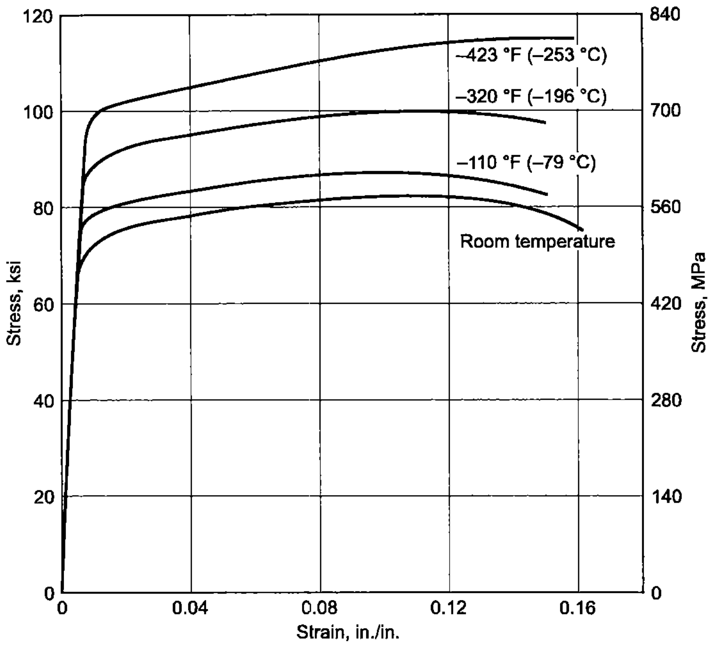
Source: "Typical Tensile Stress Strain Curves for 7075 T6," Alcoa Research Laboratories, 20 Dec 1957. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3207, CINDAS/Purdue University, 1995, p 15



WA.272 7075-T6 aluminum alloy sheet, complete stress-strain curves at room and elevated temperatures

Test direction: transverse. Composition: Al-5.6Zn-2.5Mg-1.6Cu-0.3Cr. UNS A97075

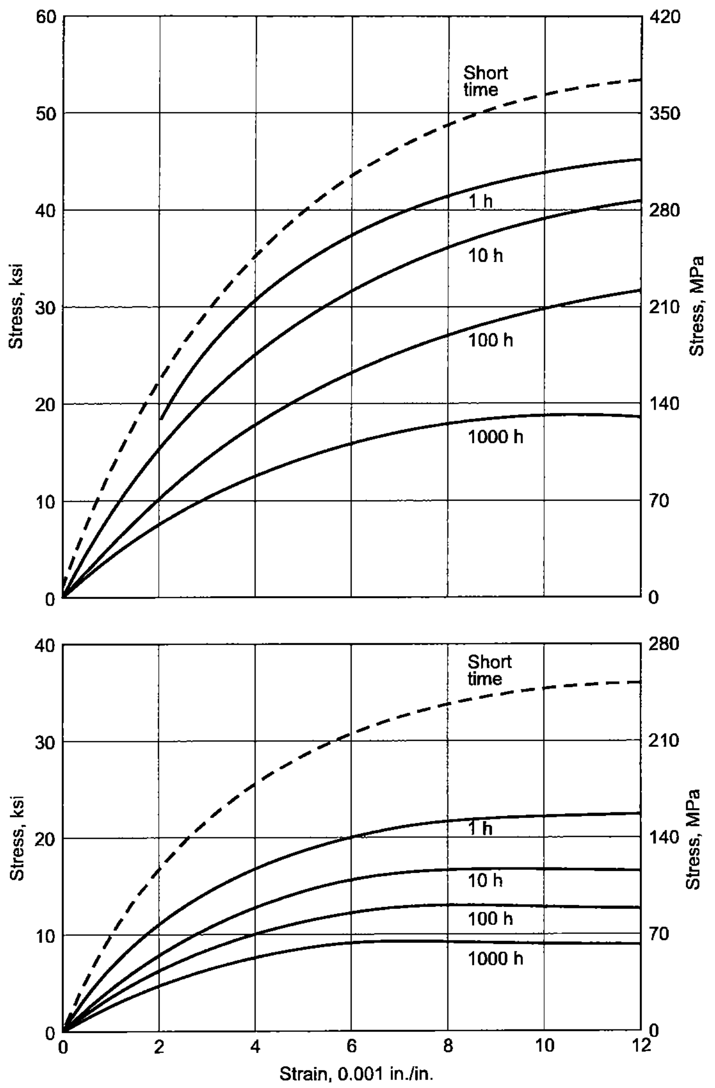
G. Sachs, G. Espey, and G.B. Kasik, "Correlation of Information Available on the Fabrication of Aluminum Alloys," Sec IV, Pt V, National Defense Research Committee, 15 Sept 1944. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3207, CINDAS/Purdue University, 1995, p 16



WA.273 7075-T6 aluminum alloy bar, complete stress-strain curves

Tested at room and elevated temperatures. Bar diameter: 19 mm (0.75 in.). Composition: Al-5.6Zn-2.5Mg-1.6Cu-0.3Cr. UNS A97075

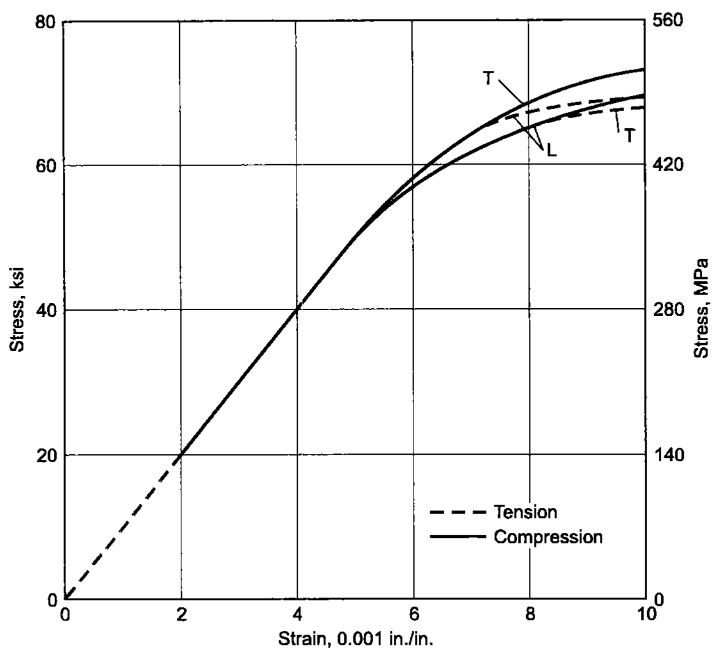
K.A. Warren and R.P. Reed, "Tensile and Impact Properties of Selected Materials from 20 to 300 K," Monograph 63, National Bureau of Standards, 1963. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3207, CINDAS/Purdue University, 1995, p 16



WA.274 7075-T6 aluminum alloy, isochronous stress-strain curves in tension

Tested at: (top) 149 °C (300 °F); (bottom) 204 °C (400 °F). Composition: Al-5.6Zn-2.5Mg-1.6Cu-0.3Cr. UNS A97075

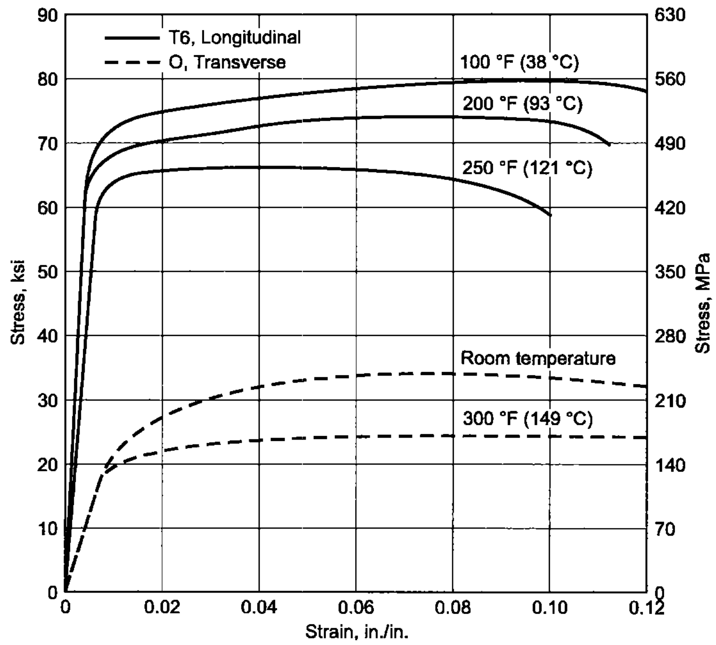
Source: F.M. Howell and G.W. Stickley, "Isochronous Stress Strain Curves for Several Heat Treated Wrought Aluminum Alloys at 300 and 400F," Alcoa Research Laboratories, Mechanical Testing Div., 29 April 1958. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3207, CINDAS/Purdue University, 1995, p 20



WA.275 7075-T6 aluminum alloy clad sheet, plate, effect of test direction on stress-strain curves

Test direction: L, longitudinal; T, transverse. Composition (7075): Al-5.5Zn-2.5Mg-1.6Cu-0.3Cr. Clad with low zinc, 7072, alloy. UNS A97075

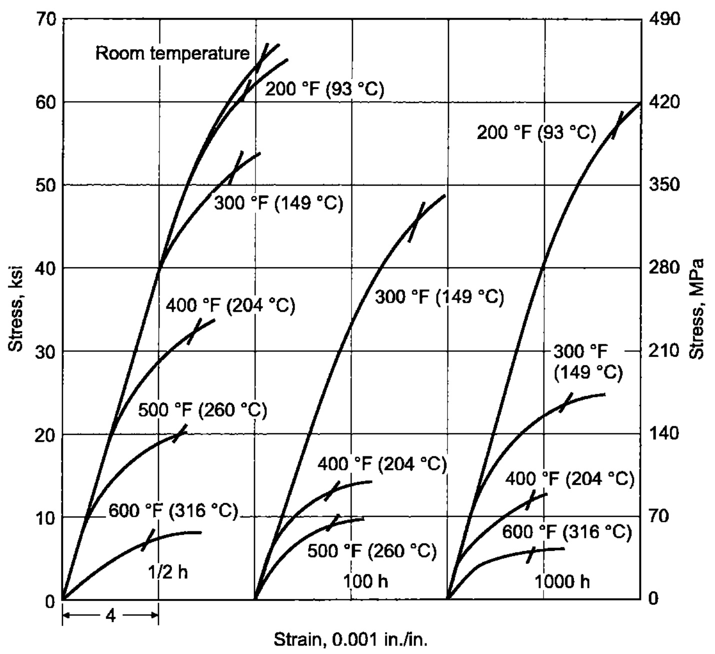
Source: "Strength of Metal Aircraft Elements," ANC-5, Department of Defense, March 1955. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3208, CINDAS/Purdue University, 1995, p 2



WA.276 7075-O and 7075-T6 aluminum alloy clad sheet, complete tensile stress-strain curves at room and elevated temperatures

Sheet thickness: 1.626 mm (0.064 in.). Composition (7075): Al-5.5Zn-2.5Mg-1.6Cu-0.3Cr. Clad with low zinc, 7072, alloy. UNS A97075

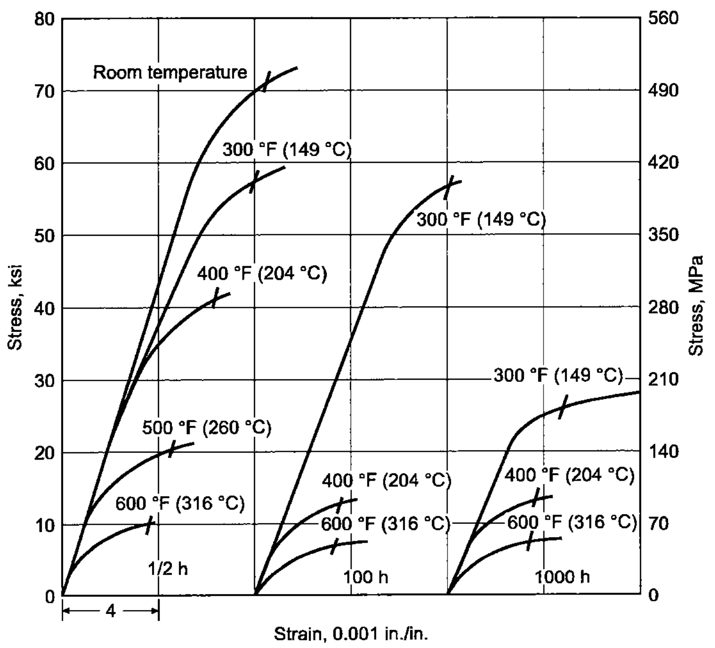
Source: G. Sachs, G. Espey, and G.B. Kasik, "Correlation of Information Available on the Fabrication of Aluminum Alloys," Sec IV, Pt V, National Defense Research Committee, 15 Sept 1944. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3208, CINDAS/Purdue University, 1995, p 2



WA.277 7075-T6 aluminum alloy sheet, tensile stress-strain curves at room and elevated temperatures

Test direction: transverse. Sheet thickness: 1.626 mm (0.064 in.). Composition (7075): Al-5.5Zn-2.5Mg-1.6Cu-0.3Cr. Clad with low zinc, 7072, alloy. UNS A97075

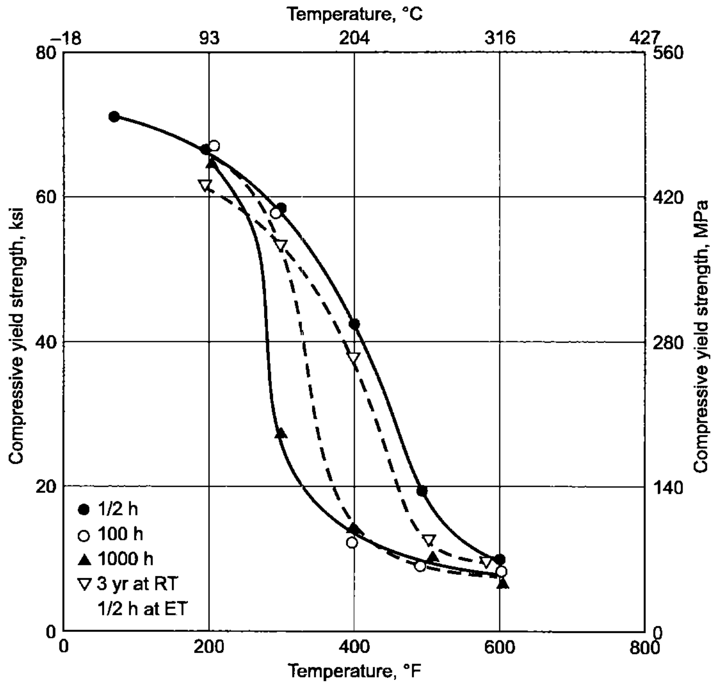
Source: D.D. Doerr, "Determination of Physical Properties of Non-Ferrous Structural Sheet Materials at Elevated Temperatures," AF TR 6517, Pt 1, Dec 1951. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3208, CINDAS/Purdue University, 1995, p 3



WA.278 7075-T6 aluminum alloy sheet, compressive stress-strain curves

Tested at room and elevated temperatures. Test direction: transverse. Sheet thickness: 1.626 mm (0.064 in.). Composition (7075): Al-5.5Zn-2.5Mg-1.6Cu-0.3Cr. Clad with low zinc, 7072, alloy. UNS A97075

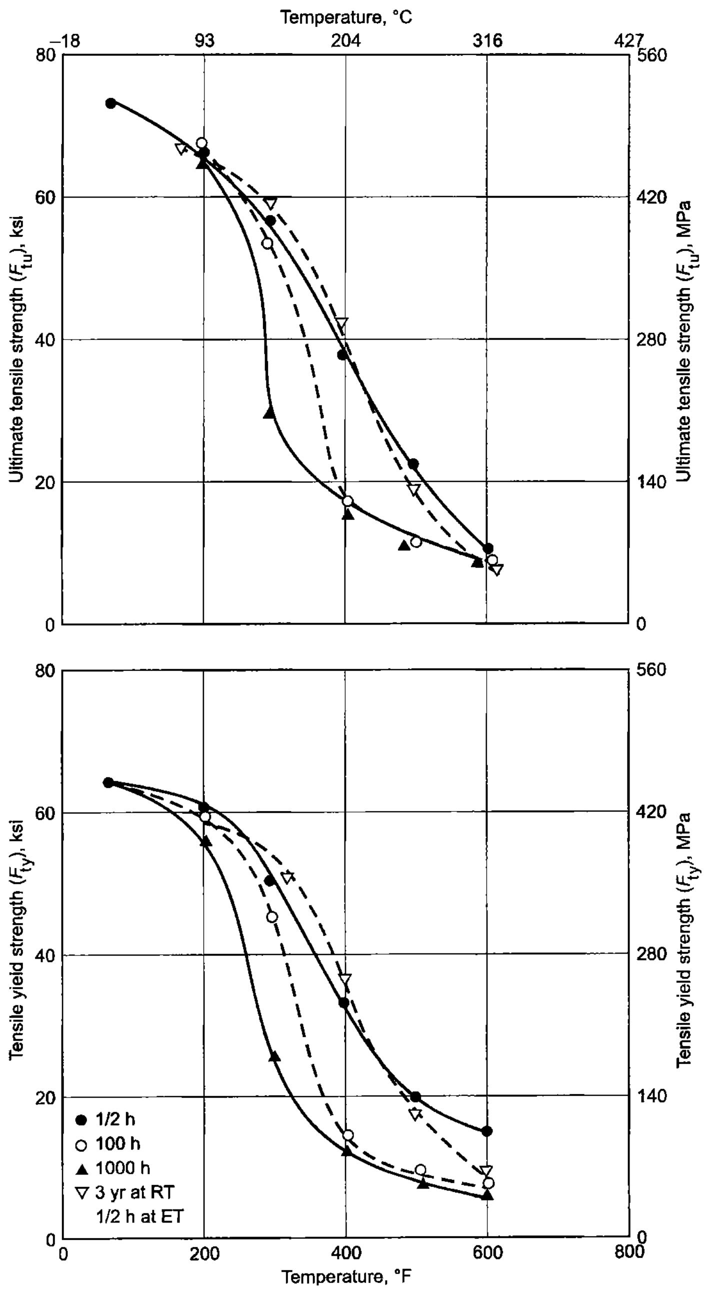
Source: D.D. Doerr, "Determination of Physical Properties of Non-Ferrous Structural Sheet Materials at Elevated Temperatures," AF TR 6517, Pt 1, Dec 1951. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3208, CINDAS/Purdue University, 1995, p 3



WA.279 7075-T6 aluminum alloy clad sheet, effect of exposure and test temperature on compressive yield strength

Sheet thickness: 1.626 mm (0.064 in.). RT, room temperature; ET, elevated temperature. Composition (7075): Al-5.5Zn-2.5Mg-1.6Cu-0.3Cr. Clad with low zinc, 7072, alloy. UNS A97075

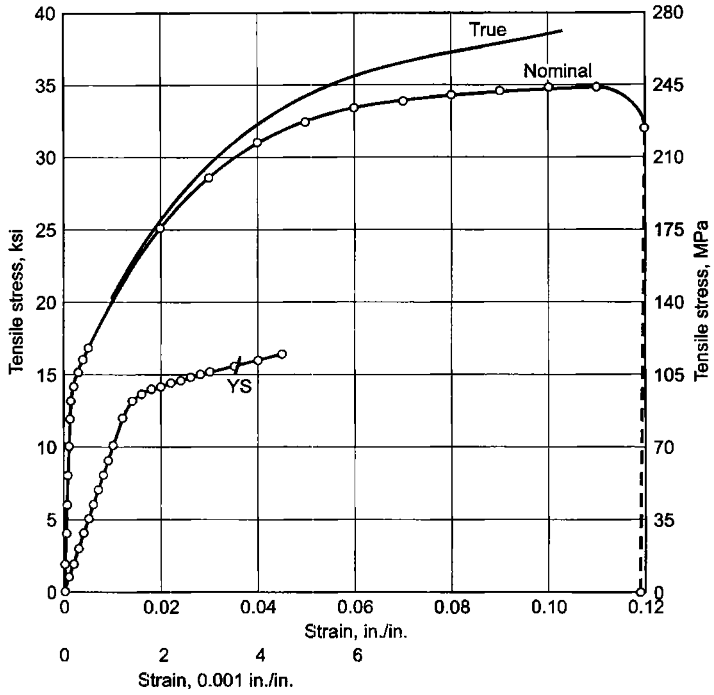
Source: D.D. Doerr, "Determination of Physical Properties of Non-Ferrous Structural Sheet Materials at Elevated Temperatures," AF TR 6517, Pt 1, Dec 1951. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3208, CINDAS/Purdue University, 1995, p 3



WA.280 7075-T6 aluminum alloy clad sheet, effect of exposure and test temperature on tensile properties

Sheet thickness: 1.626 mm (0.064 in.). RT, room temperature; ET, elevated temperature. Note one sample was aged for 3 years. Composition (7075): Al-5.5Zn-2.5Mg-1.6Cu-0.3Cr. Clad with low zinc, 7072, alloy.
UNS A97075

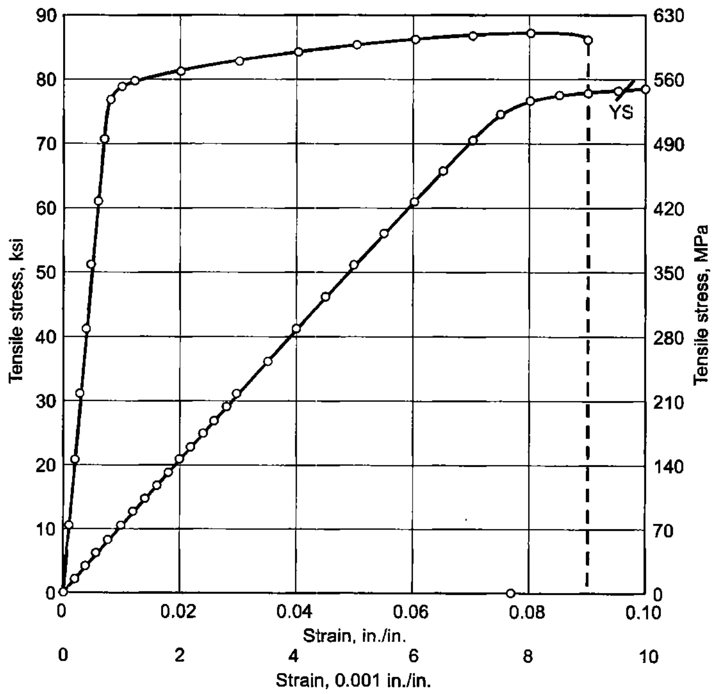
Source: D.D. Doerr, "Determination of Physical Properties of Non-Ferrous Structural Sheet Materials at Elevated Temperatures," AF TR 6517, Pt 1, Dec 1951. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3208, CINDAS/Purdue University, 1995, p 3



WA.281 7075-O aluminum alloy rolled and drawn rod, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Rod size: 19 mm (3/4 in.) diam. Test specimen diam, 12.7 mm (1/2 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 241 MPa (35.0 ksi). True tensile strength, 268 MPa (38.8 ksi). Nominal yield strength (0.2% offset), 108 MPa (15.7 ksi). Elongation (in 50.8 mm, or 2 in.), 11.9%. Reduction of area, 40%. True strain at maximum load, 10.4%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.09 in the area of uniform plastic deformation. UNS A97075

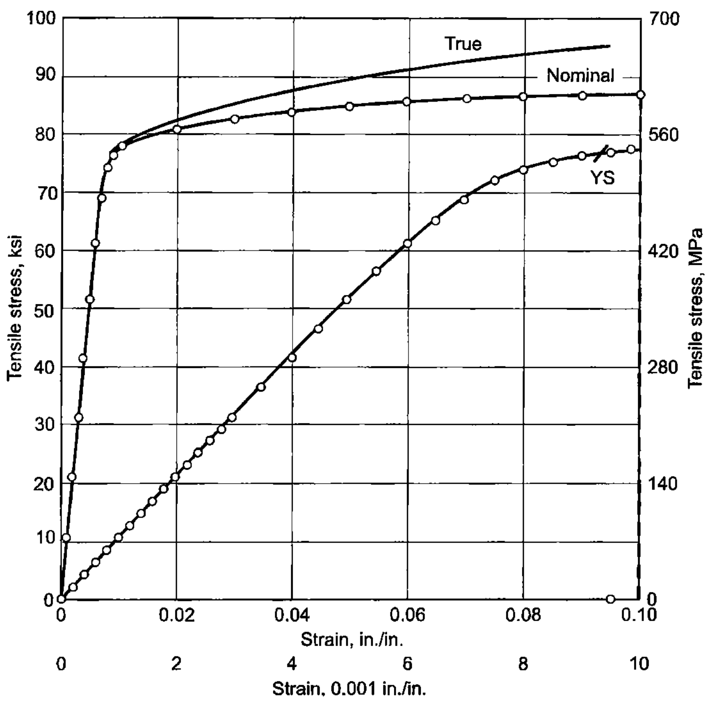
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, June 1953



WA.282 7075-T6 aluminum alloy plate, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test direction: longitudinal. Nominal thickness: 15.9 mm (5/8 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 600 MPa (87.0 ksi). True tensile strength, 658 MPa (95.5 ksi). Nominal yield strength (0.2% offset), 531 MPa (77.0 ksi). Elongation (in 50.8 mm, or 2 in.), 10.0%. Reduction of area, 17%. True strain at maximum load, 9.5%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.10 in the area of uniform plastic deformation. UNS A97075

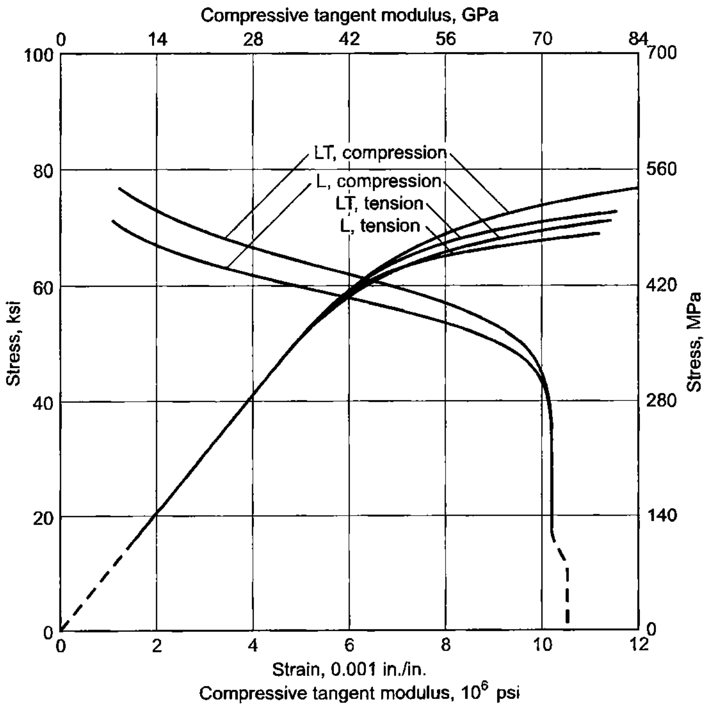
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, April 1951



WA.283 7075-T6 aluminum alloy plate, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test direction: transverse. Nominal thickness: 15.9 mm (5/8 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 600 MPa (87.0 ksi). True tensile strength, 658 MPa (95.5 ksi). Nominal yield strength (0.2% offset), 531 MPa (77.0 ksi). Elongation (in 50.8 mm, or 2 in.), 10.0%. Reduction of area, 17%. True strain at maximum load, 9.5%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.10 in the area of uniform plastic deformation. UNS A97075

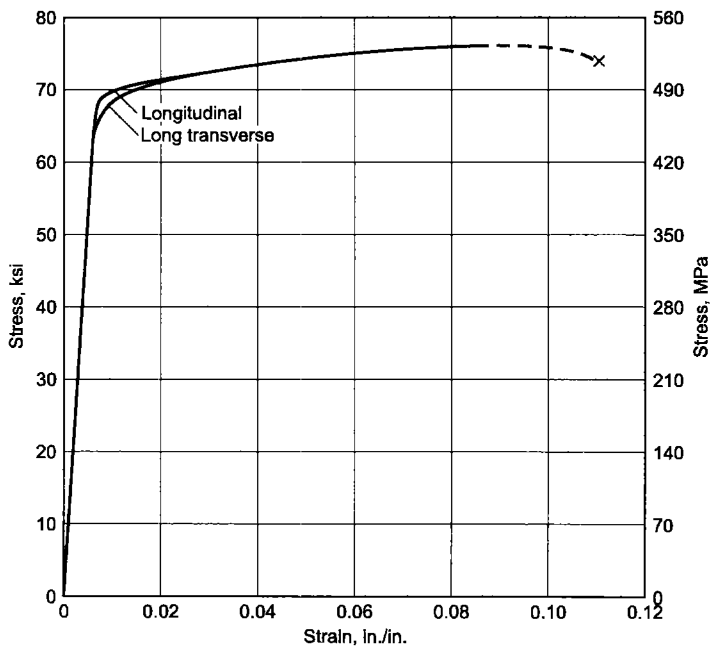
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA, April 1951



WA.284 7075-T6 aluminum alloy clad sheet, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for sheet thickness 4.775–6.325 mm (0.188–0.249 in.). Ramberg-Osgood parameter, n(L, tension) = 17; n(LT, tension) = 15 n(L, compression) = 13; n(LT, compression) = 12. UNS A97075

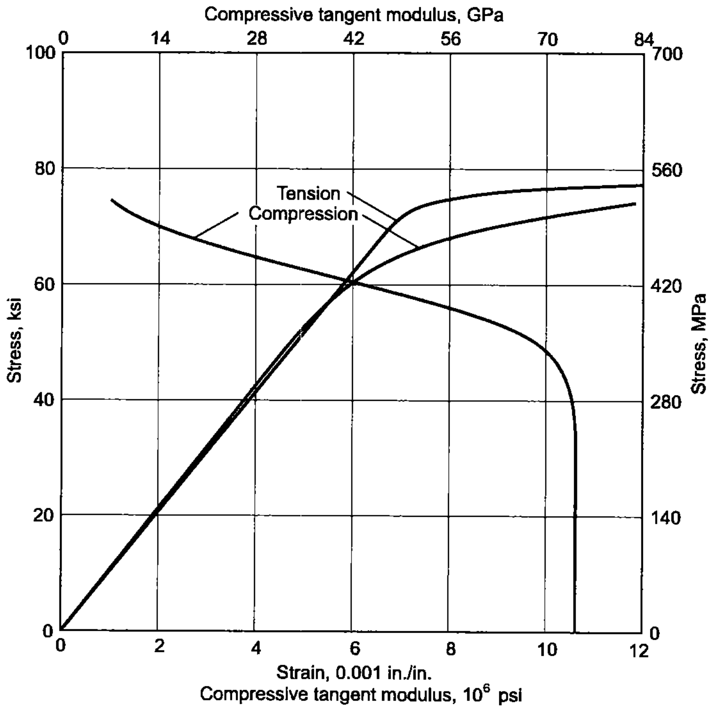
Source: *MIL-HDBK-5H*, 1 Dec 1998, p 3-371



WA.285 7075-T6 aluminum alloy clad sheet, tensile stress-strain curves (full range)

Tested at room temperature. Typical. UNS A97075

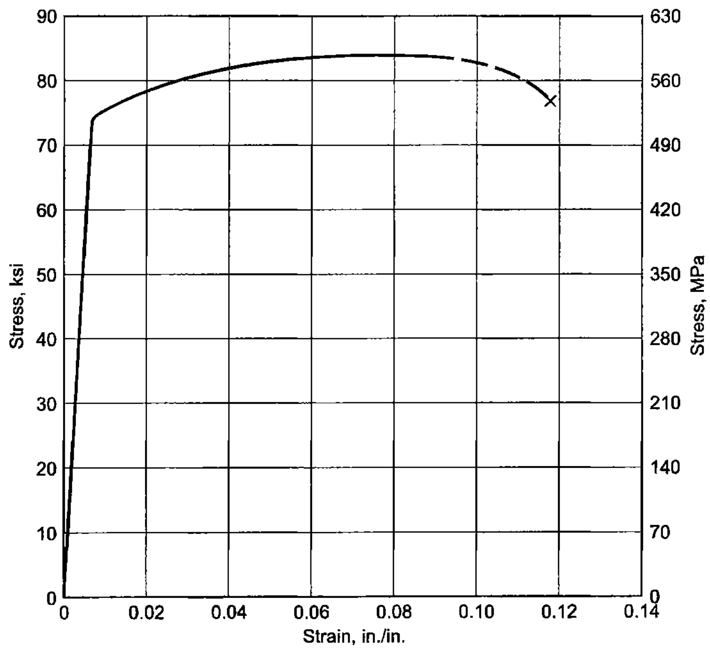
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–378



WA.286 7075-T6 and 7075-T651 aluminum alloy rolled bar, rod, and shape, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: longitudinal. Typical for specimen thickness ≤76.20 mm (≤3.000 in.). Ramberg-Osgood parameter, n(longitudinal, tension) = 50; n(longitudinal, compression) = 13. UNS A97075

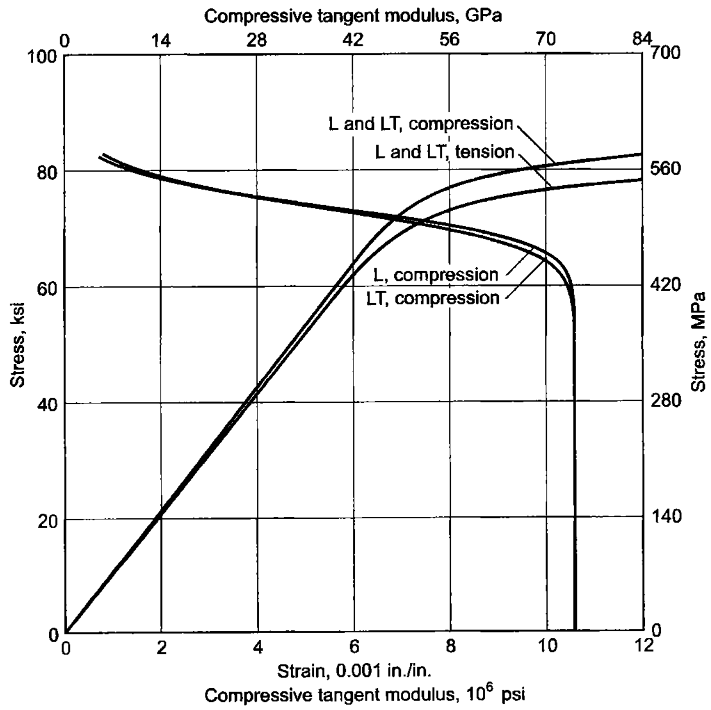
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–376



WA.287 7075-T6 and 7075-T651 aluminum alloy rolled or cold-finished bar, tensile stress-strain curve (full range)

Tested at room temperature. Test direction: longitudinal. Typical. UNS A97075

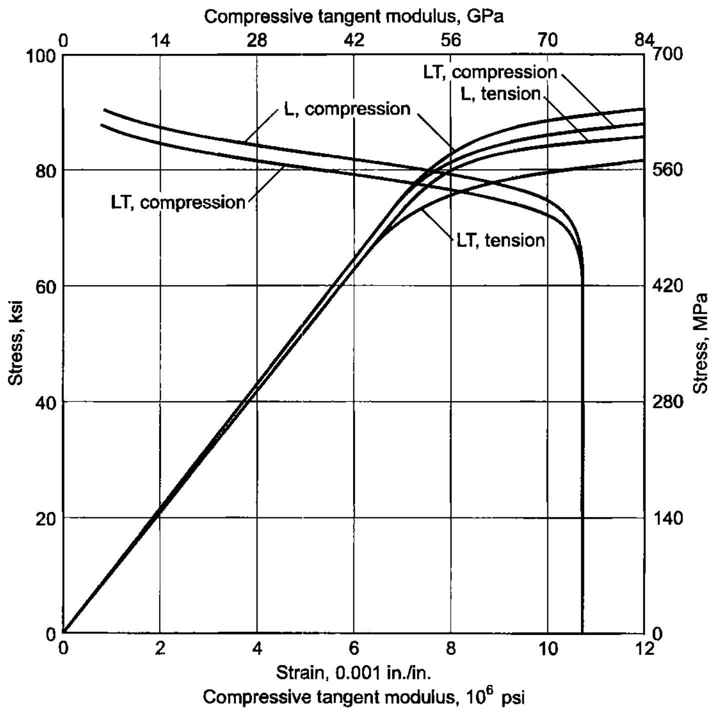
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–379



WA.288 7075-T62 aluminum alloy plate, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for plate thickness 6.350–50.80 mm (0.250–2.000 in.). Ramberg-Osgood parameter, n(L, tension) = 22; n(LT, tension) = 22 n(L, compression) = 25; n(LT, compression) = 22. UNS A97075

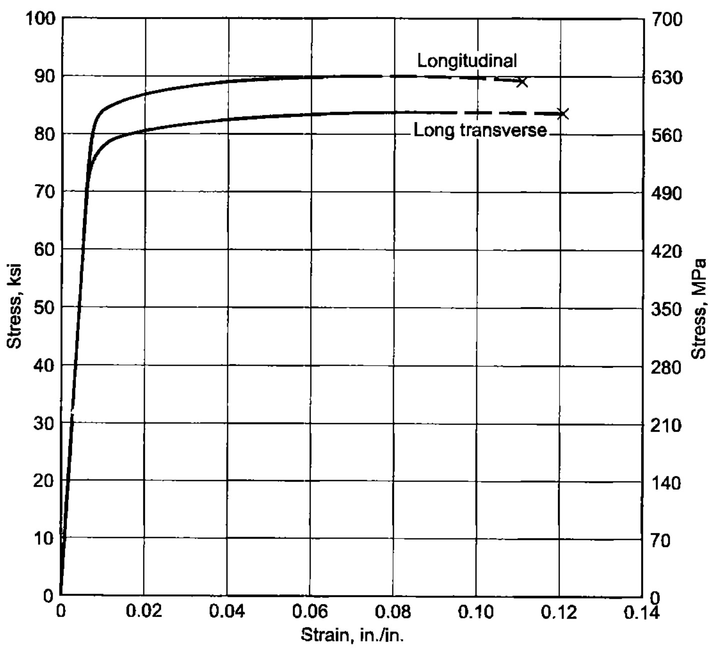
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–375



WA.289 7075-T62 aluminum alloy extrusion, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for extrusion thickness 6.350–38.075 mm (0.250–1.499 in.). Ramberg-Osgood parameter, n(L, tension) = 33; n(LT, tension) = 22 n(L, compression) = 27; n(LT, compression) = 23.
UNS A97075

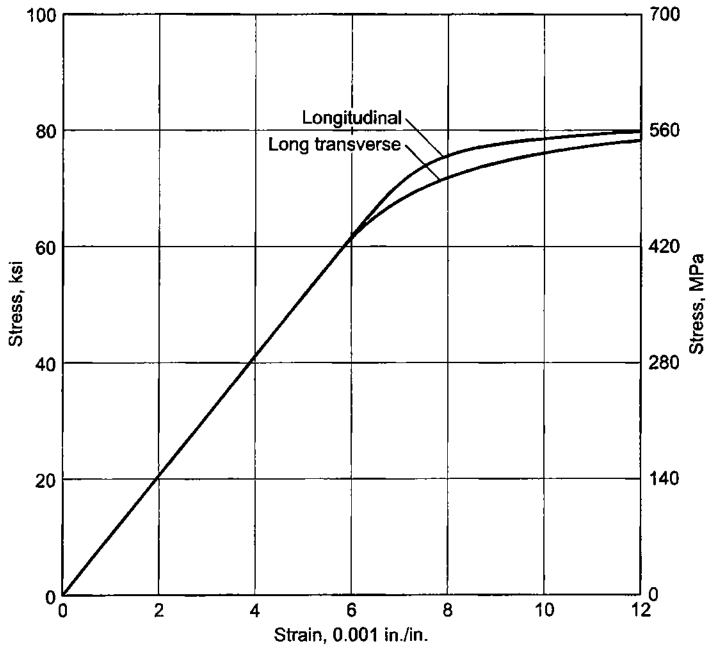
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–377



WA.290 7075-T62 aluminum alloy extrusion, tensile stress-strain curves (full range)

Tested at room temperature. Typical for extrusion thickness 6.35–38.07 mm (0.250–1.499 in.). UNS A97075

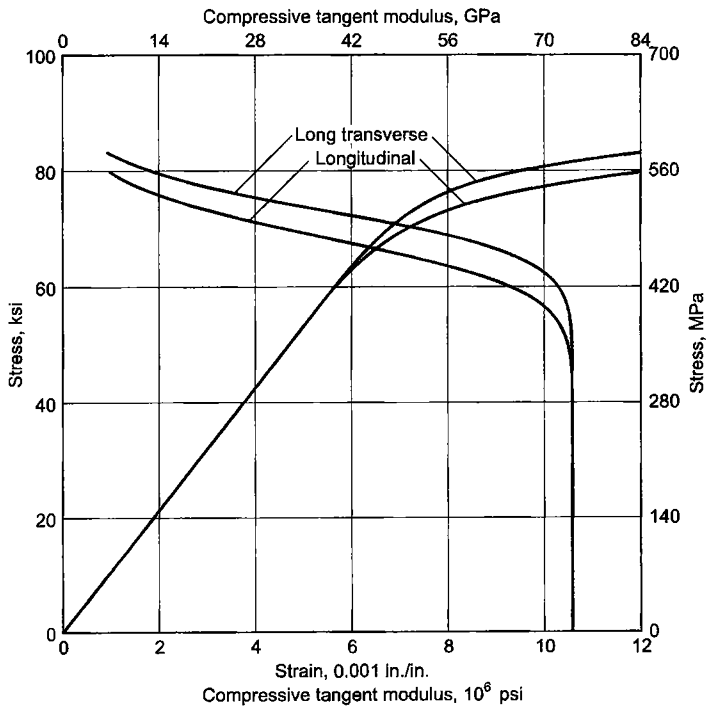
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–381



WA.291 7075-T651 aluminum alloy plate, tensile stress-strain curves

Tested at room temperature. Typical for plate thickness 6.35–50.80 mm (0.250–2.000 in.). Ramberg-Osgood parameter, n(longitudinal, tension) = 32; n(long transverse, tension) = 17. UNS A97075

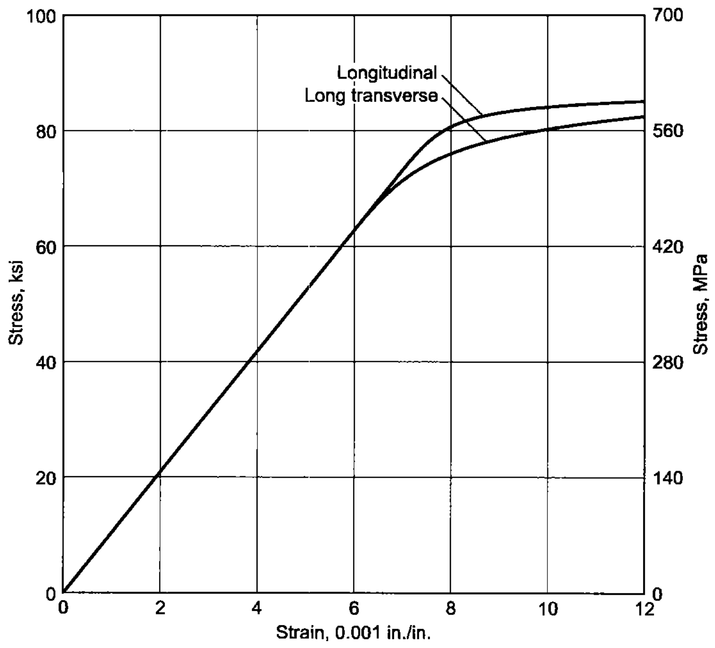
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–374



WA.292 7075-T651 aluminum alloy plate, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for plate thickness 6.35–50.80 mm (0.250–2.000 in.). Ramberg-Osgood parameter, n(longitudinal, compression) = 16; n(long transverse, compression) = 19. UNS A97075

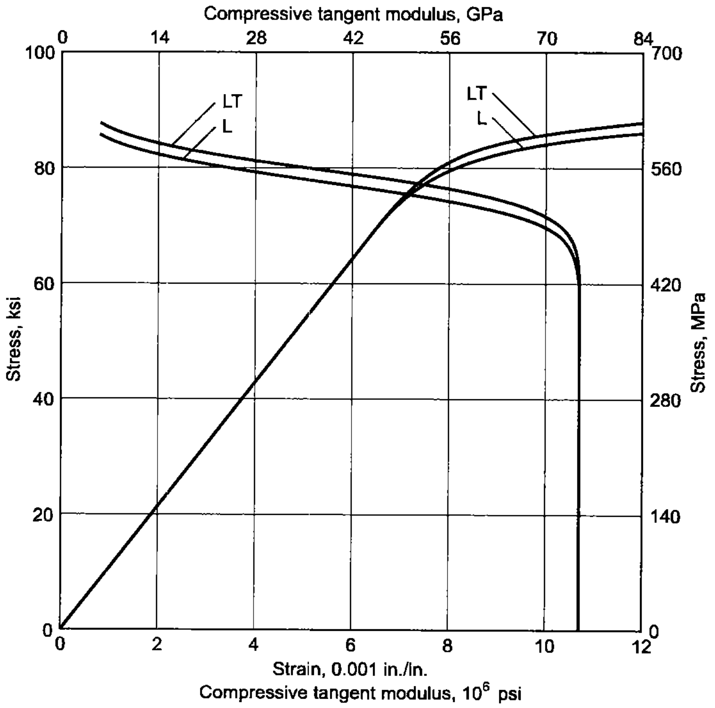
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–375



WA.293 7075-T651X aluminum alloy extrusion, tensile stress-strain curves

Tested at room temperature. Typical for extrusion thickness 12.7–19.0 mm (0.500–0.749 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 50; *n*(long transverse, tension) = 22. UNS A97075

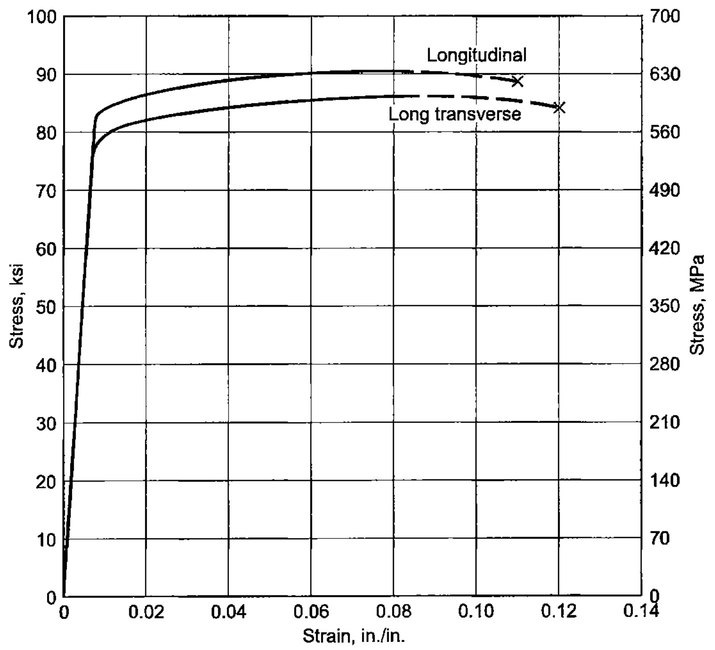
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–376



WA.294 7075-T651X aluminum alloy extrusion, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for extrusion thickness 12.7–19.0 mm (0.500–0.749 in.). Ramberg-Osgood parameter, *n*(L, compression) = 26; *n*(LT, compression) = 27. UNS A97075

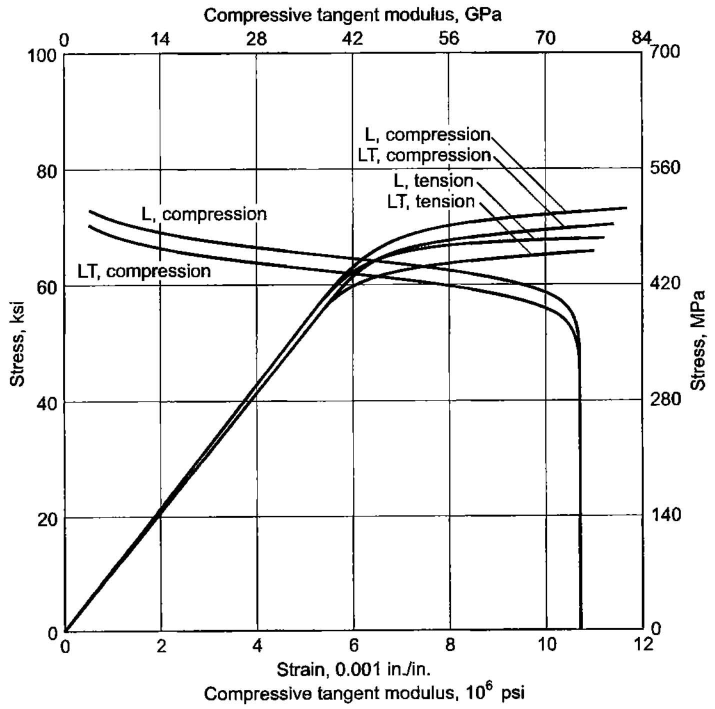
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–377



WA.295 7075-T651X aluminum alloy extrusion, tensile stress-strain curves (full range)

Tested at room temperature. Typical for extrusion thickness 12.7–19.0 mm (0.500–0.749 in.). UNS A97075

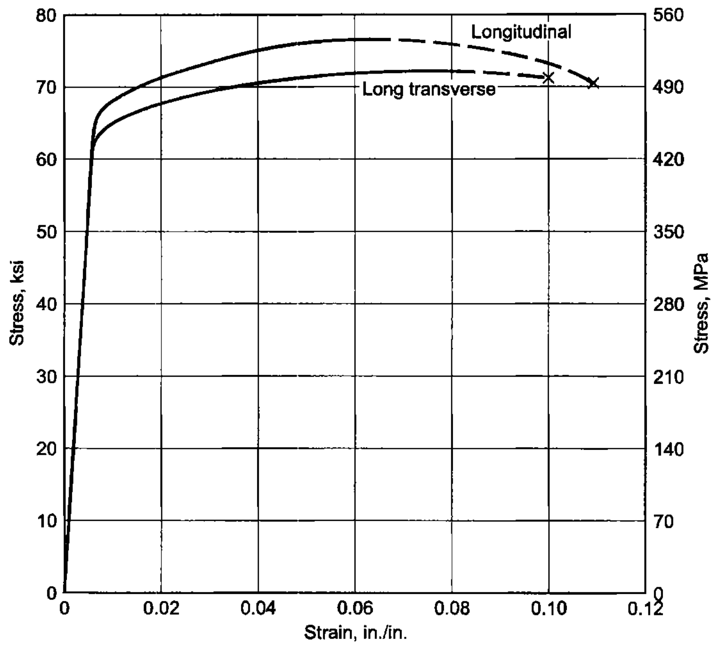
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–380



WA.296 7075-T73 aluminum alloy extrusion, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for extrusion thickness 6.35–38.07 mm (0.250–1.499 in.). Ramberg-Osgood parameter, n(L, tension) = 48; n(LT, tension) = 30 n(L, compression) = 27; n(LT, compression) = 26.
UNS A97075

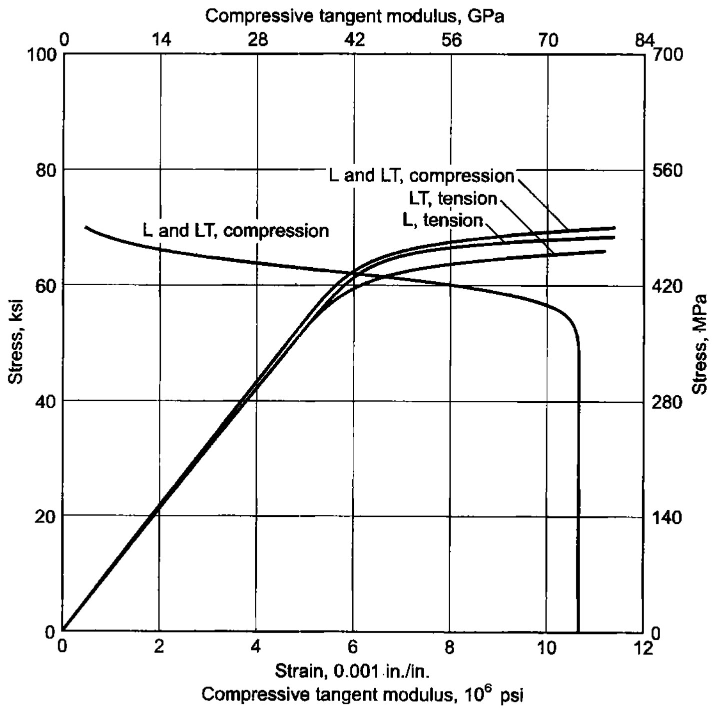
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–395



WA.297 7075-T73 aluminum alloy extrusion, tensile stress-strain curves (full range)

Tested at room temperature. Typical for extrusion thickness 6.35–38.07 mm (0.250–1.499 in.). UNS A97075

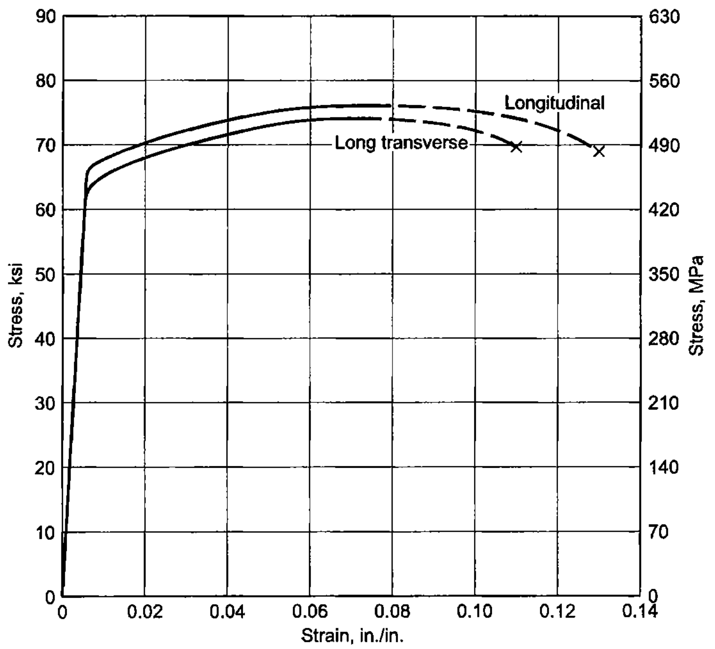
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–398



WA.298 7075-T7351X aluminum alloy extrusion, tensile and compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for extrusion thickness 12.7–19.0 mm (0.500–0.749 in.). Ramberg-Osgood parameter, n(L, tension) = 34; n(LT, tension) = 25 n(L, compression) = 28; n(LT, compression) = 28. UNS A97075

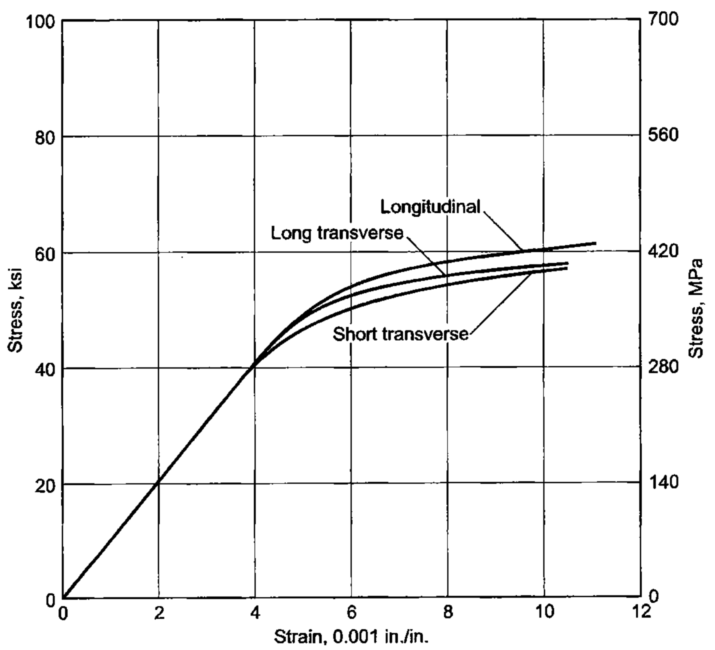
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–395



WA.299 7075-T7351X aluminum alloy extrusion, tensile stress-strain curves (full range)

Tested at room temperature. Typical for extrusion thickness 12.7–19.02 mm (0.500–0.749 in.). UNS A97075

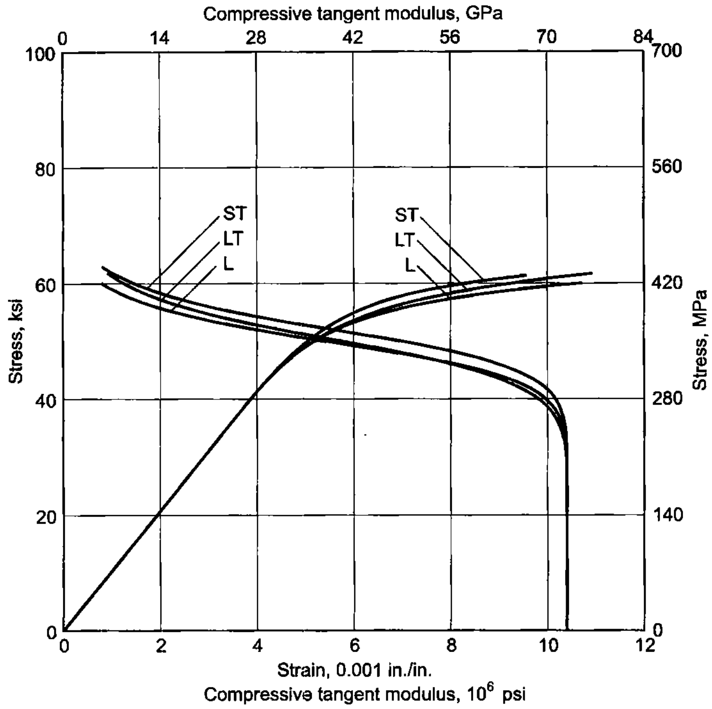
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–397



WA.300 7075-T7352 aluminum alloy hand forging, tensile stress-strain curves

Tested at room temperature. Typical for forging thickness 76.2–127.0 mm (3.001–5.000 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 15; *n*(long transverse, tension) = 17; *n*(short transverse, tension) = 12. UNS A97075

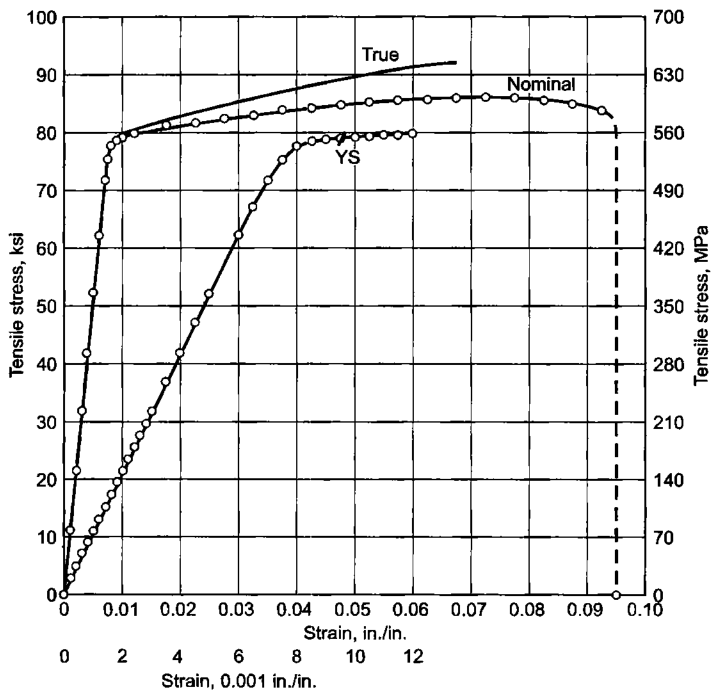
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–396



WA.301 7075-T7352 aluminum alloy hand forging, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse; ST, short transverse. Typical for forging thickness 76.2–127.0 mm (3.001–5.000 in.). Ramberg-Osgood parameter, n(L, compression) = 15; n(LT, compression) = 13; n(ST, compression) = 15. UNS A97075

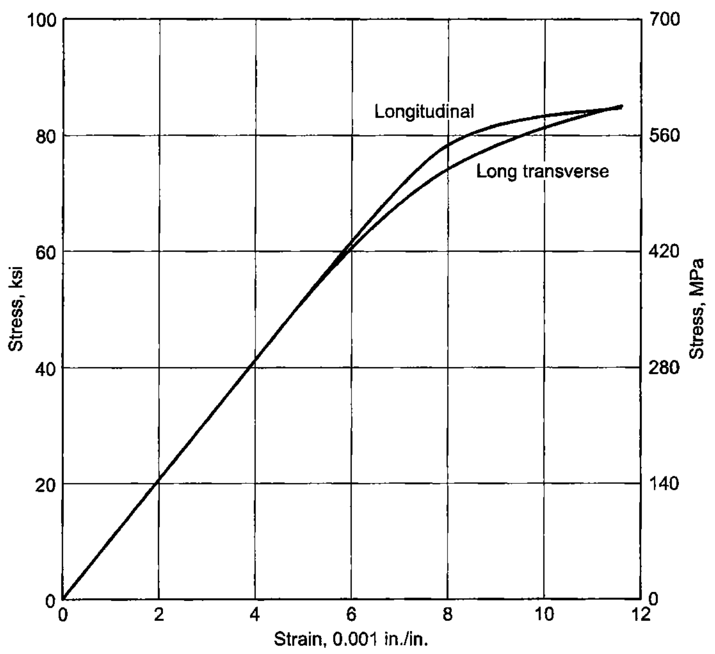
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–396



WA.302 7079-T6 aluminum alloy extrusion, tensile stress-strain curves

The upper row of strain values on the abscissa applies to both the complete true curve and the complete nominal curve. The lower row of strain values applies to the expanded portion of the curves; this expanded portion is essentially identical for both the true and nominal curves. YS, yield strength. Test direction: longitudinal (midway center to surface). Nominal size: 76 × 152 mm (3 × 6 in.) rectangle. Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 594 MPa (86.2 ksi). True tensile strength, 636 MPa (92.2 ksi). Nominal yield strength (0.2% offset), 545 MPa (79.1 ksi). Elongation (in 50.8 mm, or 2 in.), 9.5%. Reduction of area, 18%. True strain at maximum load, 6.8%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.09 in the area of uniform plastic deformation. This is no longer an active alloy but is included for reference purposes. UNS A97079

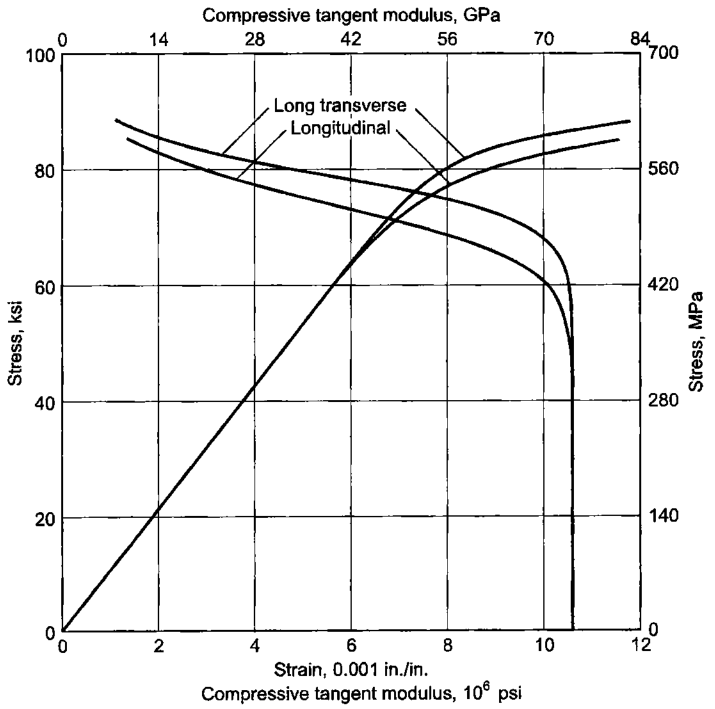
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA



WA.303 7150-T6151 aluminum alloy plate, tensile stress-strain curves

Tested at room temperature. Typical for plate thickness 19.050–25.40 mm (0.750–1.000 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 30; *n*(long transverse, tension) = 11. Composition: Al-6.4Zn-2.4Mg-2.2Cu-0.12Zr. UNS A97150

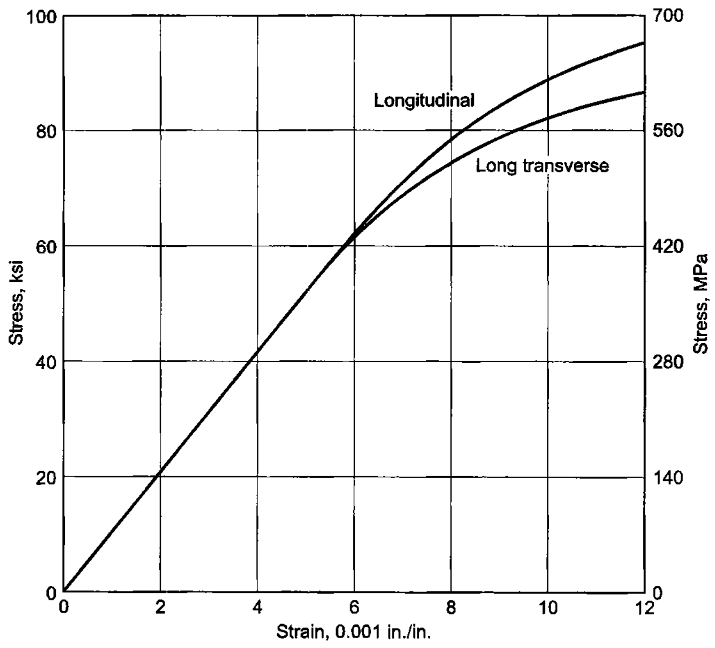
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–408



WA.304 7150-T6151 aluminum alloy plate, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for plate thickness 19.05–25.40 mm (0.750–1.000 in.). Ramberg-Osgood parameter, *n*(longitudinal, compression) = 15; *n*(long transverse, compression) = 20. Composition: Al-6.4Zn-2.4Mg-2.2Cu-0.12Zr. UNS A97150

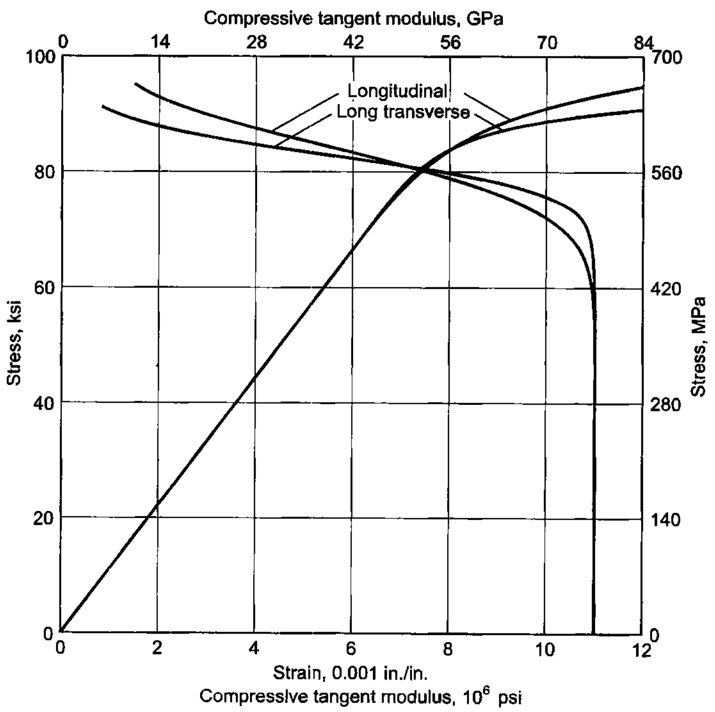
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–408



WA.305 7150-T61511 aluminum alloy extrusion, tensile stress-strain curves

Tested at room temperature. Typical for extrusion thickness 20.3–69.85 mm (0.800–2.750 in.). Ramberg-Osgood parameter, n(longitudinal, tension) = 9.5; n(long transverse, tension) = 9.5. Composition: Al-6.4Zn-2.4Mg-2.2Cu-0.12Zr. UNS A97150

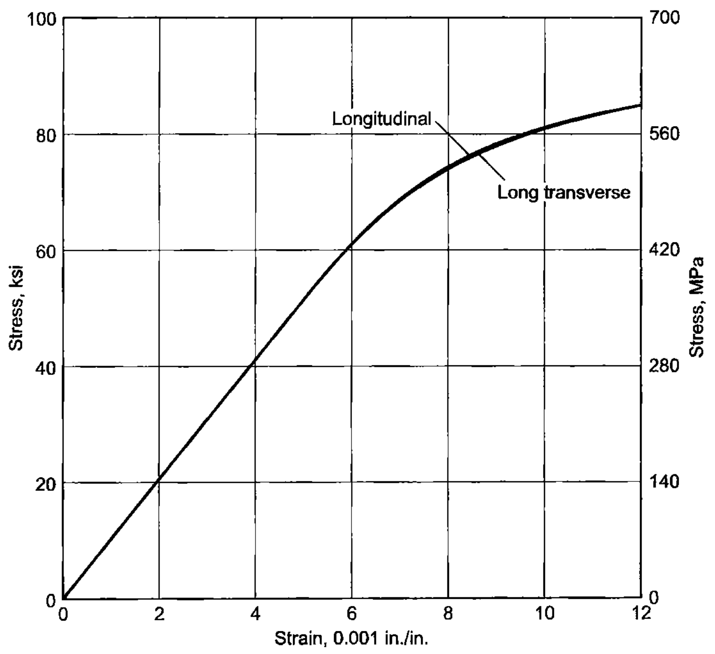
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–409



WA.306 7150-T61511 aluminum alloy extrusion, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for extrusion thickness 20.320–69.850 mm (0.800–2.750 in.). Ramberg-Osgood parameter, n(longitudinal, compression) = 16; n(long transverse, compression) = 27. Composition: Al-6.4Zn-2.4Mg-2.2Cu-0.12Zr. UNS A97150

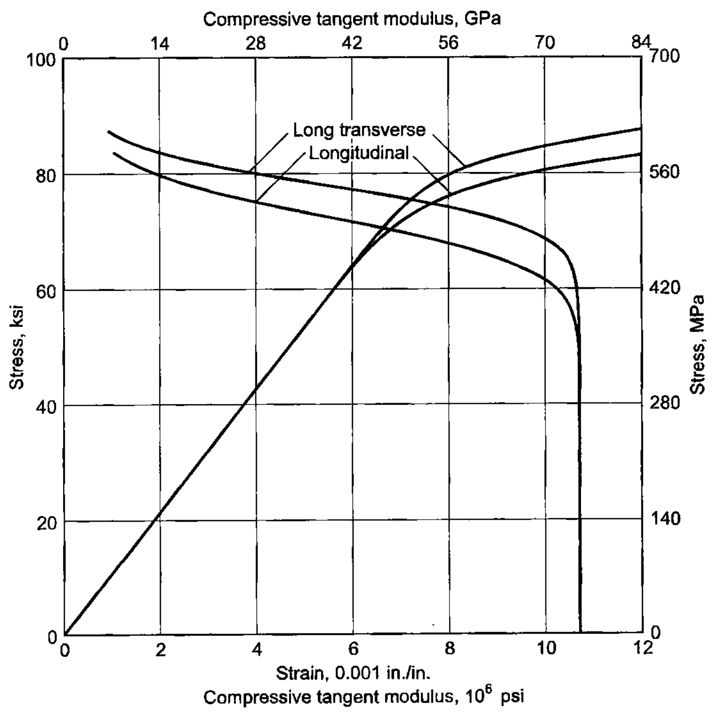
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–409



WA.307 7150-T7751 aluminum alloy plate, tensile stress-strain curves

Tested at room temperature. Typical for plate thickness 8.636–47.625 mm (0.340–1.875 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 12; *n*(long transverse, tension) = 11. Composition: Al-6.4Zn-2.4Mg-2.2Cu-0.12Zr. UNS A97150

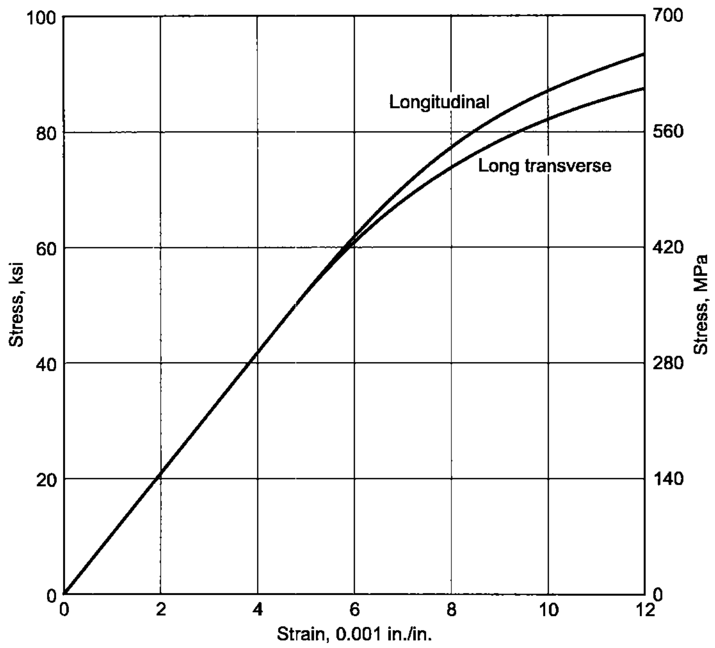
Source: *MIL-HDBK-5H*, 1 Dec 1998, p 3–410



WA.308 7150-T7751 aluminum alloy plate, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for plate thickness 8.636–47.625 mm (0.340–1.875 in.). Ramberg-Osgood parameter, *n*(longitudinal, compression) = 17; *n*(long transverse, compression) = 22. Composition: Al-6.4Zn-2.4Mg-2.2Cu-0.12Zr. UNS A97150

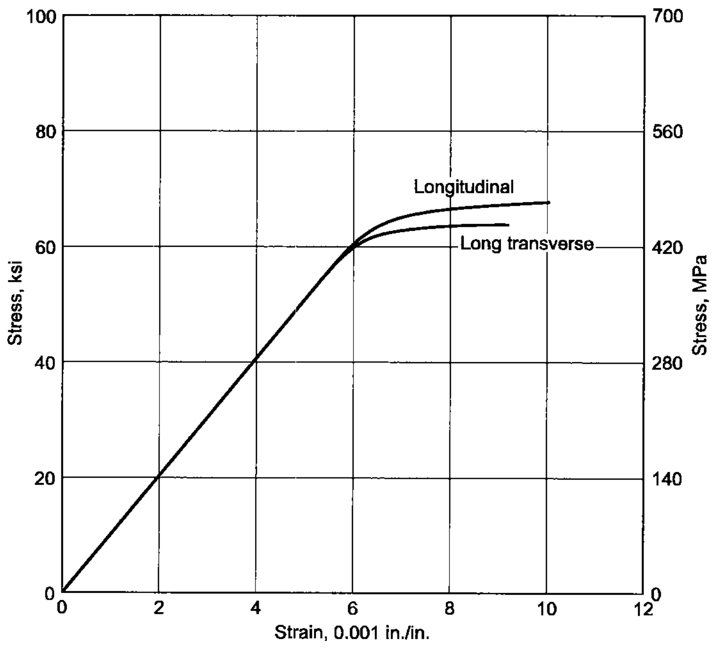
Source: *MIL-HDBK-5H*, 1 Dec 1998, p 3–410



WA.309 7150-T77511 aluminum alloy extrusion, tensile stress-strain curves

Tested at room temperature. Typical for extrusion thickness 17.78–29.108 mm (0.700–1.145 in.). Ramberg-Osgood parameter, n(longitudinal, tension) = 8.8; n(long transverse, tension) = 8.2. UNS A97150

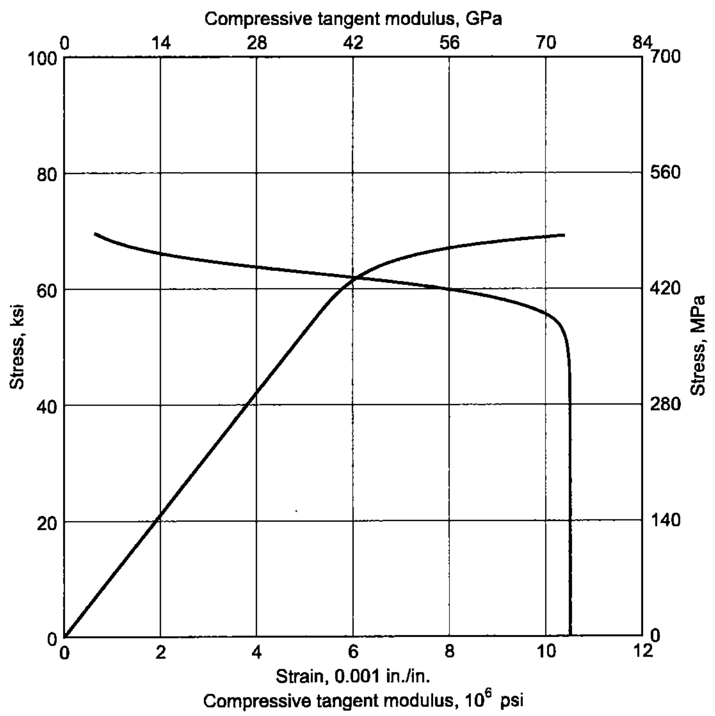
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–411



WA.310 7175-T73511 aluminum alloy extrusion, tensile stress-strain curves

Tested at room temperature. Typical for extrusion thickness 25.40–50.80 mm (1.000–2.000 in.). Cross-sectional area: 206–419 cm^2 (32–65 in.^{2}). Ramberg-Osgood parameter, n(longitudinal, tension) = 41; n(long transverse, tension) = 58. Composition: Al-5.6Zn-2.5Mg-1.6Cu-0.23Cr. UNS A97175

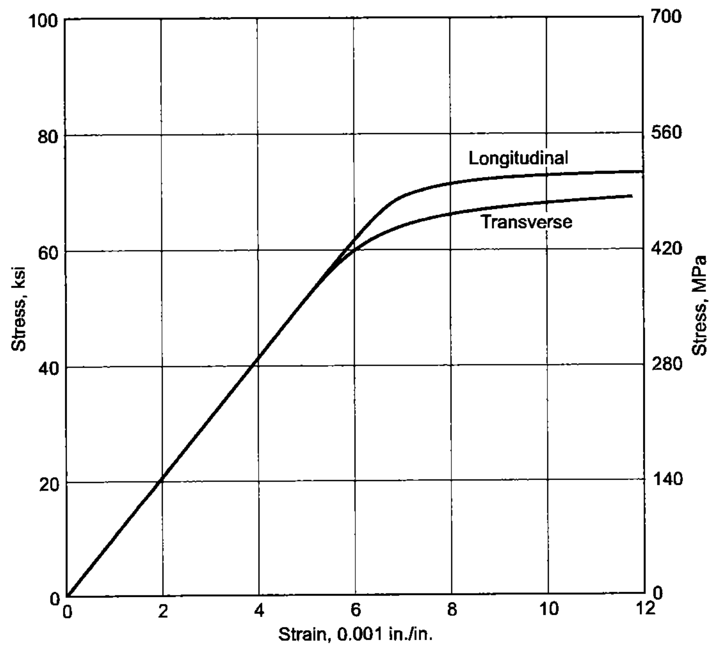
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–420



WA.311 7175-T73511 aluminum alloy extrusion, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: longitudinal and long transverse. Typical for extrusion thickness 25.40–50.80 mm (1.000–2.000 in.). Cross-sectional area: 206–419 cm^2 (32–65 $in.^2$). Ramberg-Osgood parameter, *n*(longitudinal and long transverse, compression) = 13. Composition: Al-5.6Zn-2.5Mg-1.6Cu-0.23Cr. UNS A97175

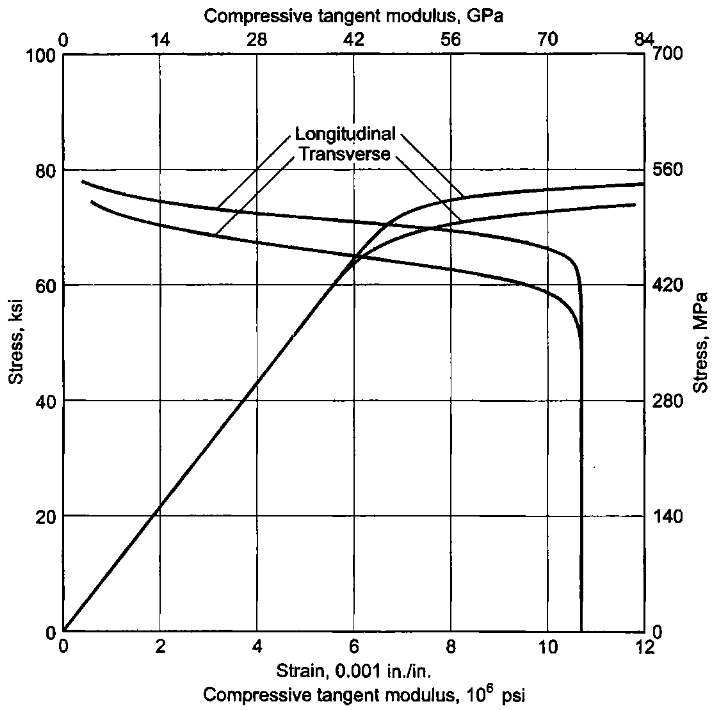
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–420



WA.312 7175-T74 aluminum alloy die forging, tensile stress-strain curves

Tested at room temperature. Typical for forging thickness ≤76.20 mm (≤3.000 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 50; *n*(transverse, tension) = 25. Composition: Al-5.6Zn-2.5Mg-1.6Cu-0.23Cr. UNS A97175

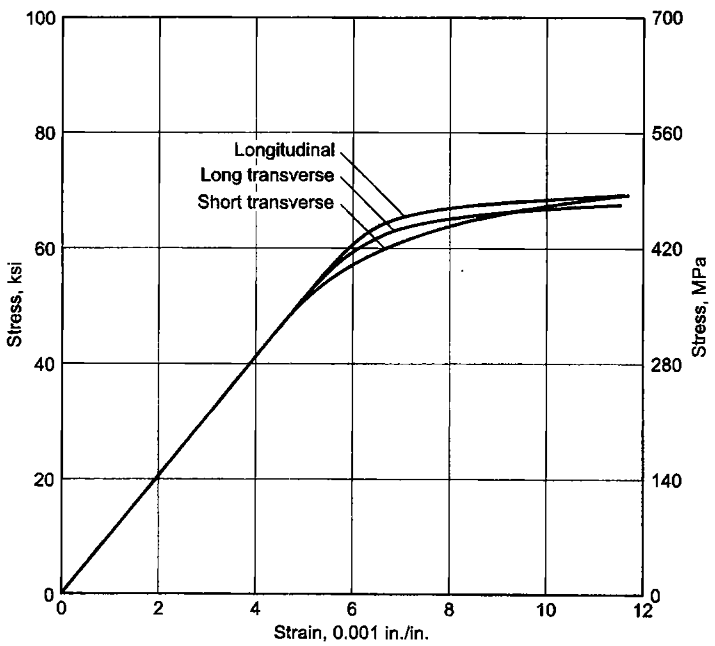
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–425



WA.313 7175-T74 aluminum alloy die forging, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for forging thickness ≤76.20 mm (≤3.000 in.). Ramberg-Osgood parameter, *n*(longitudinal, compression) = 50; *n*(transverse, compression) = 25. Composition: Al-5.6Zn-2.5Mg-1.6Cu-0.23Cr. UNS A97175

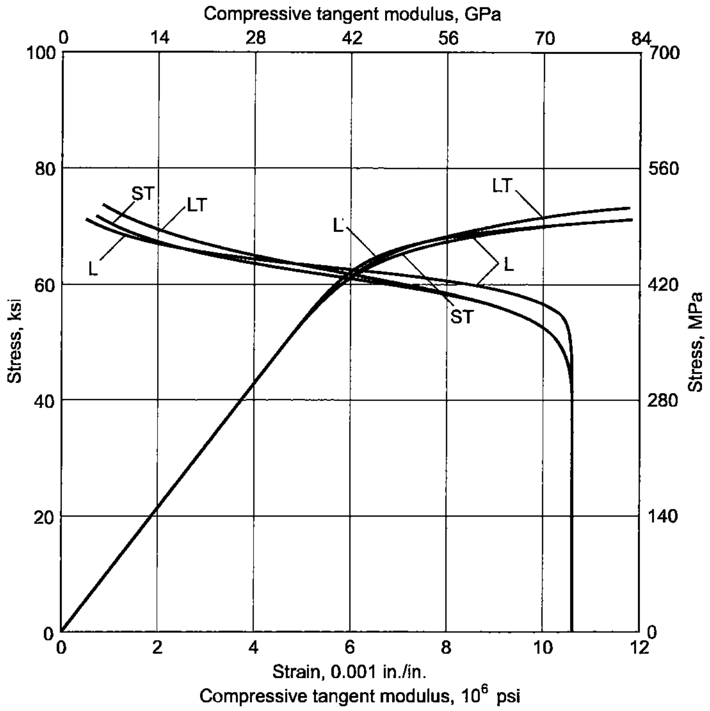
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–425



WA.314 7175-T74 aluminum alloy hand forging, tensile stress-strain curves

Tested at room temperature. Typical for forging thickness ≤101.60 mm (≤4.000 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 34; *n*(long transverse, tension) = 26; *n*(short transverse, tension) = 13. Composition: Al-5.6Zn-2.5Mg-1.6Cu-0.23Cr. UNS A97175

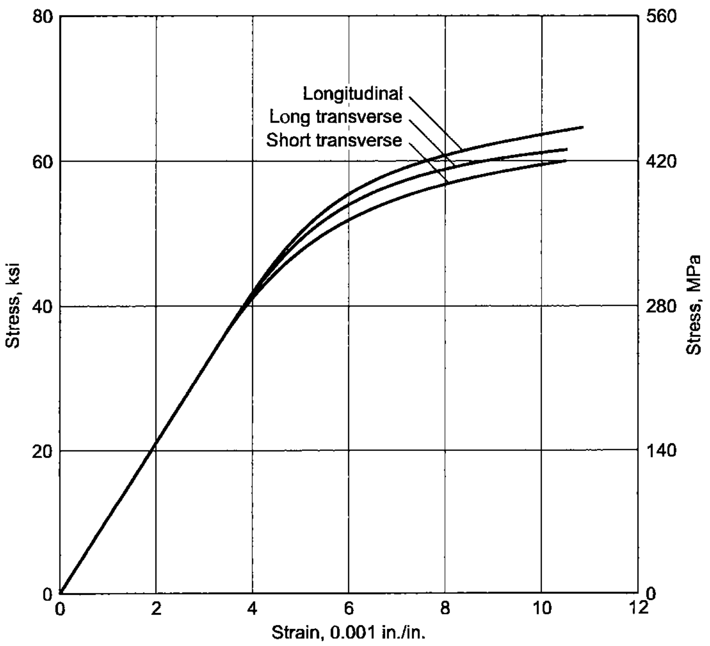
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–426



WA.315 7175-T74 aluminum alloy hand forging, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse, ST, short transverse. Typical for forging thickness ≤101.60 mm (≤4.000 in.). Ramberg-Osgood parameter, *n*(L, compression) = 27; *n*(LT, compression) = 17; *n*(ST, compression) = 19. Composition: Al-5.6Zn-2.5Mg-1.6Cu-0.23Cr. UNS A97175

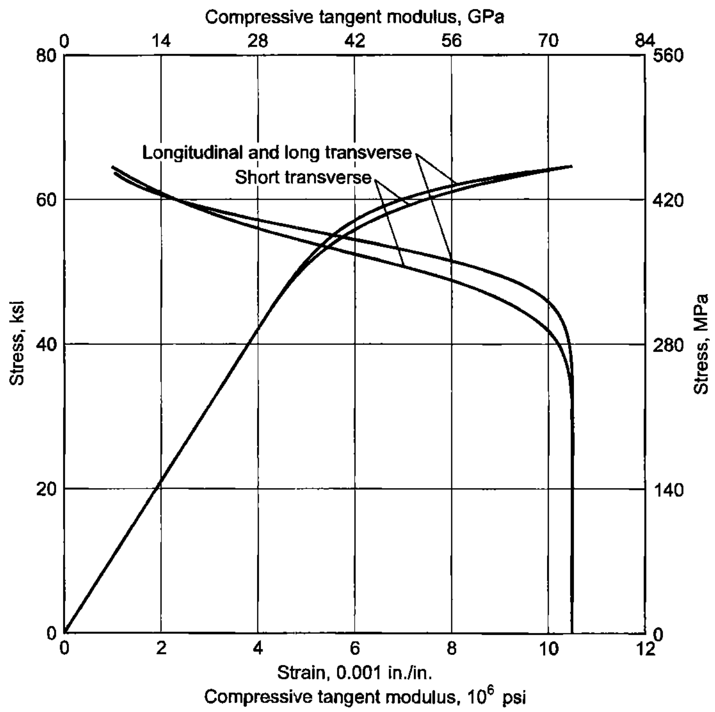
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–426



WA.316 7175-T7452 aluminum alloy hand forging, tensile stress-strain curves

Tested at room temperature. Typical for forging thickness 101.625–127.0 mm (4.001–5.000 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 12; *n*(long transverse, tension) = 13; *n*(short transverse, tension) = 10. Composition: Al-5.6Zn-2.5Mg-1.6Cu-0.23Cr. UNS A97175

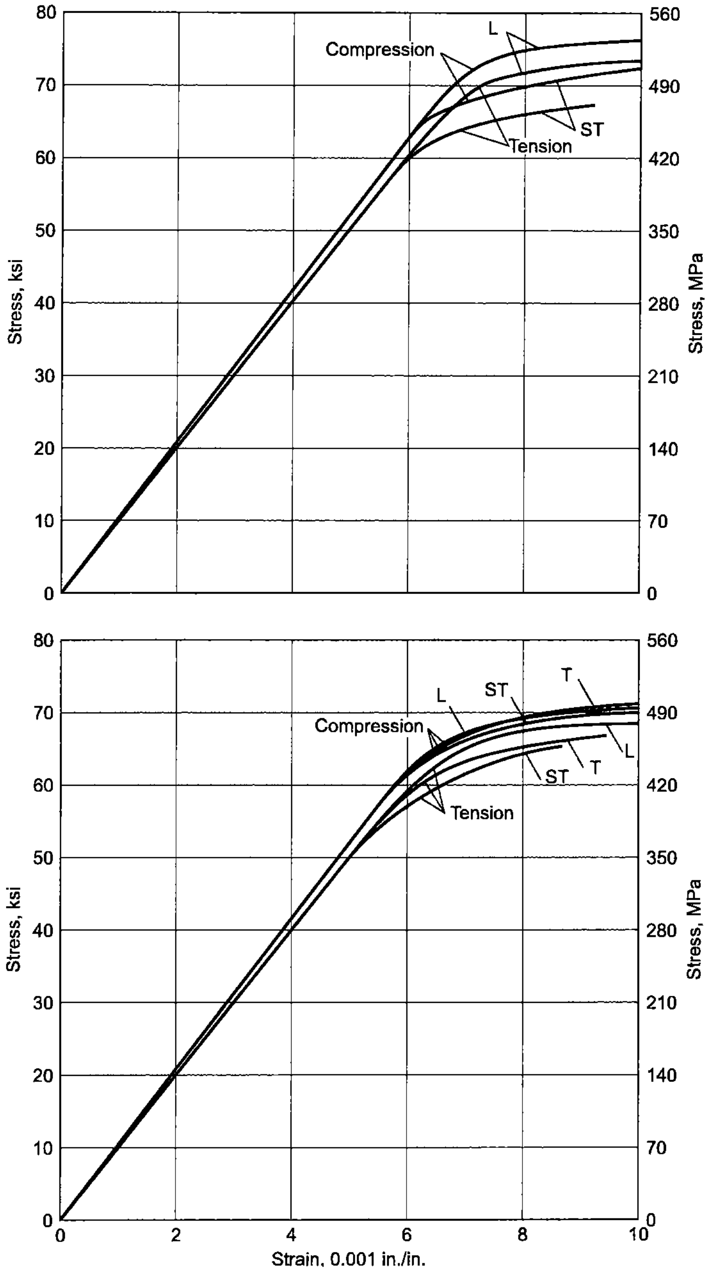
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–427



WA.317 7175-T7452 aluminum alloy hand forging, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for forging thickness 101.625–127.0 mm (4.001–5.000 in.). Ramberg-Osgood parameter, n(longitudinal, compression) = 13; n(long transverse, compression) = 15; n(short transverse, compression) = 17. Composition: Al-5.6Zn-2.5Mg-1.6Cu-0.23Cr. UNS A97175

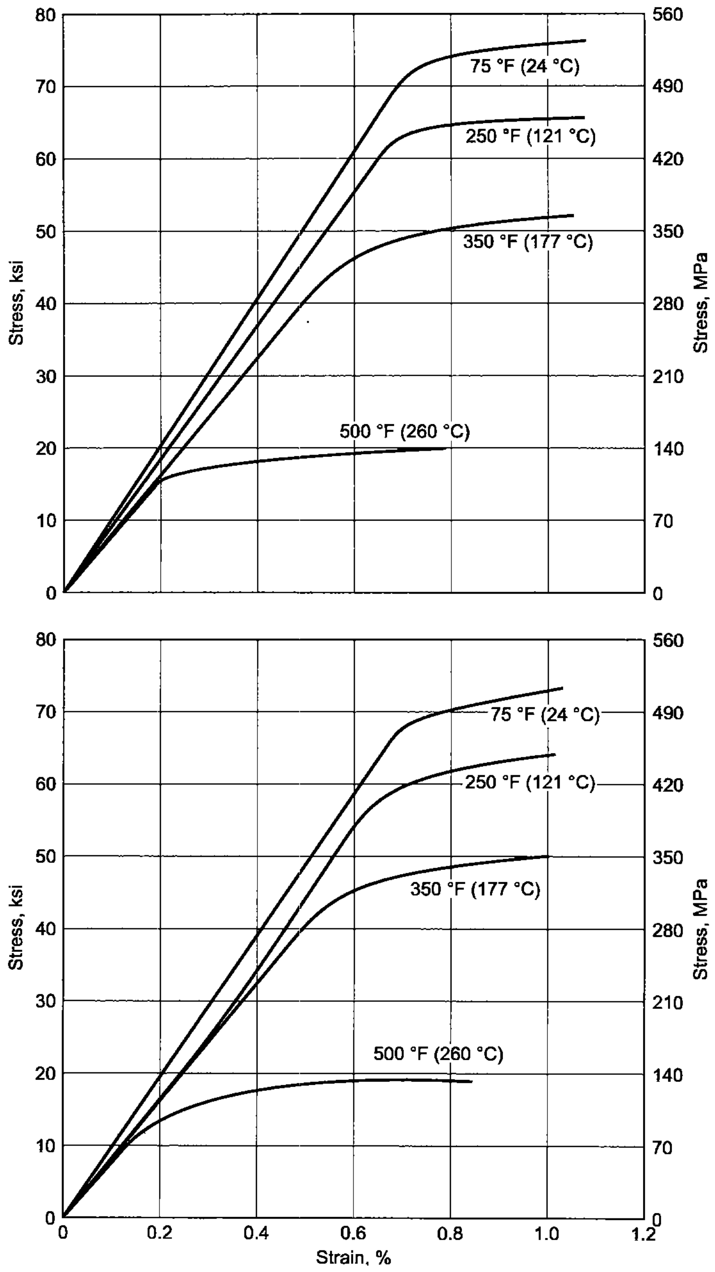
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–427



WA.318 7175-T74 aluminum alloy die (top) and hand forging (bottom), tensile and compressive stress-strain curves

Tested at room temperature. Test direction: L, longitudinal; T, transverse; ST, short transverse. Typical for die forging thickness ≤76.20 mm (≤3.000 in.) top, and hand forging thickness ≤101.60 mm (4.000 in.) bottom. Composition: Al-5.6Zn-2.5Mg-1.6Cu-0.23Cr-low Ti,Mn,Si. UNS A97175

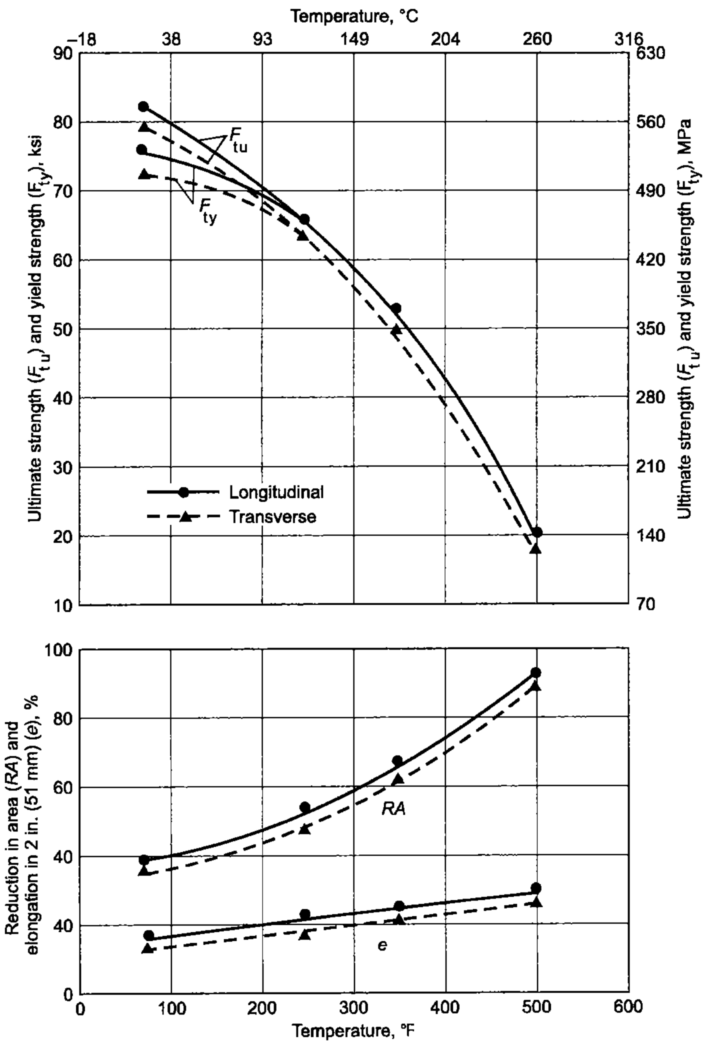
Source: C.F. Babilon, R.H. Wygonik, G.E. Nordmark, and B.W. Lifka, "Mechanical Properties, Fracture Toughness, Fatigue, Environmental Fatigue Crack Growth Rates, and Corrosion Characteristics of High Toughness Aluminum Alloy Forgings, Sheet and Plate," AFML-TR-73-83, Air Force Materials Laboratory, April 1973. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3219, CINDAS/Purdue University, 1995, p 10



WA.319 7175-T74 aluminum alloy forging, tensile stress-strain curves

Tested at various temperatures. Test direction: longitudinal (top) and transverse (bottom). Composition: Al-5.6Zn-2.5Mg-1.6Cu-0.23Cr-low Ti,Mn,Si.
UNS A97175

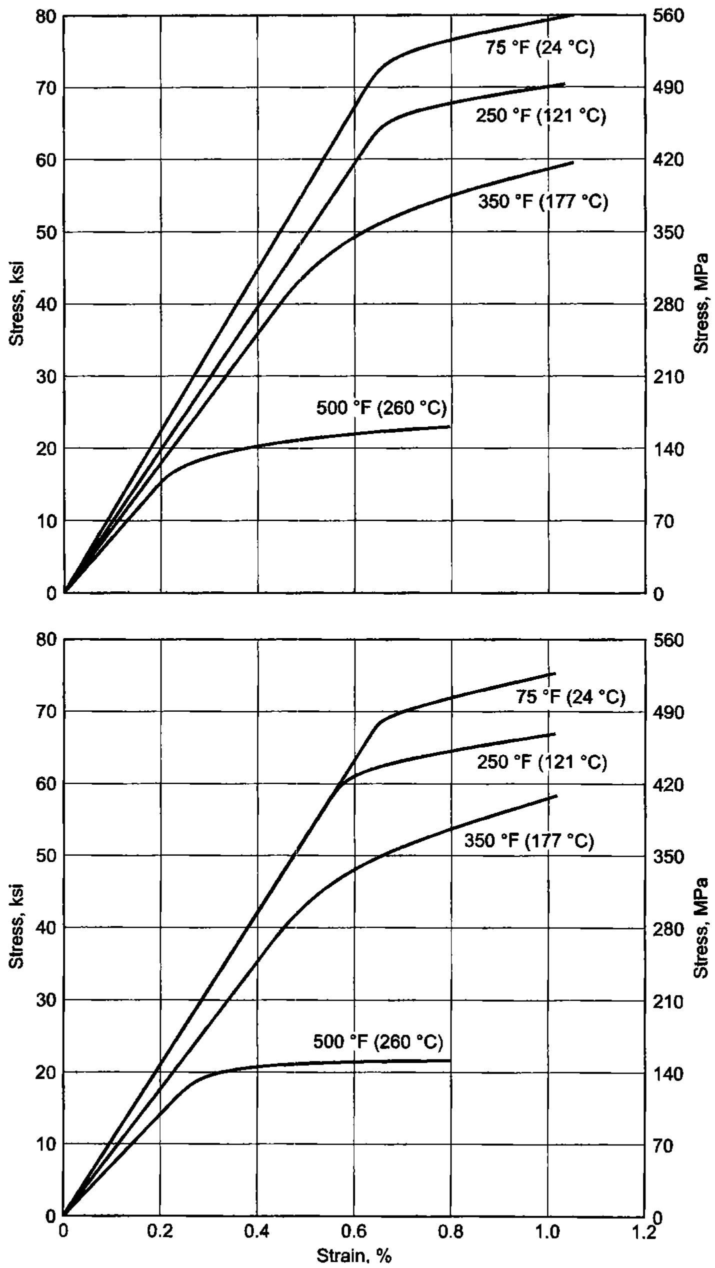
Source: AMS 4038A, 1966. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3219, CINDAS/Purdue University, 1995, p 12



WA.320 7175-T74 aluminum alloy forging, effect of temperature on tensile properties

Composition: Al-5.6Zn-2.5Mg-1.6Cu-0.23Cr-low Ti,Mn,Si. UNS A97175

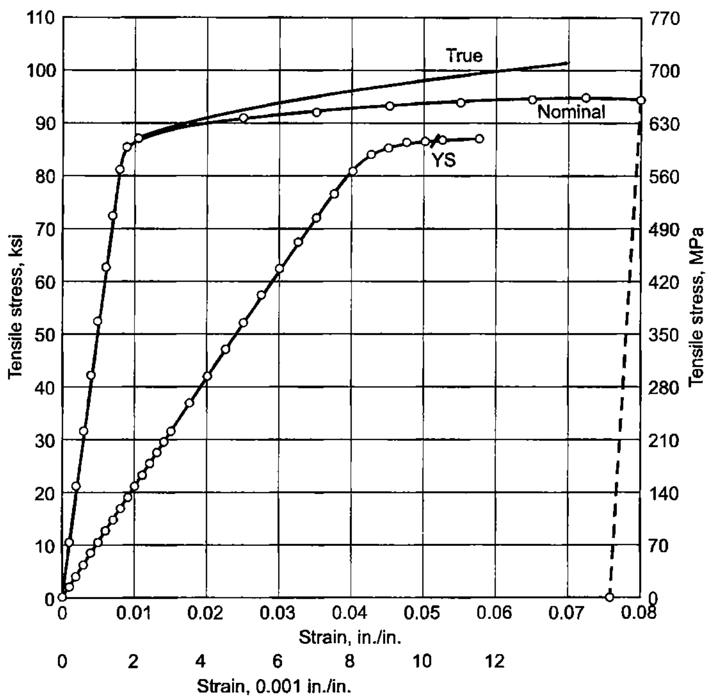
Source: AMS 4038A, 1966. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3219, CINDAS/Purdue University, 1995, p 14



WA.321 7175-T74 aluminum alloy forging, compressive stress strain curves

Tested at various temperatures. Test direction: longitudinal (top) and transverse (bottom). Composition: Al-5.6Zn-2.5Mg-1.6Cu-0.23Cr-low Ti,Mn,Si. UNS A97175

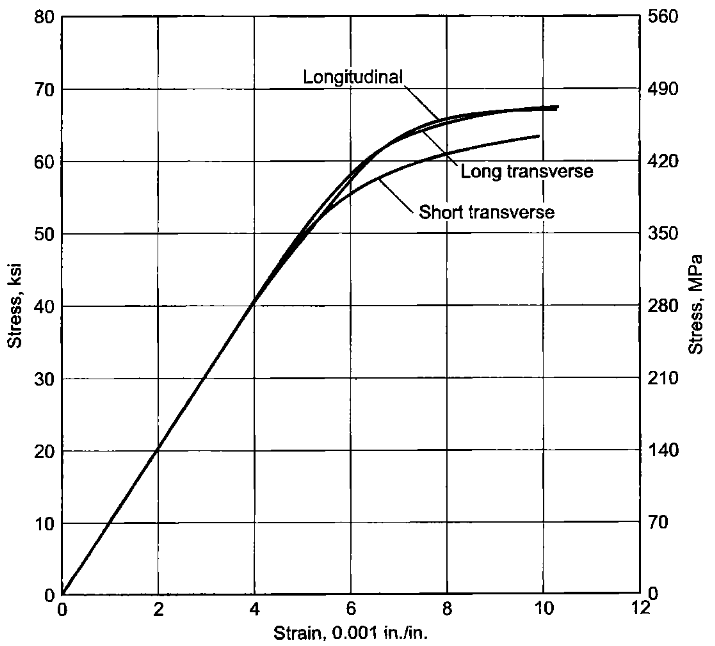
Source: AMS 4038A, 1966. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3219, CINDAS/Purdue University, 1995, p 14



WA.322 7178-T6 aluminum alloy extruded bar, tensile stress-strain curves

YS, yield strength. Nominal size: 15.9 × 76.2 mm (5/8 × 3 in.). Test specimen diam, 12.7 mm (0.5 in.). Gage length: 203.2 mm (8 in.). Nominal tensile strength, 655 MPa (95.0 ksi). True tensile strength, 703 MPa (102 ksi). Nominal yield strength (0.2% offset), 600 MPa (87.0 ksi). Elongation (in 50.8 mm, or 2 in.), 7.6%. Reduction of area, 14%. True strain at maximum load, 7.0%. A log-log plot of the stress-strain curve would yield a slope of (n) of 0.08 in the area of uniform plastic deformation. Composition: Al-6.8Zn-2.7Mg-2.0Cu-0.3Cr. UNS A97178

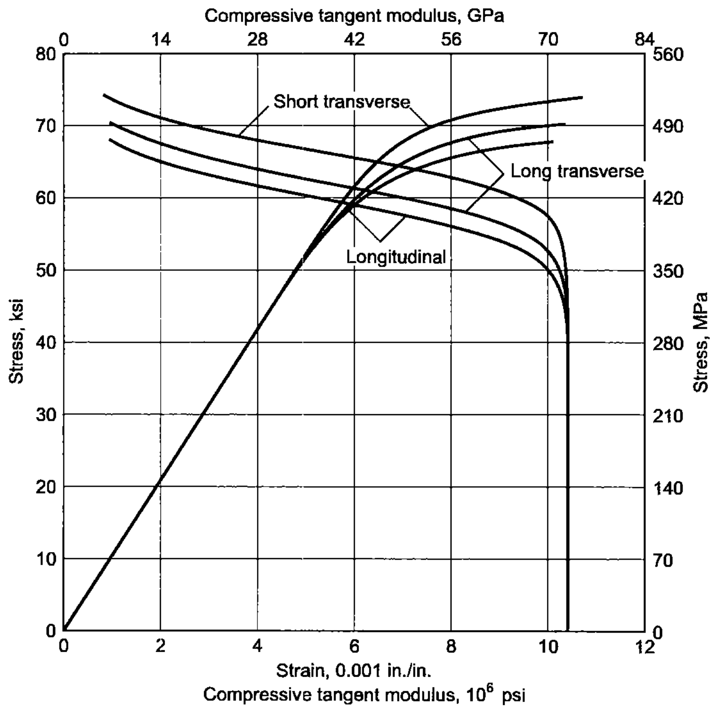
Source: Alcoa, Aluminum Research Laboratory, New Kensington, PA



WA.323 7249-T7452 aluminum alloy hand forging, tensile stress-strain curves

Tested at room temperature. Ramberg-Osgood parameter, n(longitudinal, tension) = 26.0; n(long transverse, tension) = 24.0; n(short transverse, tension) = 14.0. Tensile yield strength: longitudinal = 461.6 MPa (67.0 ksi); long transverse = 454.7 MPa (66.0 ksi); short transverse = 420.3 MPa (61.0 ksi). Composition: Al-4.7Zn-2.2Mg-1.6Cu-0.15Cr. UNS A97249

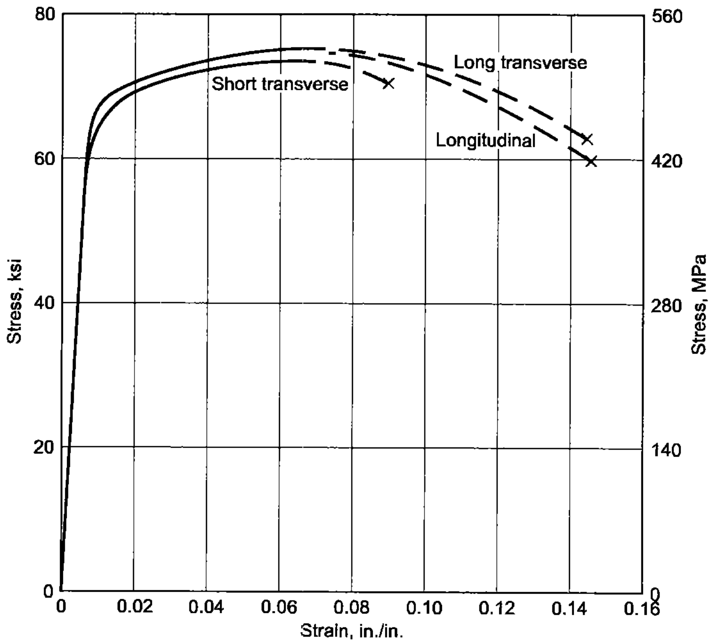
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–432



WA.324 7249-T7452 aluminum alloy hand forging, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Ramberg-Osgood parameter, n(longitudinal, compression) = 20.0; n(long transverse, compression) = 20.0; n(short transverse, compression) = 23.0. Tensile yield strength: longitudinal = 420.3 MPa (61.0 ksi); long transverse = 475.4 MPa (69.0 ksi); short transverse = 496.1 MPa (72.0 ksi). Composition: Al-4.7Zn-2.2Mg-1.6Cu-0.15Cr. UNS A97249

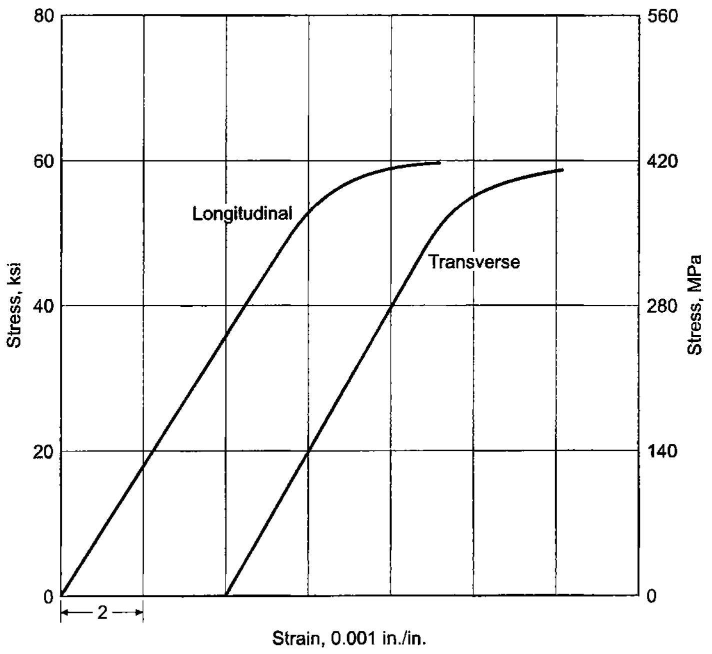
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–432



WA.325 7249-T7452 aluminum alloy hand forging, tensile stress-strain curves (full range)

Tested at room temperature. Typical for forging thickness: in longitudinal and long transverse directions, 38.10–152.40 mm (1.500–6.000 in.); in short transverse direction, 76.20–152.40 mm (3.000–6.000 in.). Composition: Al-4.7Zn-2.2Mg-1.6Cu-0.15Cr. UNS A97249

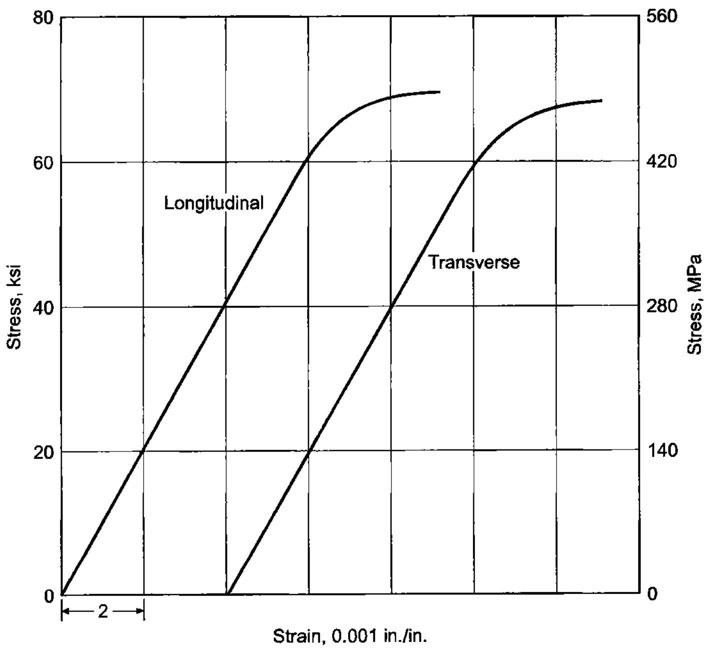
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–433



WA.326 7475-T7351 aluminum alloy plate, tensile stress-strain curves

Plate thickness: 38.1 mm (1.5 in.). Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

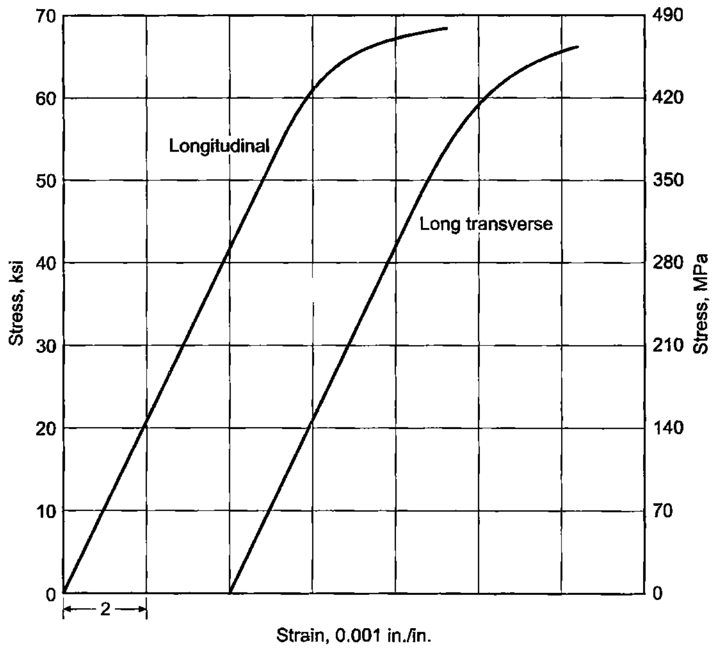
Source: R.R. Cervay, "Static & Dynamic Fracture Properties for Aluminum Alloy 7475-T651 and T7351," AFML-TR-75-20, Air Force Materials Laboratory, April 1975. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3220, CINDAS/Purdue University, 1995, p 12



WA.327 7475-T651 aluminum alloy plate, tensile stress-strain curves

Plate thickness: 38.1 mm (1.5 in.). Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

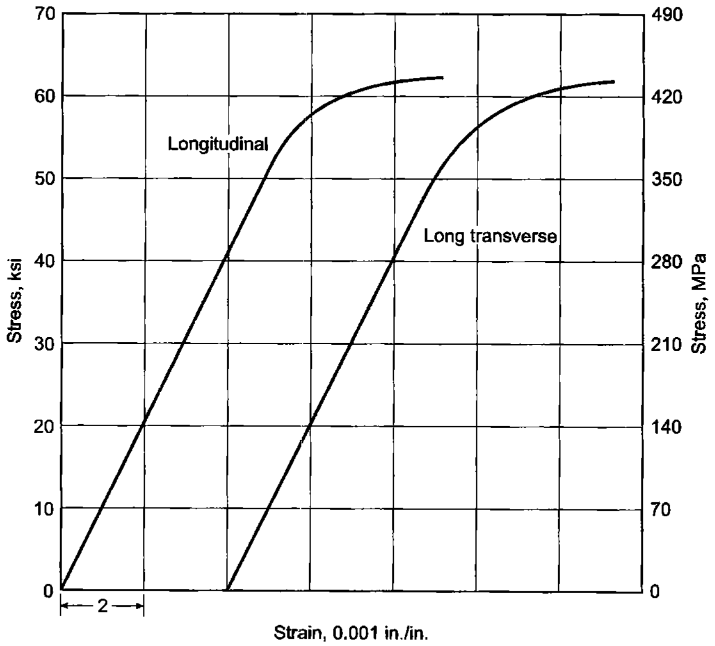
Source: R.R. Cervay, "Static & Dynamic Fracture Properties for Aluminum Alloy 7475-T651 and T7351," AFML-TR-75-20, Air Force Materials Laboratory, April 1975. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3220, CINDAS/Purdue University, 1995, p 12



WA.328 7475-T61 aluminum alloy clad sheet, tensile stress-strain curves

Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

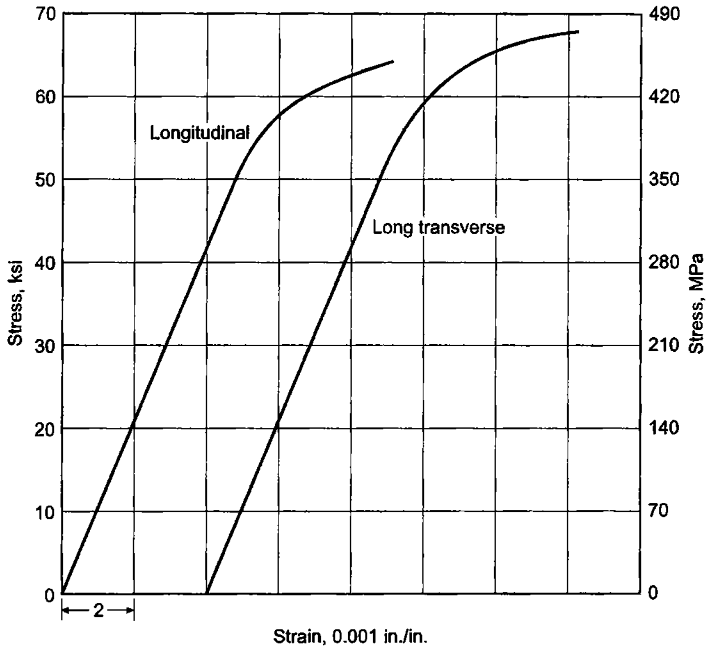
Source: J.A. Dickson, "Alcoa 467 Process X7475 Alloy," Alcoa Green Letter G.L. 216 5-70, Aluminum Co. of America, May 1970. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3220, CINDAS/Purdue University, 1995, p 12



WA.329 7475-T761 aluminum alloy clad sheet, tensile stress-strain curves

Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

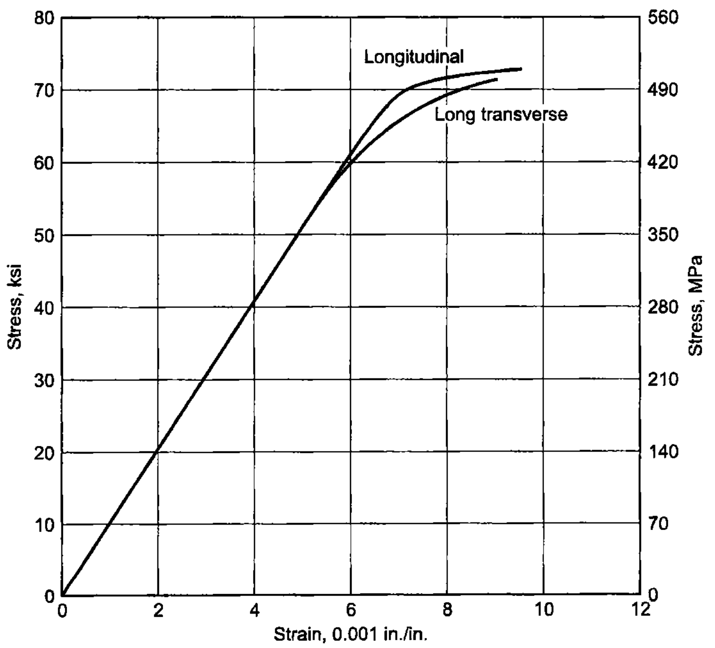
Source: J.A. Dickson, "Alcoa 467 Process X7475 Alloy," Alcoa Green Letter G.L. 216 5-70, Aluminum Co. of America, May 1970. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3220, CINDAS/Purdue University, 1995, p 12



WA.330 7475-T761 aluminum alloy clad sheet, compressive stress-strain curves

Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

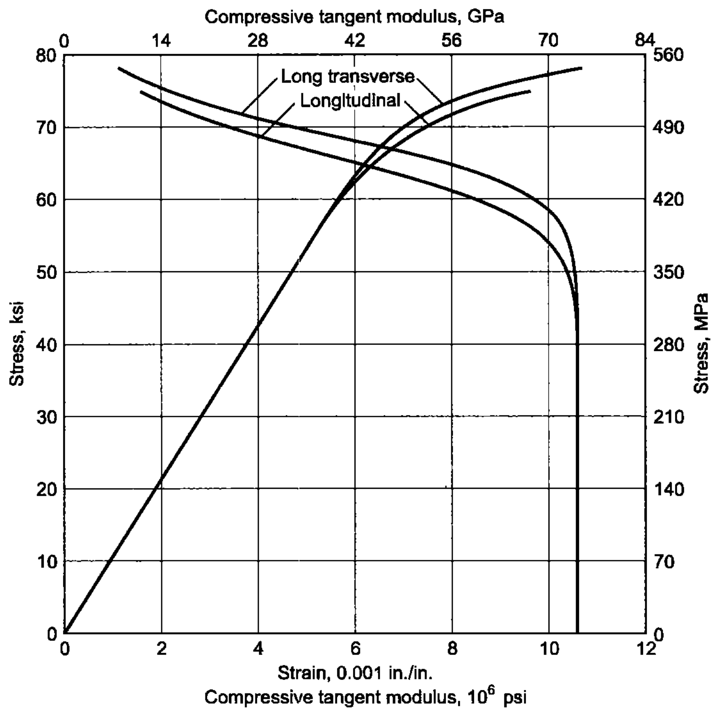
Source: J.A. Dickson, "Alcoa 467 Process X7475 Alloy," Alcoa Green Letter G.L. 216 5-70, Aluminum Co. of America, May 1970. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3220, CINDAS/Purdue University, 1995, p 16



WA.331 7475-T651 aluminum alloy plate, tensile stress-strain curves

Tested at room temperature. Typical for plate thickness 6.350–38.10 mm (0.250–1.500 in.). Ramberg-Osgood parameter, n(longitudinal, tension) = 50; n(long transverse, tension) = 15. Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

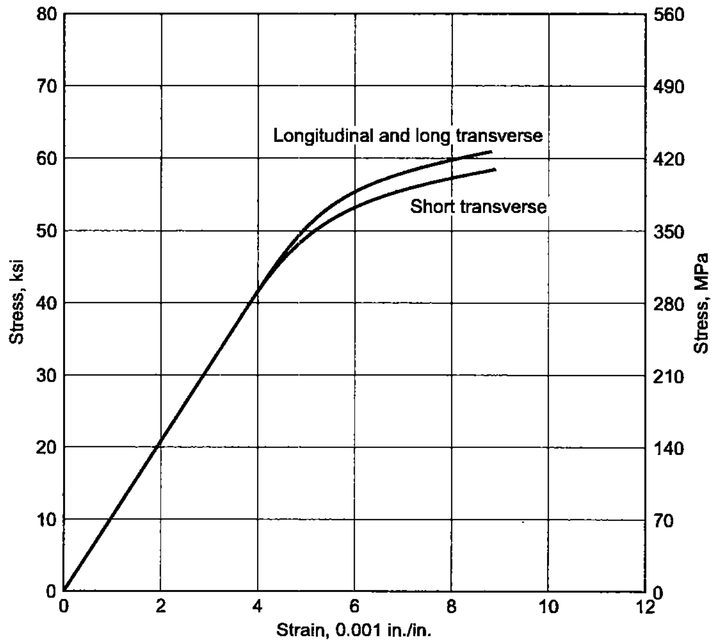
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–441



WA.332 7475-T651 aluminum alloy plate, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for plate thickness 6.350–38.10 mm (0.250–1.500 in.). Ramberg-Osgood parameter, n(longitudinal, compression) = 15; n(long transverse, compression) = 18. Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

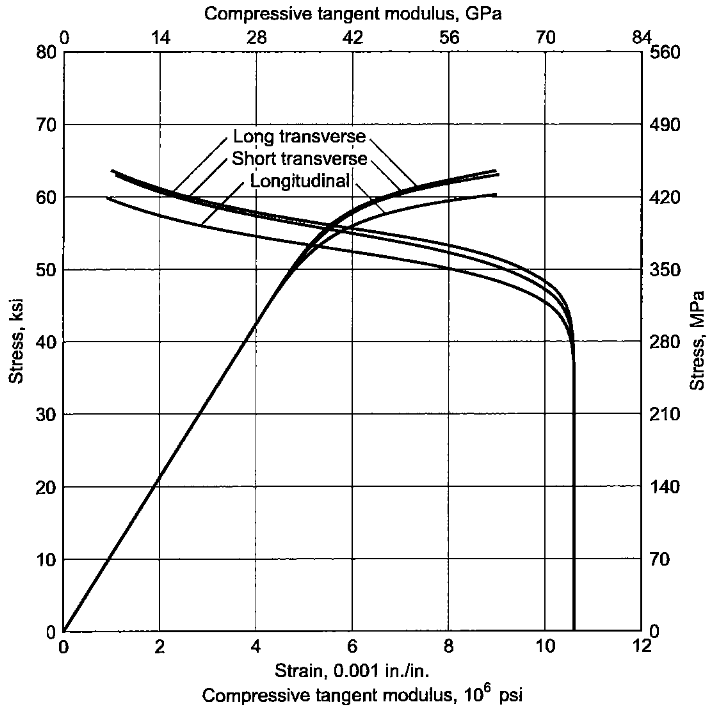
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–441



WA.333 7475-T7351 aluminum alloy plate, tensile stress-strain curves

Tested at room temperature. Typical for plate thickness 12.70–101.60 mm (0.500–4.000 in.). Ramberg-Osgood parameter, n(longitudinal, tension) = 15; n(long transverse, tension) = 13; n(short transverse, tension) = 13. Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

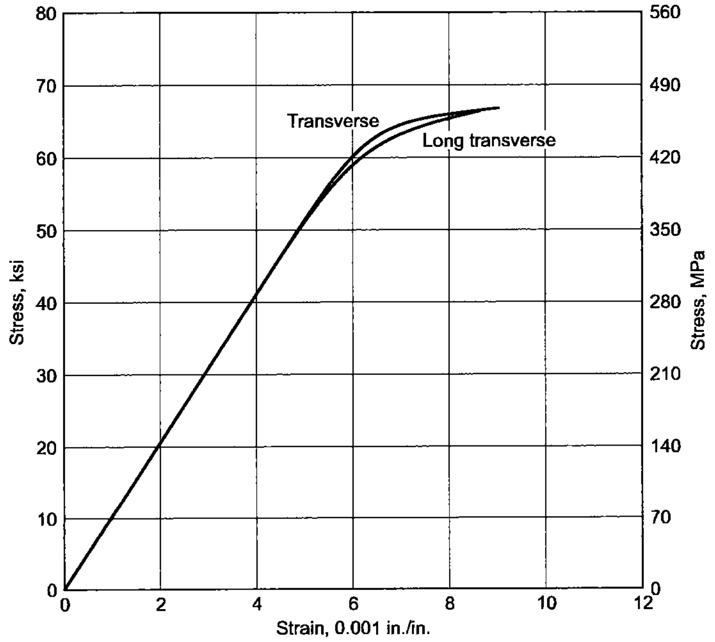
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–448



WA.334 7475-T7351 aluminum alloy plate, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for plate thickness 12.70–101.60 mm (0.500–4.000 in.). Ramberg-Osgood parameter, *n*(longitudinal, compression) = 20; *n*(long transverse, compression) = 20; *n*(short transverse, compression) = 19. Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

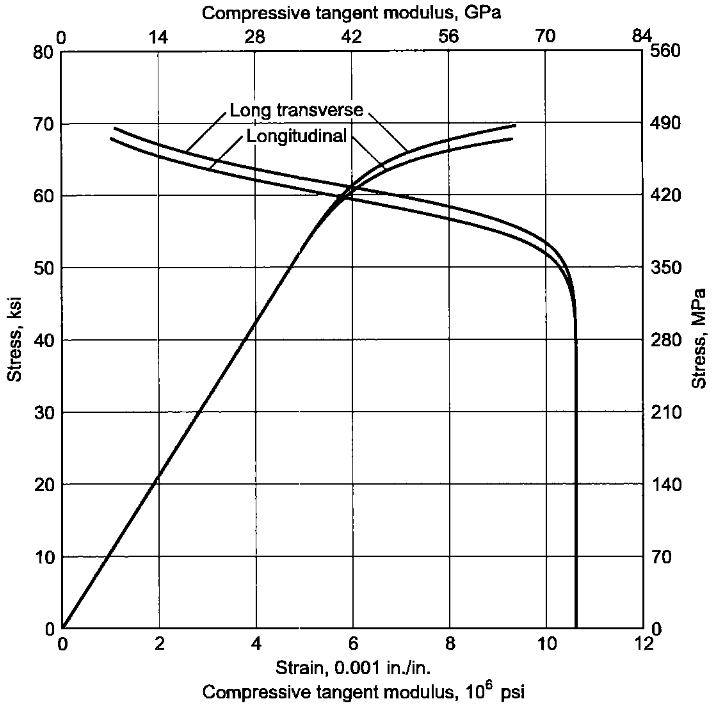
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–448



WA.335 7475-T7651 aluminum alloy plate, tensile stress-strain curves

Tested at room temperature. Typical for plate thickness 6.350–38.10 mm (0.250–1.500 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 33; *n*(long transverse, tension) = 19. Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

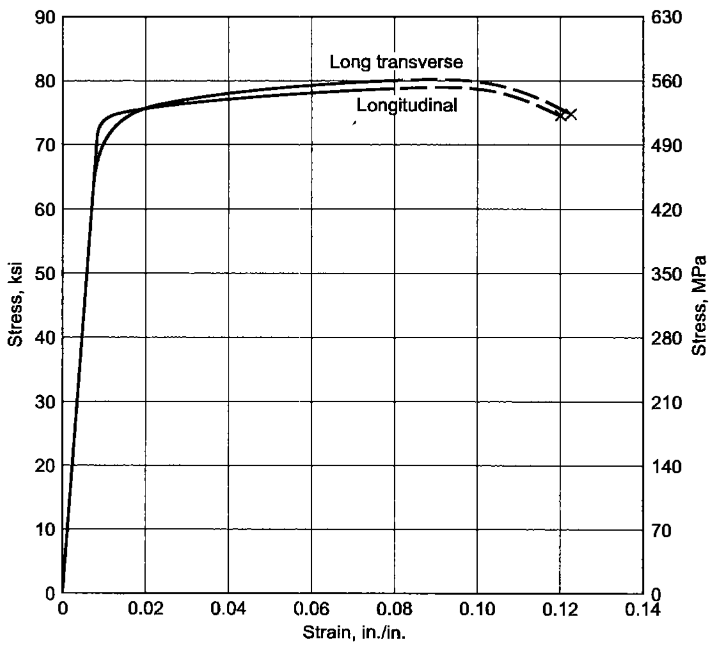
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–458



WA.336 7475-T7651 aluminum alloy plate, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for plate thickness 6.350–38.10 mm (0.250–1.500 in.). Ramberg-Osgood parameter, *n*(longitudinal and long transverse, compression) = 20. Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

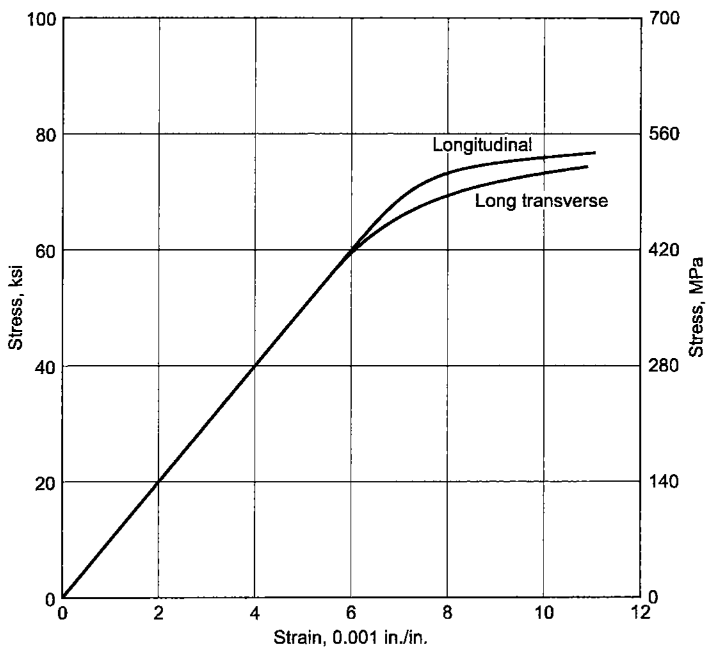
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–458



WA.337 7475-T61 aluminum alloy sheet, tensile stress-strain curves (full range)

Tested at room temperature. Typical for sheet thickness 1.016–6.325 mm (0.040–0.249 in.). Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti.
UNS A97475

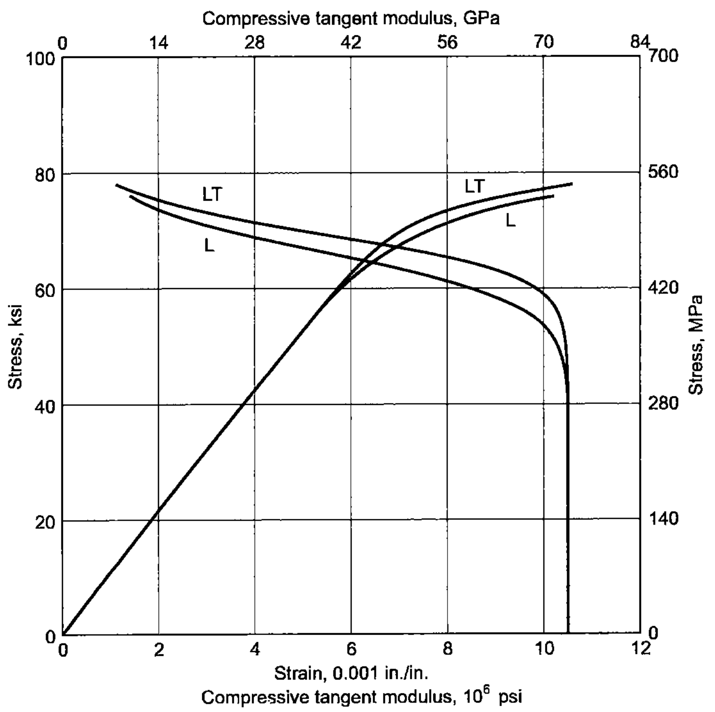
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–442



WA.338 7475-T61 aluminum alloy sheet, tensile stress-strain curves (expanded portion)

Tested at room temperature. Typical for sheet thickness 1.016–6.325 mm (0.040–0.249 in.). Ramberg-Osgood parameter, n(longitudinal, tension) = 33; n(long transverse, tension) = 16. Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

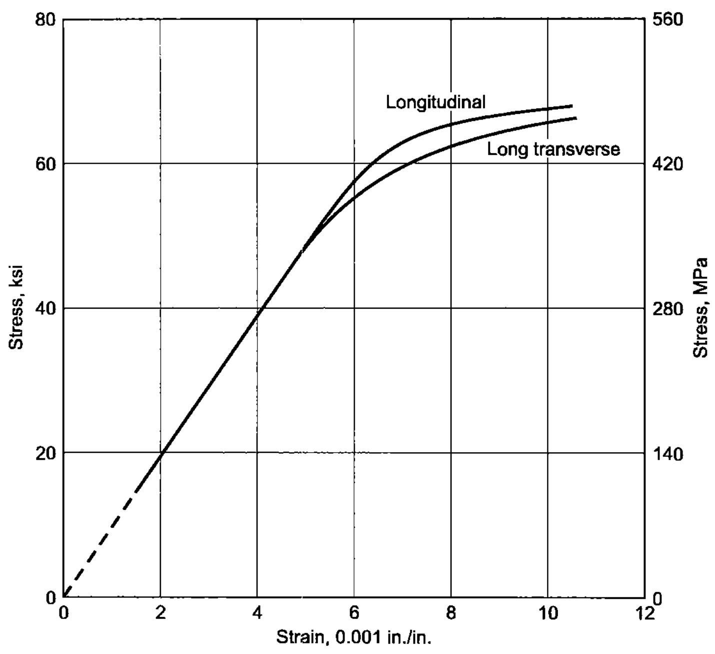
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–439



WA.339 7475-T61 aluminum alloy sheet, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Test direction: L, longitudinal; LT, long transverse. Typical for sheet thickness 1.016–6.325 mm (0.040–0.249 in.). Ramberg-Osgood parameter, n(longitudinal, compression) = 15; n(long transverse, compression) = 19. Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

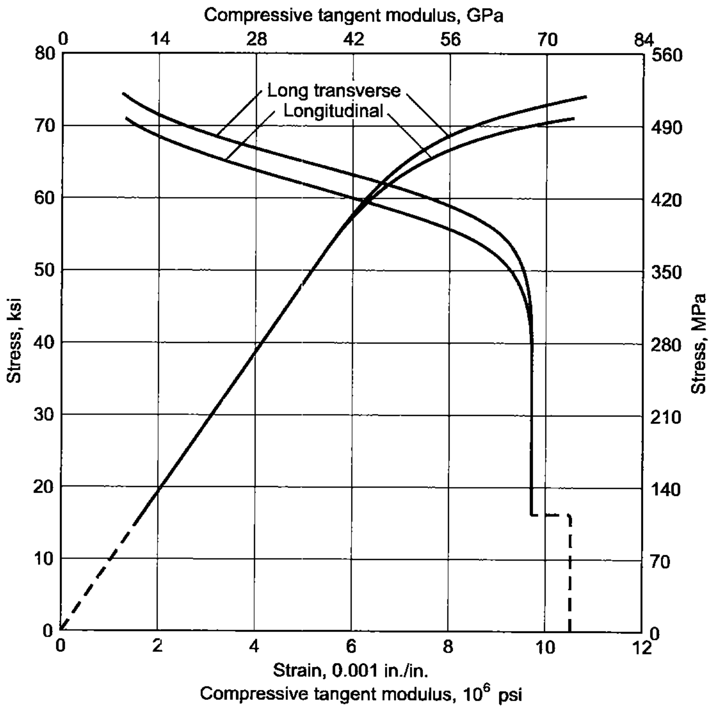
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–439



WA.340 7475-T61 aluminum alloy clad sheet, tensile stress-strain curves

Tested at room temperature. Typical for sheet thickness 1.6–4.75 mm (0.063–0.187 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 26; *n*(long transverse, tension) = 14. Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

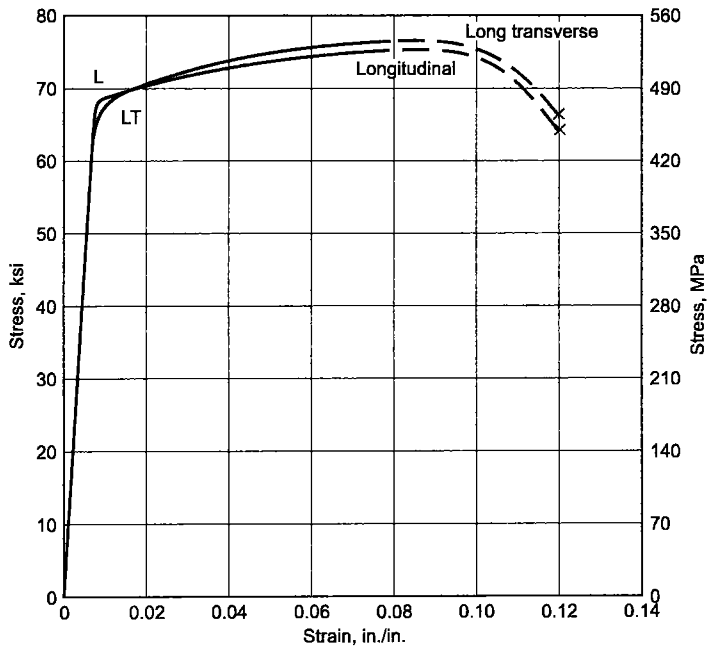
Source: *MIL-HDBK-5H*, 1 Dec 1998, p 3–440



WA.341 7475-T61 aluminum alloy clad sheet, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for sheet thickness 1.600–4.750 mm (0.063–0.187 in.). Ramberg-Osgood parameter, *n*(longitudinal, compression) = 15; *n*(long transverse, compression) = 16. Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

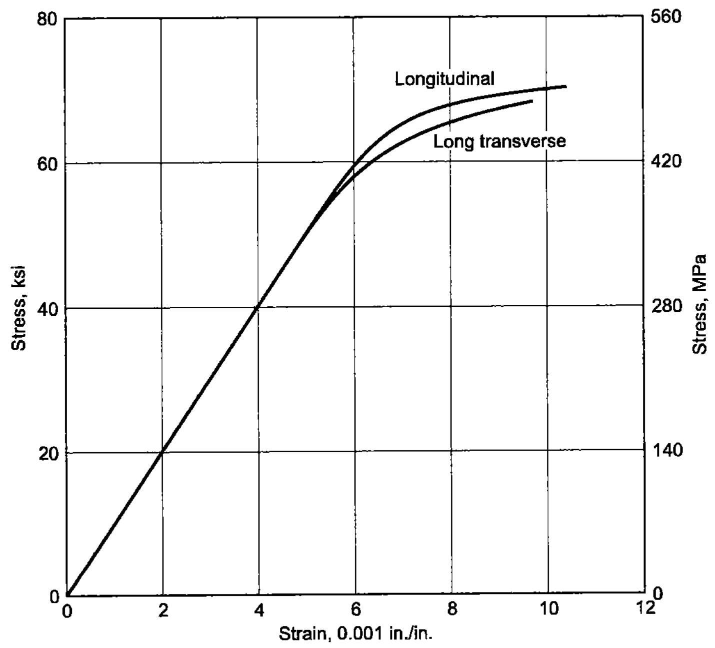
Source: *MIL-HDBK-5H*, 1 Dec 1998, p 3–440



WA.342 7475-T761 aluminum alloy sheet, tensile stress-strain curves (full range)

Tested at room temperature. Typical for sheet thickness 1.016–6.325 mm (0.040–0.249 in.). Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

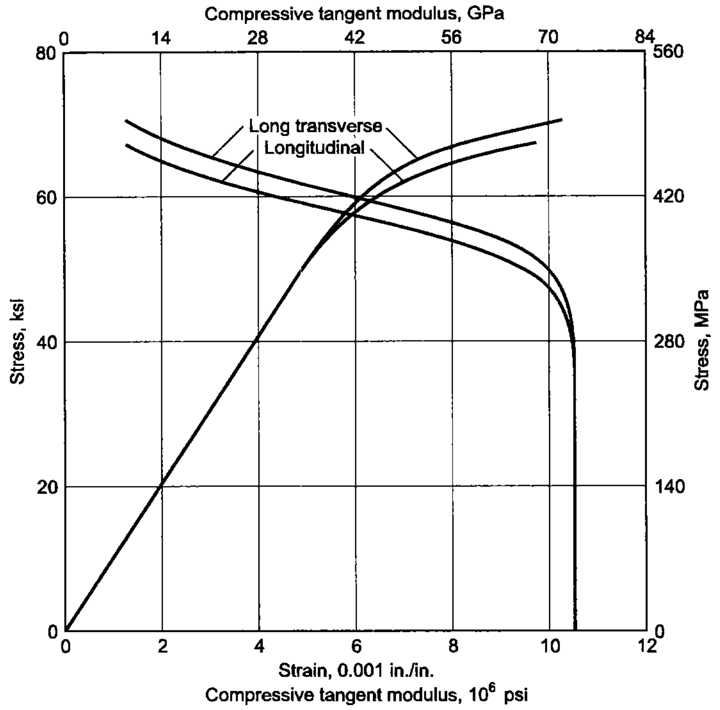
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–459



WA.343 7475-T761 aluminum alloy sheet, tensile stress-strain curves

Tested at room temperature. Typical for sheet thickness 1.016–6.325 mm (0.040–0.249 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 26; *n*(long transverse, tension) = 16. Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

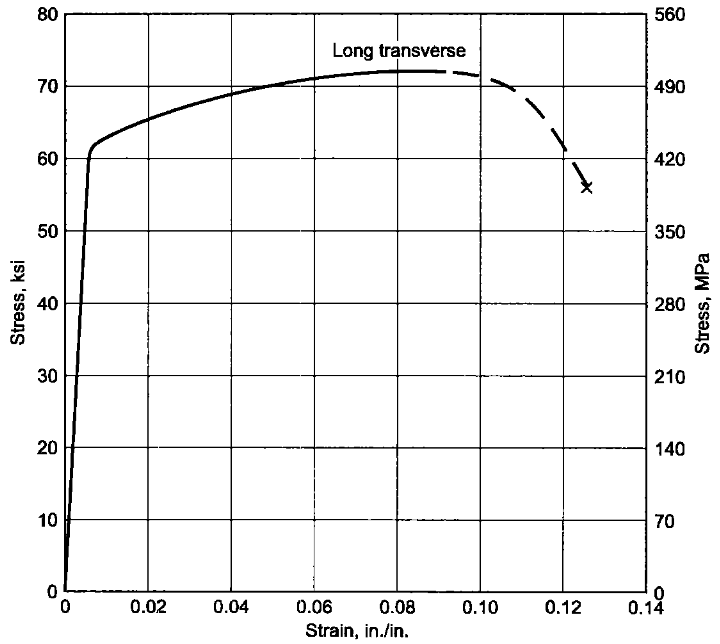
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–454



WA.344 7475-T761 aluminum alloy sheet, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for sheet thickness 1.016–6.325 mm (0.040–0.249 in.). Ramberg-Osgood parameter, *n*(longitudinal, compression) = 15; *n*(long transverse, compression) = 19. Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

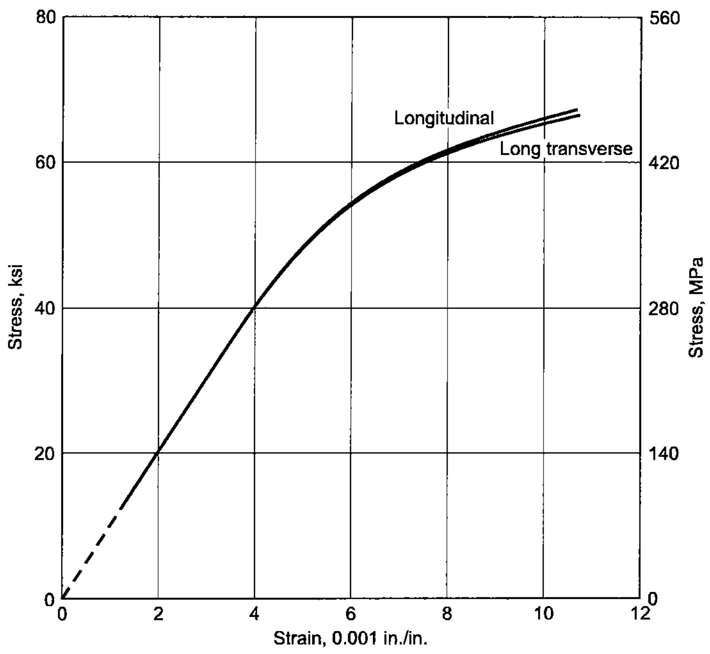
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–454



WA.345 7475-T761 aluminum alloy clad sheet, tensile stress-strain curve (full range)

Tested at room temperature. Typical for sheet thickness 1.016–6.325 mm (0.040–0.249 in.). Based on two lots. Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

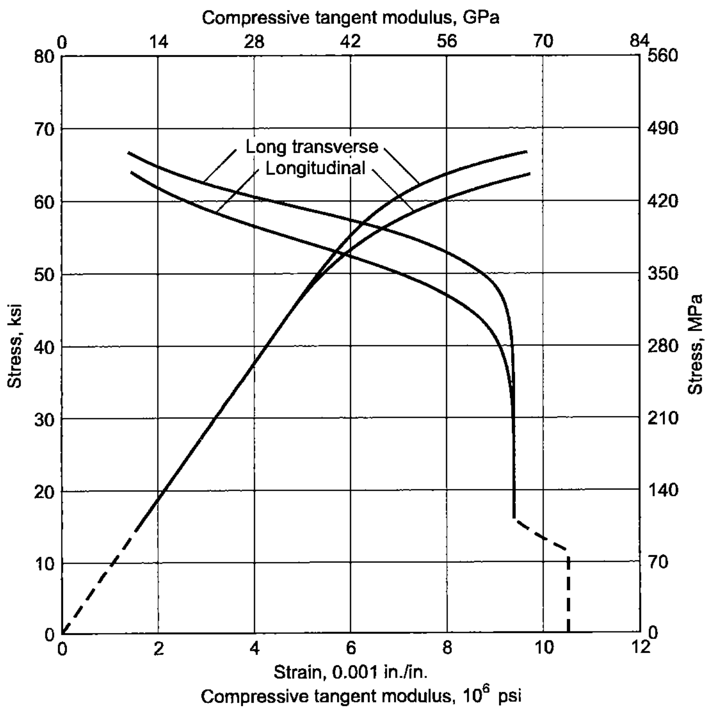
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–460



WA.346 7475-T761 aluminum alloy clad sheet, tensile stress-strain curves

Tested at room temperature. Typical for sheet thickness 1.016–1.575 mm (0.040–0.062 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 9.0; *n*(long transverse, tension) = 9.1. Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

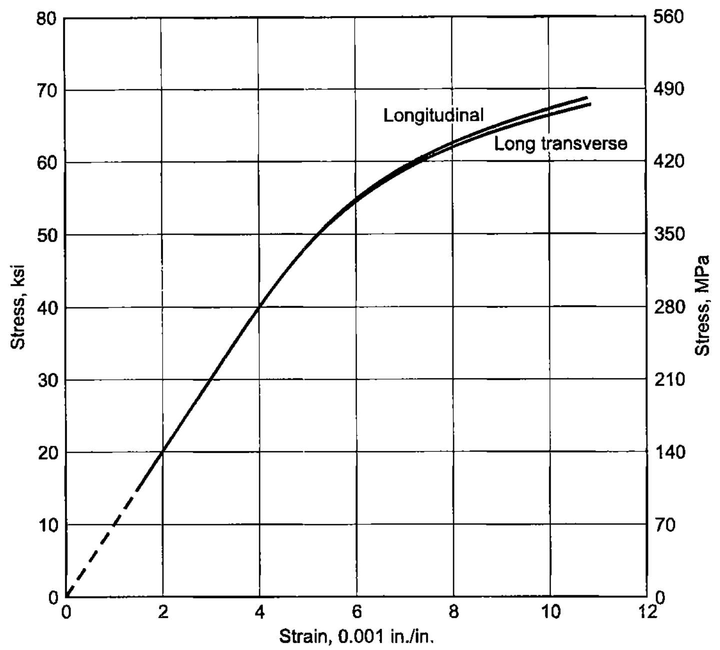
Source: *MIL-HDBK-5H*, 1 Dec 1998, p 3–455



WA.347 7475-T761 aluminum alloy clad sheet, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for sheet thickness 1.016–1.575 mm (0.040–0.062 in.). Ramberg-Osgood parameter, *n*(longitudinal, compression) = 12; *n*(long transverse, compression) = 16. Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

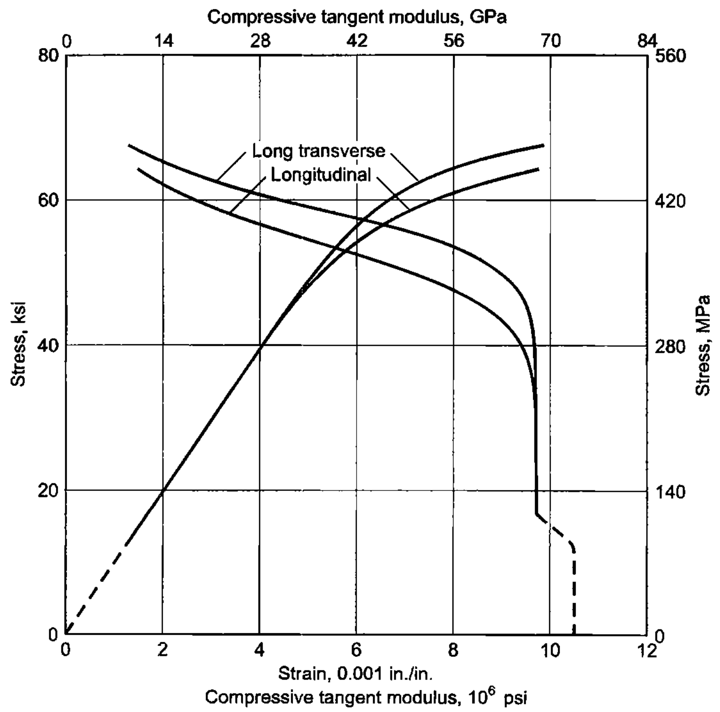
Source: *MIL-HDBK-5H*, 1 Dec 1998, p 3–456



WA.348 7475-T761 aluminum alloy clad sheet, tensile stress-strain curves

Tested at room temperature. Typical for sheet thickness 1.600–4.750 mm (0.063–0.187 in.). Ramberg-Osgood parameter, n(longitudinal, tension) = 9.0; n(long transverse, tension) = 9.1. Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

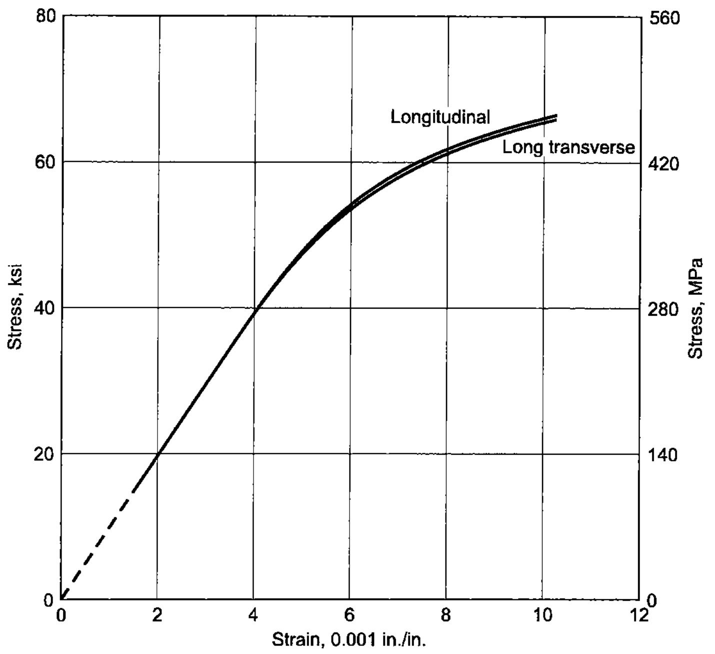
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–455



WA.349 7475-T761 aluminum alloy clad sheet, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for sheet thickness 1.600–4.750 mm (0.063–0.187 in.). Ramberg-Osgood parameter, n(longitudinal, compression) = 12; n(long transverse, compression) = 16. Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

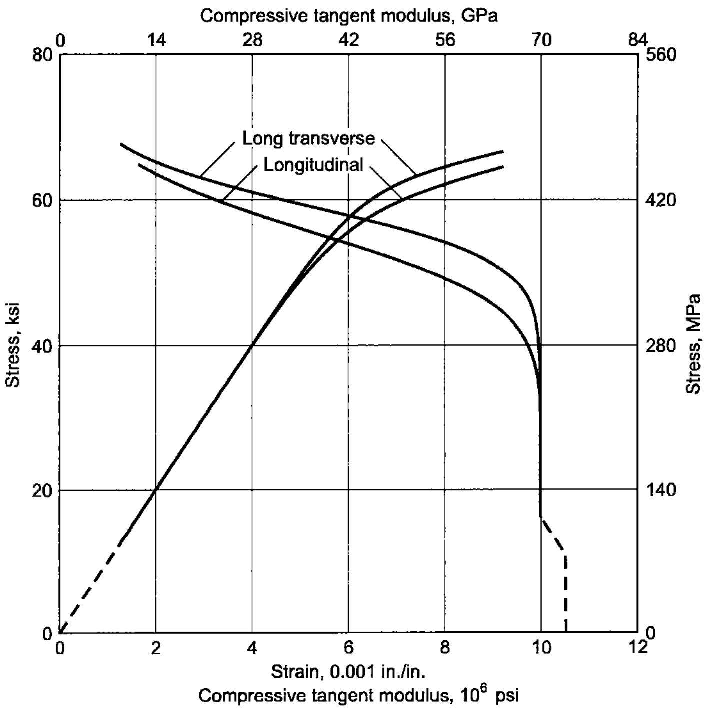
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–457



WA.350 7475-T761 aluminum alloy clad sheet, tensile stress-strain curves

Tested at room temperature. Typical for sheet thickness 4.775–6.325 mm (0.188–0.249 in.). Ramberg-Osgood parameter, *n*(longitudinal, tension) = 9.0; *n*(long transverse, tension) = 9.1. Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

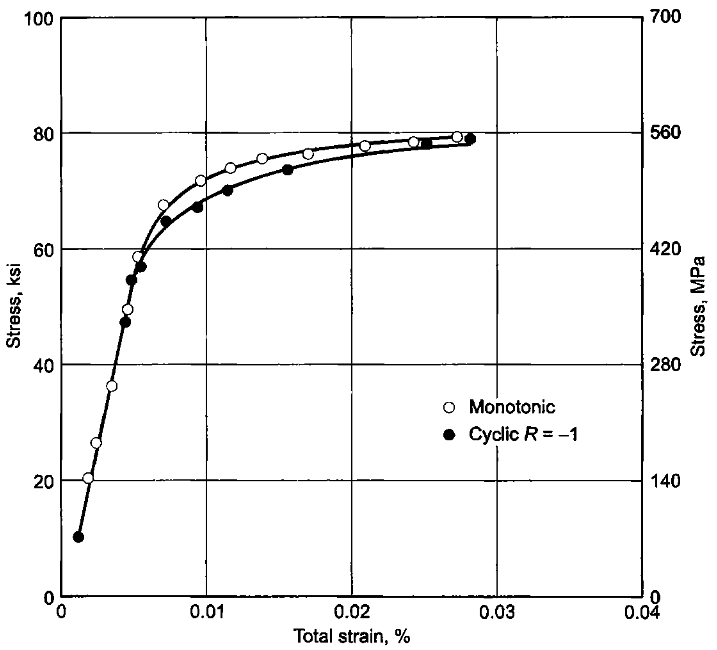
Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–456



WA.351 7475-T761 aluminum alloy clad sheet, compressive stress-strain and compressive tangent modulus curves

Tested at room temperature. Typical for sheet thickness 4.775–6.325 mm (0.188–0.249 in.). Ramberg-Osgood parameter, *n*(longitudinal, compression) = 12; *n*(long transverse, compression) = 16. Composition: Al-5.6Zn-2.2Mg-1.5Cu-0.21Cr-low Si,Fe,Mn,Ti. UNS A97475

Source: *MIL-HDBK-5H,* 1 Dec 1998, p 3–457

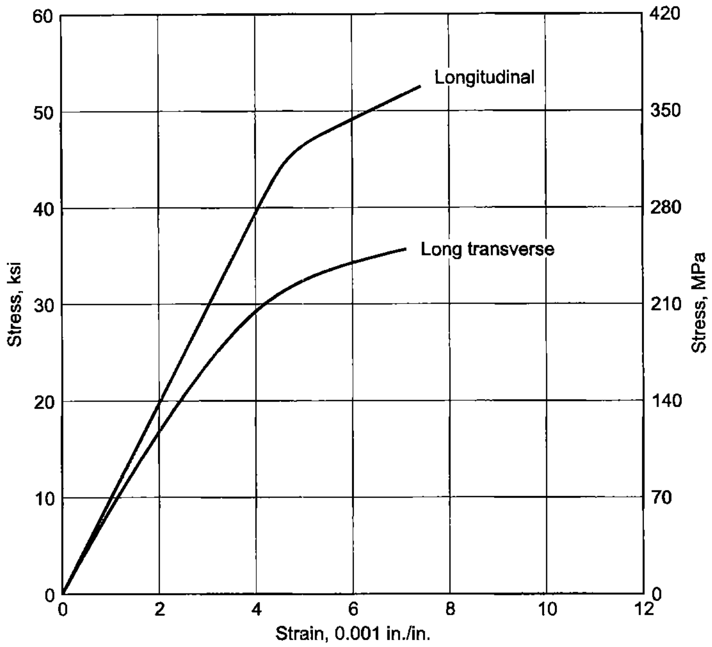


WA.352 8090-T8 aluminum alloy plate, monotonic and stabilized cyclic stress-strain curves

Solution heat treated with cold water quench followed by 3% stretch and artificial aging at 198 °C (389 °F) for 16 h. Test direction: Longitudinal. Composition: Al-2.5Li-1.3Cu-1.0Mg. UNS A98090

Source: K.T. Venkateswara Rao and R.O. Ritchie, Fatigue of Aluminum Lithium Alloys, *Int. Mater. Rev.*, 1992. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3225, CINDAS/Purdue University, 1995, p 26

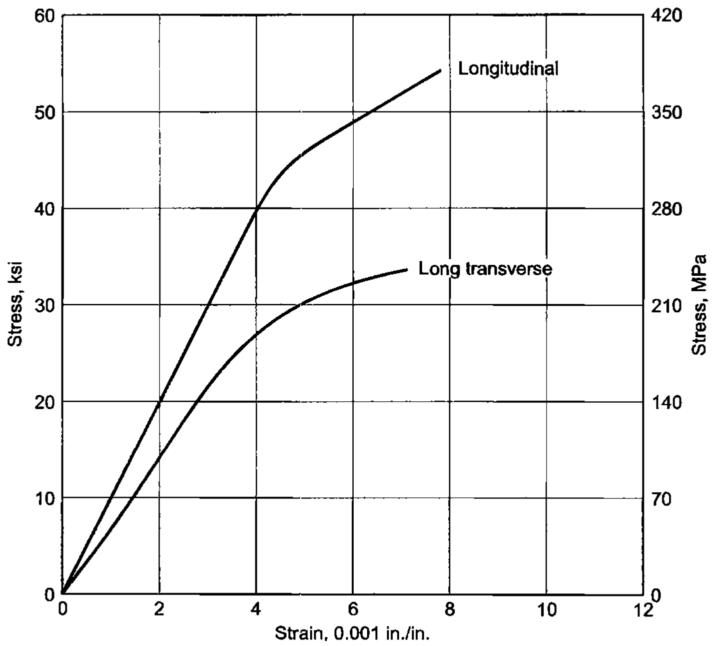
Aluminum Laminates (LA)



LA.001 2024-T3 aluminum alloy, aramid-fiber-reinforced sheet laminate (AMS 4254), 2/1 lay-up, typical tensile stress-strain curves

Thickness, 0.81 mm (0.032 in.). Ultimate tensile strength: longitudinal, 621 MPa (90 ksi); long transverse, 331 MPa (48 ksi). Tensile yield strength: longitudinal, 331 MPa (48 ksi); long transverse, 228 MPa (33 ksi). Ramberg-Osgood parameter, n(long transverse, tension) = 12

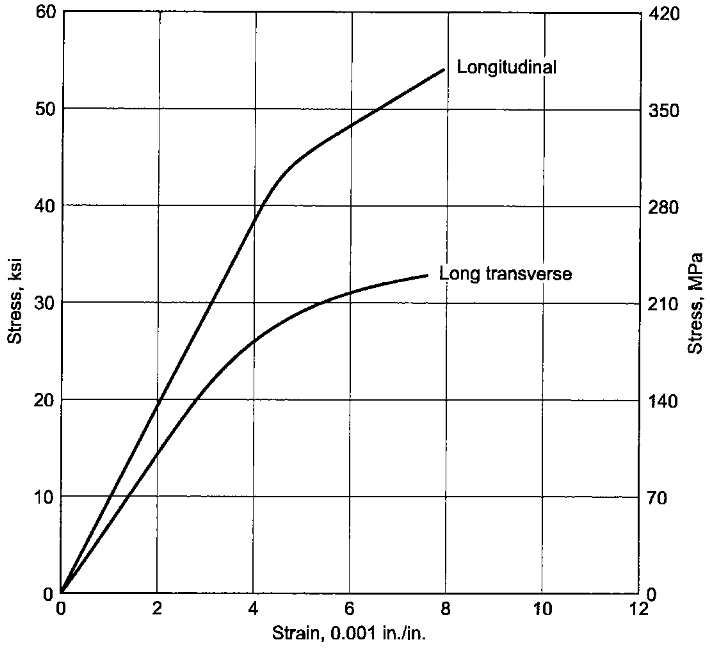
Source: *MIL-HDBK-5H,* Dec 1998, p 7–34



LA.002 2024-T3 aluminum alloy, aramid-fiber-reinforced sheet laminate (AMS 4254), 3/2 lay-up, typical tensile stress-strain curves

Thickness, 1.35 mm (0.053 in.). Ultimate tensile strength: longitudinal, 662 MPa (96 ksi); long transverse, 303 MPa (44 ksi). Tensile yield strength: longitudinal, 338 MPa (49 ksi); long transverse, 207 MPa (30 ksi). Ramberg-Osgood parameter, n(long transverse, tension) = 9.9

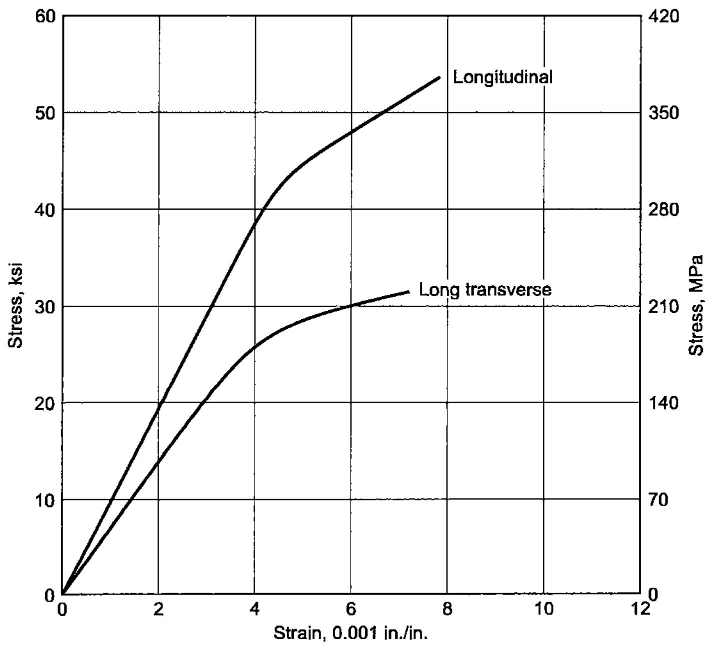
Source: *MIL-HDBK-5H,* Dec 1998, p 7–34



LA.003 2024-T3 aluminum alloy, aramid-fiber-reinforced sheet laminate (AMS 4254), 4/3 lay-up, typical tensile stress-strain curves

Thickness, 1.88 mm (0.074 in.). Ultimate tensile strength: longitudinal, 696 MPa (101 ksi); long transverse, 296 MPa (43 ksi). Tensile yield strength: longitudinal, 338 MPa (49 ksi); long transverse, 207 MPa (30 ksi). Ramberg-Osgood parameter, n(long transverse, tension) = 11

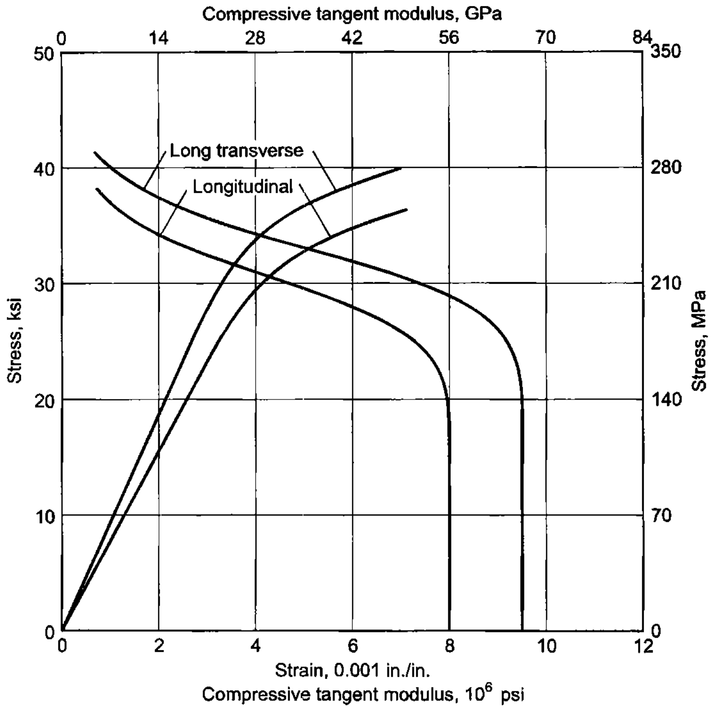
Source: *MIL-HDBK-5H*, Dec 1998, p 7–35



LA.004 2024-T3 aluminum alloy, aramid-fiber-reinforced sheet laminate (AMS 4254), 5/4 lay-up, typical tensile stress-strain curves

Thickness, 2.39 mm (0.094 in.). Ultimate tensile strength: longitudinal, 696 MPa (101 ksi); long transverse, 290 MPa (42 ksi). Tensile yield strength: longitudinal, 338 MPa (49 ksi); long transverse, 207 MPa (30 ksi). Ramberg-Osgood parameter, n(long transverse, tension) = 12

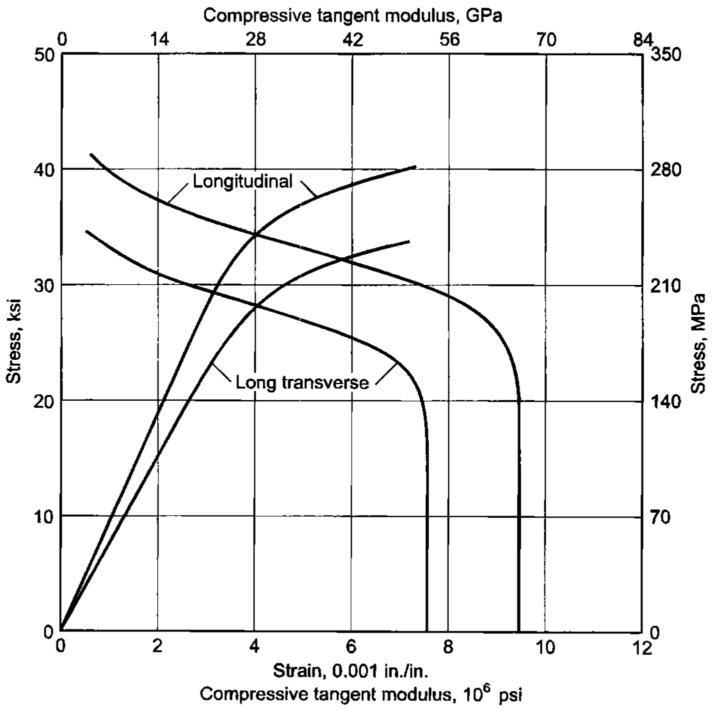
Source: *MIL-HDBK-5H*, Dec 1998, p 7–35



LA.005 2024-T3 aluminum alloy, aramid-fiber-reinforced sheet laminate (AMS 4254), 2/1 lay-up, typical compressive stress-strain and compressive tangent modulus curves

Thickness, 0.81 mm (0.032 in.). Compressive yield strength: longitudinal, 241 MPa (35 ksi); long transverse, 228 MPa (33 ksi). Ramberg-Osgood parameters: n(longitudinal, compression) = 13; n(long transverse, compression) = 12

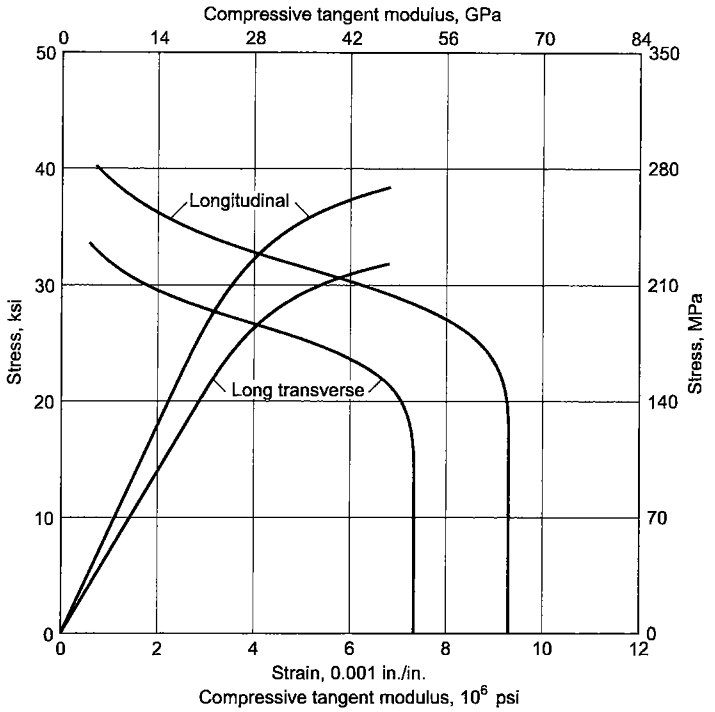
Source: *MIL-HDBK-5H,* Dec 1998, p 7–36



LA.006 2024-T3 aluminum alloy, aramid-fiber-reinforced sheet laminate (AMS 4254), 3/2 lay-up, typical compressive stress-strain and compressive tangent modulus curves

Thickness, 1.35 mm (0.053 in.). Compressive yield strength: longitudinal, 241 MPa (35 ksi); long transverse, 207 MPa (30 ksi). Ramberg-Osgood parameters: n(longitudinal, compression) = 13; n(long transverse, compression) = 13

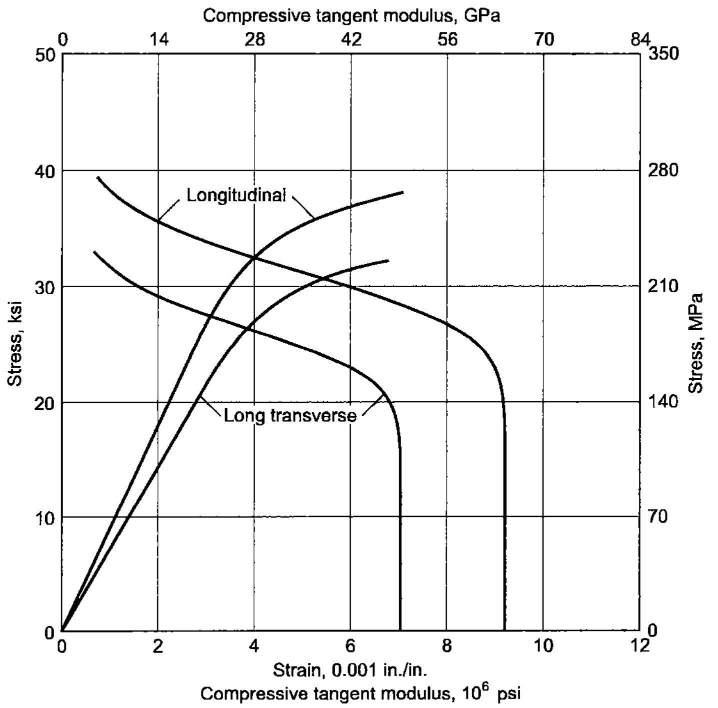
Source: *MIL-HDBK-5H,* Dec 1998, p 7–36



LA.007 2024-T3 aluminum alloy, aramid-fiber-reinforced sheet laminate (AMS 4254), 4/3 lay-up, typical compressive stress-strain and compressive tangent modulus curves

Thickness, 1.88 mm (0.074 in.). Compressive yield strength: longitudinal, 234 MPa (34 ksi); long transverse, 207 MPa (30 ksi). Ramberg-Osgood parameters: n(longitudinal, compression) = 12; n(long transverse, compression) = 12

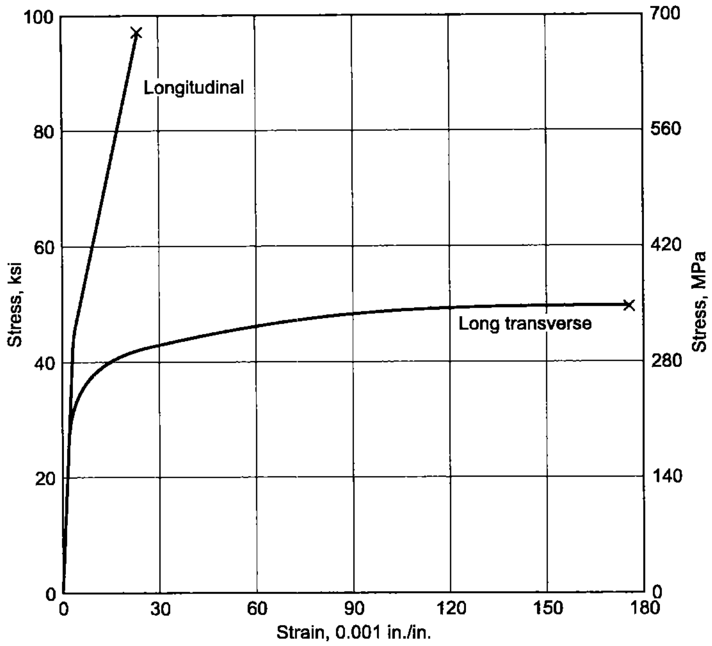
Source: *MIL-HDBK-5H*, Dec 1998, p 7–37



LA.008 2024-T3 aluminum alloy, aramid-fiber-reinforced sheet laminate (AMS 4254), 5/4 lay-up, typical compressive stress-strain and compressive tangent modulus curves

Thickness, 2.39 mm (0.094 in.). Compressive yield strength: longitudinal, 228 MPa (33 ksi); long transverse, 207 MPa (30 ksi). Ramberg-Osgood parameters: n(longitudinal, compression) = 12; n(long transverse, compression) = 12

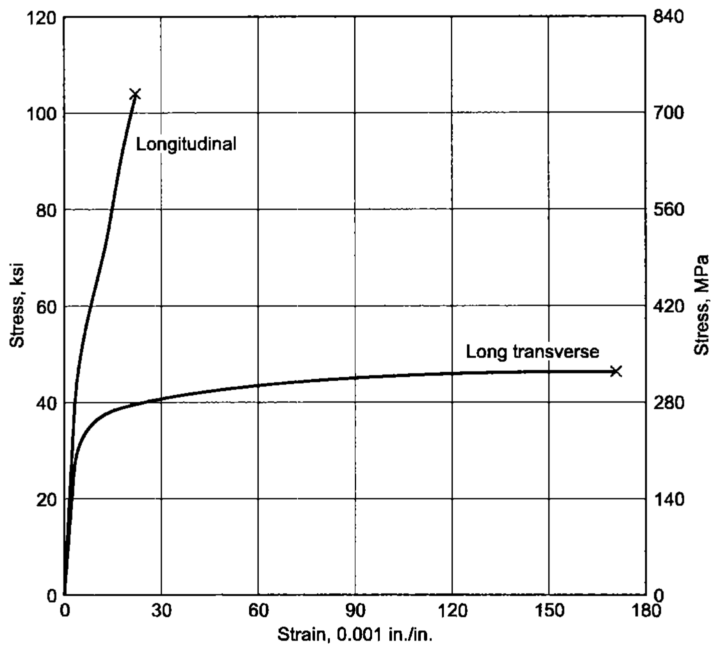
Source: *MIL-HDBK-5H*, Dec 1998, p 7–37



LA.009 2024-T3 aluminum alloy, aramid-fiber-reinforced sheet laminate (AMS 4254), 2/1 lay-up, typical tensile stress-strain curves (full range)

Thickness, 0.81 mm (0.032 in.). Ultimate tensile strength: longitudinal, 621 MPa (90 ksi); long transverse, 331 MPa (48 ksi). Tensile yield strength: longitudinal, 331 MPa (48 ksi); long transverse, 228 MPa (33 ksi)

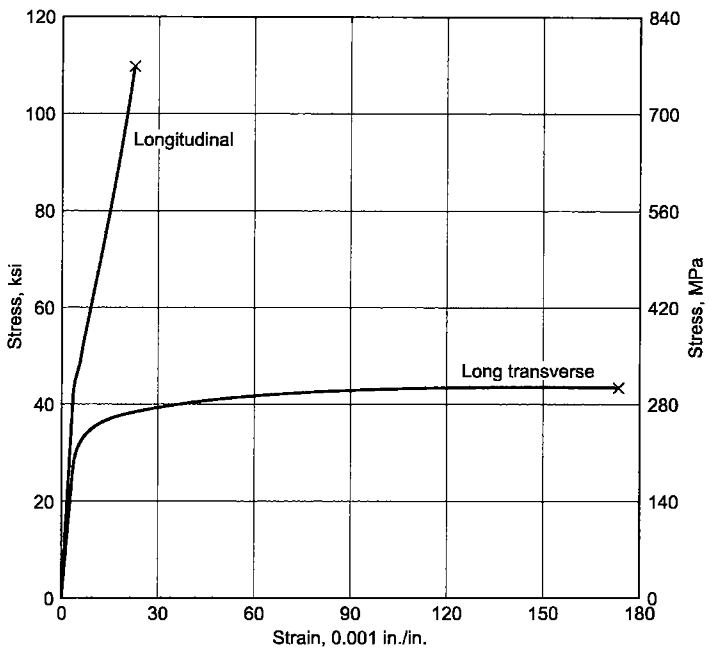
Source: *MIL-HDBK-5H,* Dec 1998, change notice 1, Oct 2001, p 7–38



LA.010 2024-T3 aluminum alloy, aramid-fiber-reinforced sheet laminate (AMS 4254), 3/2 lay-up, typical tensile stress-strain curves (full range)

Thickness, 1.35 mm (0.053 in.). Ultimate tensile strength: longitudinal, 662 MPa (96 ksi); long transverse, 303 MPa (44 ksi). Tensile yield strength: longitudinal, 338 MPa (49 ksi); long transverse, 207 MPa (30 ksi)

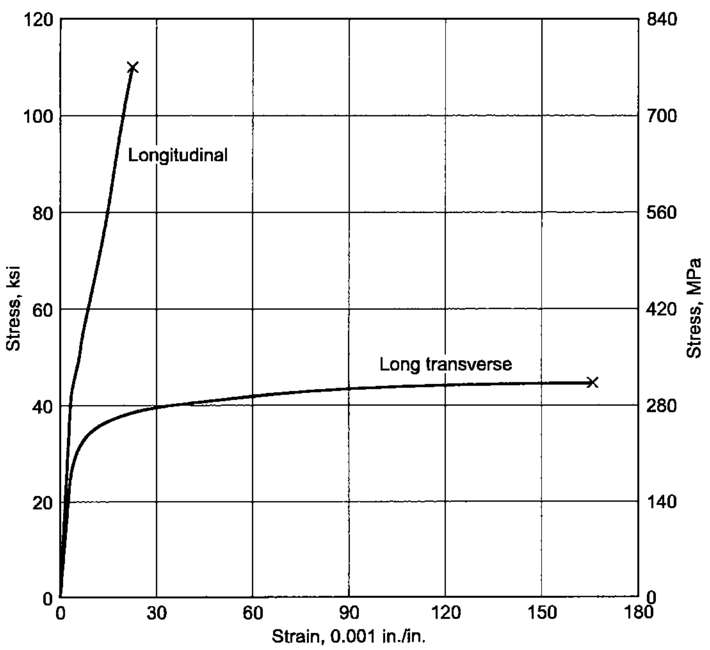
Source: *MIL-HDBK-5H,* Dec 1998, change notice 1, Oct 2001, p 7–38



LA.011 2024-T3 aluminum alloy, aramid-fiber-reinforced sheet laminate (AMS 4254), 4/3 lay-up, typical tensile stress-strain curves (full range)

Thickness, 1.88 mm (0.074 in.). Ultimate tensile strength: longitudinal, 696 MPa (101 ksi); long transverse, 296 MPa (43 ksi). Tensile yield strength: longitudinal, 338 MPa (49 ksi); long transverse, 207 MPa (30 ksi)

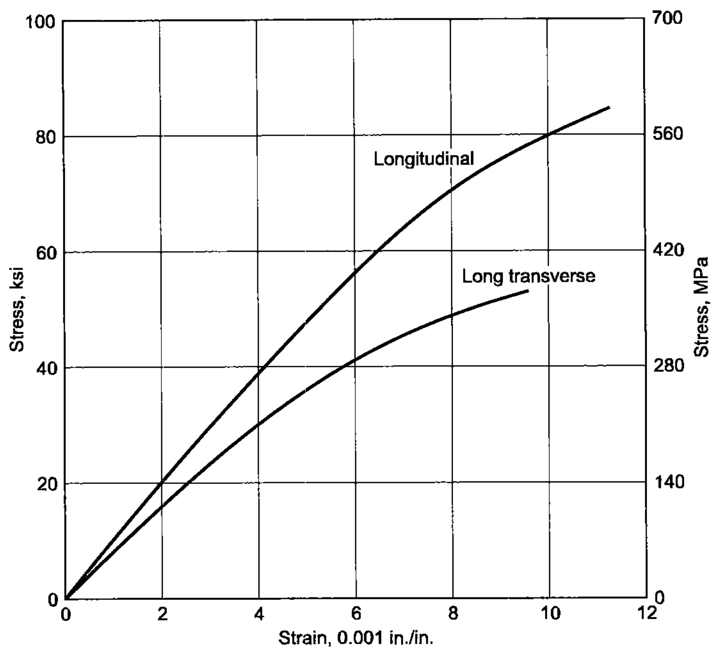
Source: *MIL-HDBK-5H,* Dec 1998, change notice 1, Oct 2001, p 7–39



LA.012 2024-T3 aluminum alloy, aramid-fiber-reinforced sheet laminate (AMS 4254), 5/4 lay-up, typical tensile stress-strain curves (full range)

Thickness, 2.39 mm (0.094 in.). Ultimate tensile strength: longitudinal, 696 MPa (101 ksi); long transverse, 290 MPa (42 ksi). Tensile yield strength: longitudinal, 338 MPa (49 ksi); long transverse, 207 MPa (30 ksi)

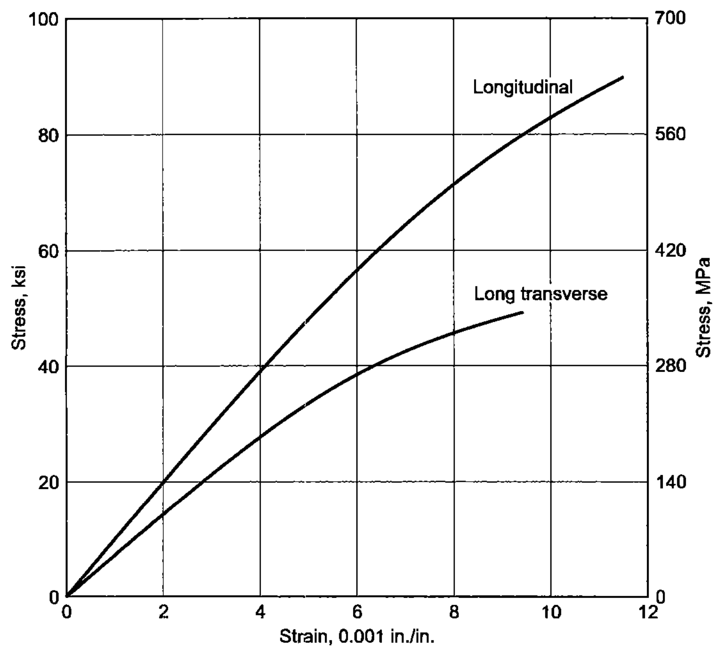
Source: *MIL-HDBK-5H,* Dec 1998, change notice 1, Oct 2001, p 7–39



LA.013 7475-T761 aluminum alloy, aramid-fiber-reinforced sheet laminate (AMS 4302), 2/1 lay-up, typical tensile stress-strain curves

Thickness, 0.81 mm (0.032 in.). Ultimate tensile strength: longitudinal, 710 MPa (103 ksi); long transverse, 386 MPa (56 ksi). Tensile yield strength: longitudinal, 524 MPa (76 ksi); long transverse, 331 MPa (48 ksi). Ramberg-Osgood parameters: n(longitudinal, tension) = 6.4; n(long transverse, tension) = 6.1

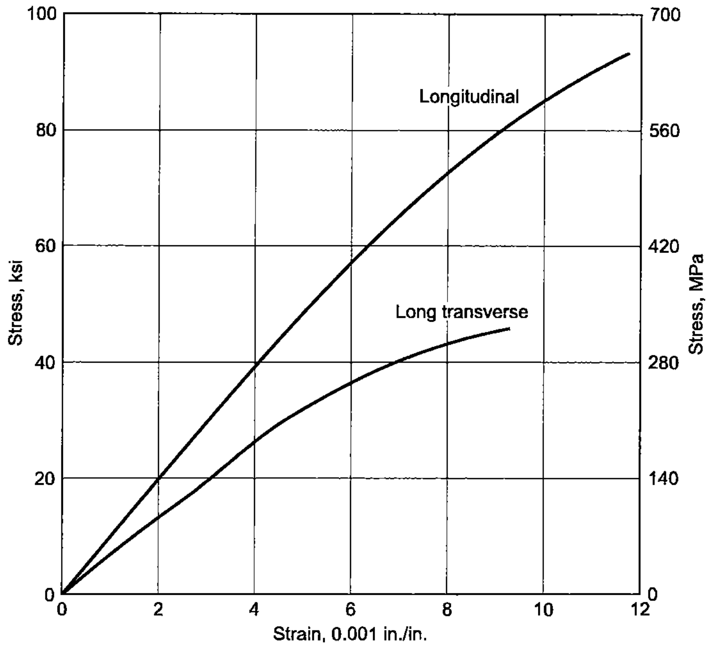
Source: *MIL-HDBK-5H,* Dec 1998, p 7–42



LA.014 7475-T761 aluminum alloy, aramid-fiber-reinforced sheet laminate (AMS 4302), 3/2 lay-up, typical tensile stress-strain curves

Thickness, 1.35 mm (0.053 in.). Ultimate tensile strength: longitudinal, 765 MPa (111 ksi); long transverse, 352 MPa (51 ksi). Tensile yield strength: longitudinal, 565 MPa (82 ksi); long transverse, 296 MPa (43 ksi). Ramberg-Osgood parameters: n(longitudinal, tension) = 5.2; n(long transverse, tension) = 5.8

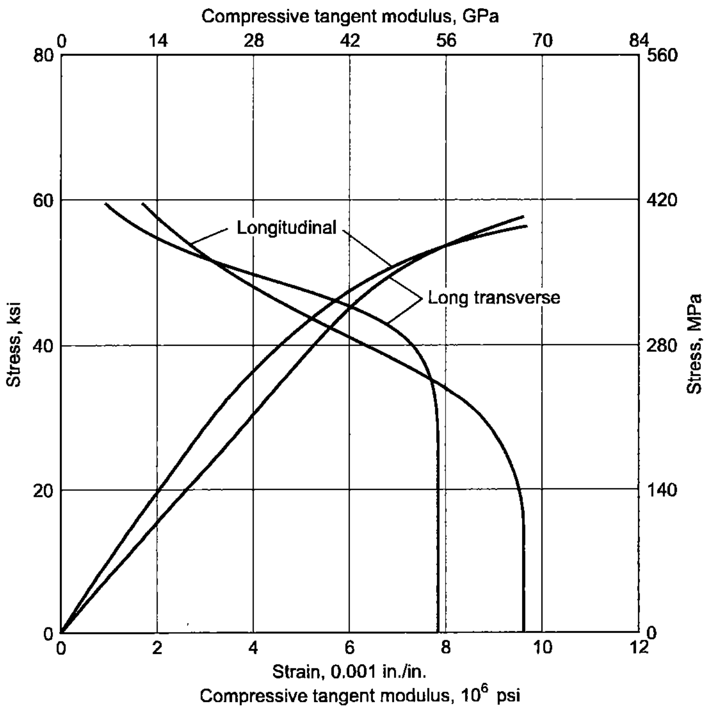
Source: *MIL-HDBK-5H,* Dec 1998, p 7–42



LA.015 7475-T761 aluminum alloy, aramid-fiber-reinforced sheet laminates (AMS 4302), 4/3 and 5/4 lay-ups, typical tensile stress-strain curves

Data for 4/3 lay-up: Thickness, 1.88 mm (0.074 in.). Ultimate tensile strength: longitudinal, 786 MPa (114 ksi); long transverse, 345 MPa (50 ksi). Tensile yield strength: longitudinal, 565 MPa (82 ksi); long transverse, 290 MPa (42 ksi). Ramberg-Osgood parameters: n(longitudinal, tension) = 5.5; n(long transverse, tension) = 7.5. Data for 5/4 lay-up: Thickness, 2.39 mm (0.094 in.). Ultimate tensile strength: longitudinal, 800 MPa (116 ksi); long transverse, 331 MPa (48 ksi). Tensile yield strength: longitudinal, 579 MPa (84 ksi); long transverse, 276 MPa (40 ksi). Ramberg-Osgood parameters: n(longitudinal, tension) = 5.7; n(long transverse, tension) = 6.4

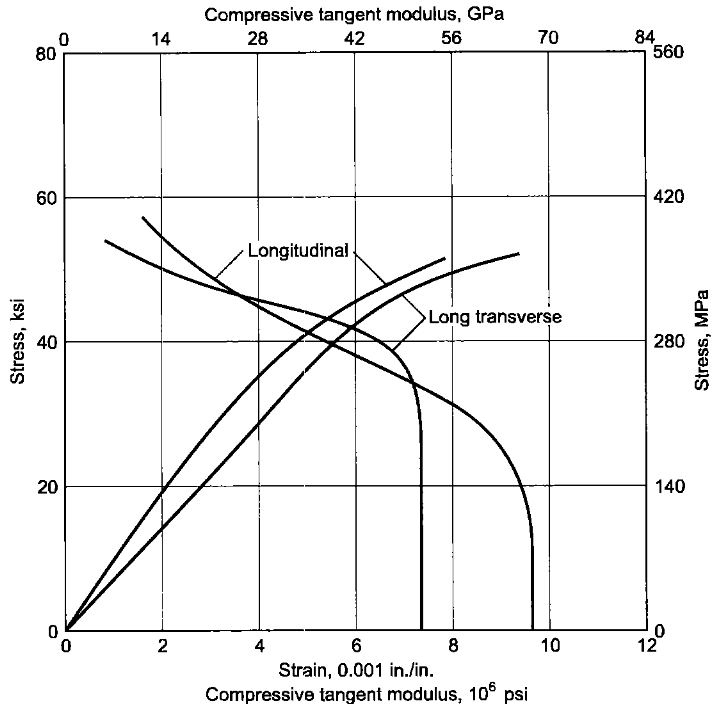
Source: *MIL-HDBK-5H*, Dec 1998, p 7–43



LA.016 7475-T761 aluminum alloy, aramid-fiber-reinforced sheet laminate (AMS 4302), 2/1 lay-up, typical compressive stress-strain and compressive tangent modulus curves

Thickness, 0.81 mm (0.032 in.). Compressive yield strength: longitudinal, 317 MPa (46 ksi); long transverse, 352 MPa (51 ksi). Ramberg-Osgood parameters: n(longitudinal, compression) = 6.7; n(long transverse, compression) = 13

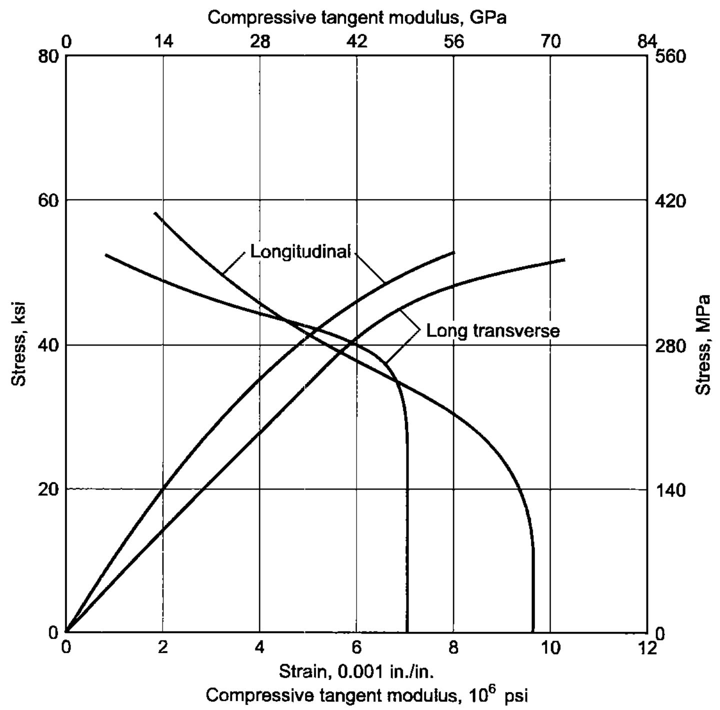
Source: *MIL-HDBK-5H*, Dec 1998, p 7–43



LA.017 7475-T761 aluminum alloy, aramid-fiber-reinforced sheet laminate (AMS 4302), 3/2 lay-up, typical compressive stress-strain and compressive tangent modulus curves

Thickness, 1.35 mm (0.053 in.). Compressive yield strength: longitudinal, 317 MPa (46 ksi); long transverse, 331 MPa (48 ksi). Ramberg-Osgood parameters: n(longitudinal, compression) = 6.2; n(long transverse, compression) = 14

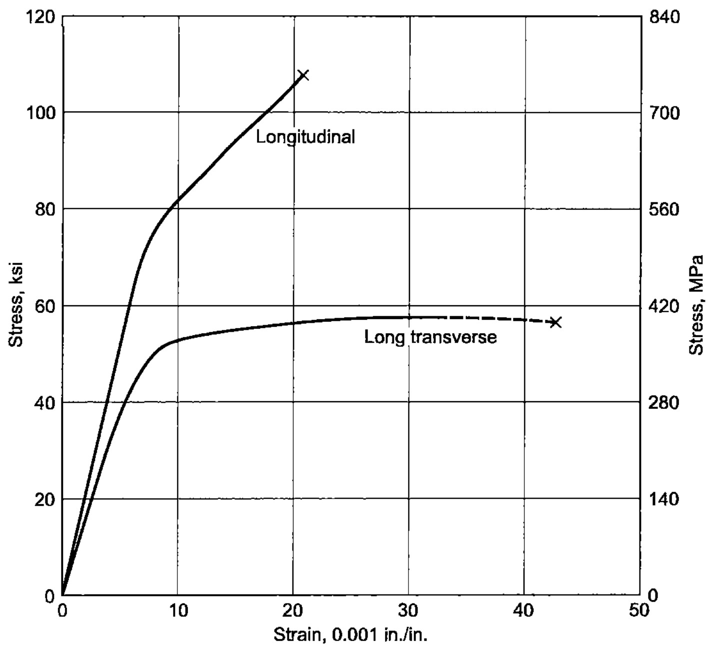
Source: *MIL-HDBK-5H,* Dec 1998, p 7–44



LA.018 7475-T761 aluminum alloy, aramid-fiber-reinforced sheet laminates (AMS 4302), 4/3 and 5/4 lay-ups, typical compressive stress-strain and compressive tangent modulus curves

Data for 4/3 lay-up: Thickness, 1.88 mm (0.074 in.). Compressive yield strength: longitudinal, 303 MPa (44 ksi); long transverse, 324 MPa (47 ksi). Ramberg-Osgood parameters: n(longitudinal, compression) = 5.3; n(long transverse, compression) = 15. Data for 5/4 lay-up: Thickness, 2.39 mm (0.094 in.). Compressive yield strength: longitudinal, 303 MPa (44 ksi); long transverse, 310 MPa (45 ksi). Ramberg-Osgood parameters: n(longitudinal, compression) = 5.8; n(long transverse, compression) = 14

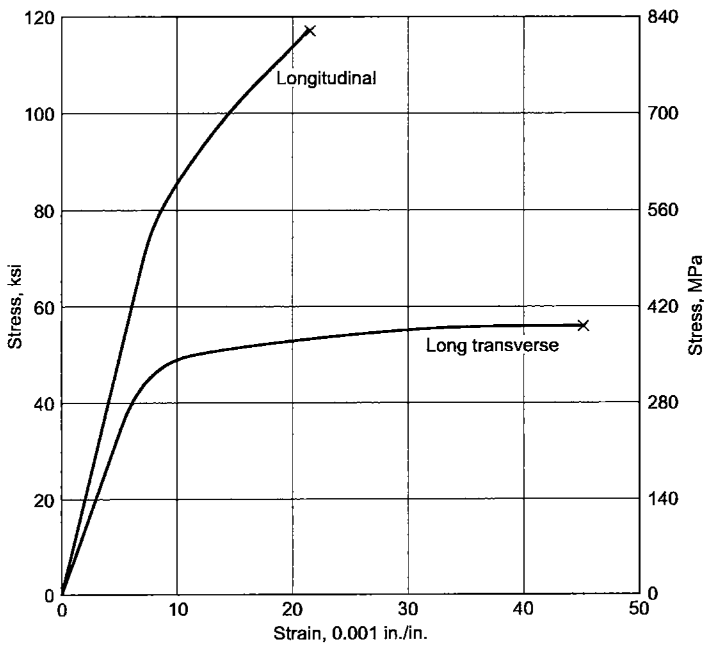
Source: *MIL-HDBK-5H,* Dec 1998, p 7–44



LA.019 7475-T761 aluminum alloy, aramid-fiber-reinforced sheet laminate (AMS 4302), 2/1 lay-up, typical tensile stress-strain curves (full range)

Thickness, 0.81 mm (0.032 in.). Ultimate tensile strength: longitudinal, 710 MPa (103 ksi); long transverse, 386 MPa (56 ksi). Tensile yield strength: longitudinal, 524 MPa (76 ksi); long transverse, 331 MPa (48 ksi)

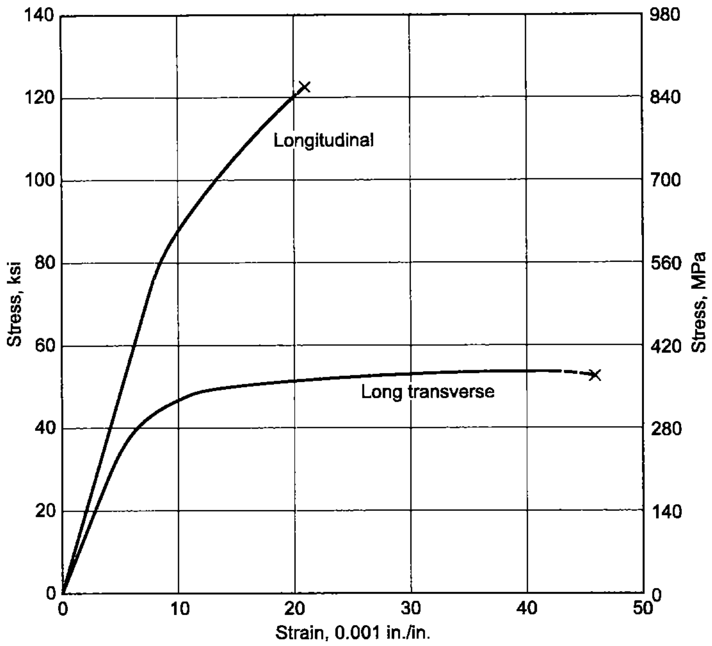
Source: *MIL-HDBK-5H*, Dec 1998, p 7–45



LA.020 7475-T761 aluminum alloy, aramid-fiber-reinforced sheet laminate (AMS 4302), 3/2 lay-up, typical tensile stress-strain curves (full range)

Thickness, 1.35 mm (0.053 in.). Ultimate tensile strength: longitudinal, 765 MPa (111 ksi); long transverse, 352 MPa (51 ksi). Tensile yield strength: longitudinal, 565 MPa (82 ksi); long transverse, 296 MPa (43 ksi)

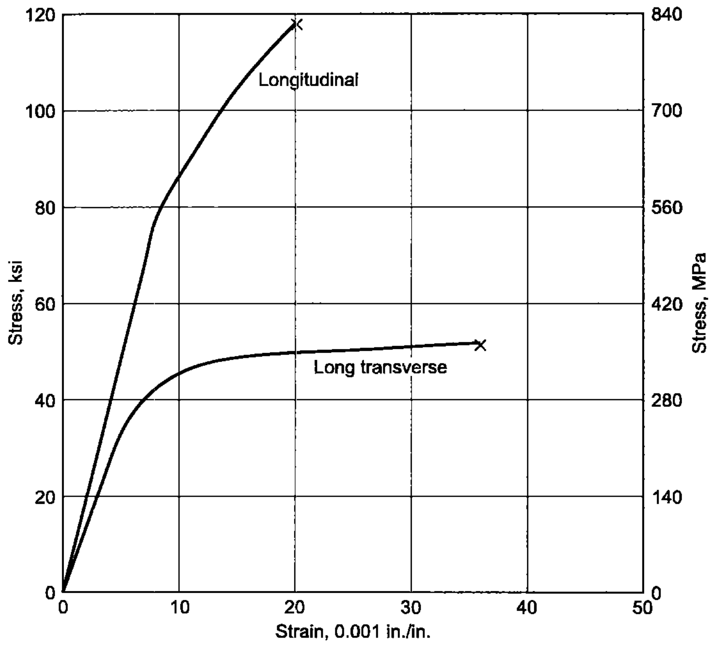
Source: *MIL-HDBK-5H*, Dec 1998, p 7–46



LA.021 7475-T761 aluminum alloy, aramid-fiber-reinforced sheet laminate (AMS 4302), 4/3 lay-up, typical tensile stress-strain curves (full range)

Thickness, 1.88 mm (0.074 in.). Ultimate tensile strength: longitudinal, 786 MPa (114 ksi); long transverse, 345 MPa (50 ksi). Tensile yield strength: longitudinal, 565 MPa (82 ksi); long transverse, 290 MPa (42 ksi)

Source: *MIL-HDBK-5H,* Dec 1998, p 7–47

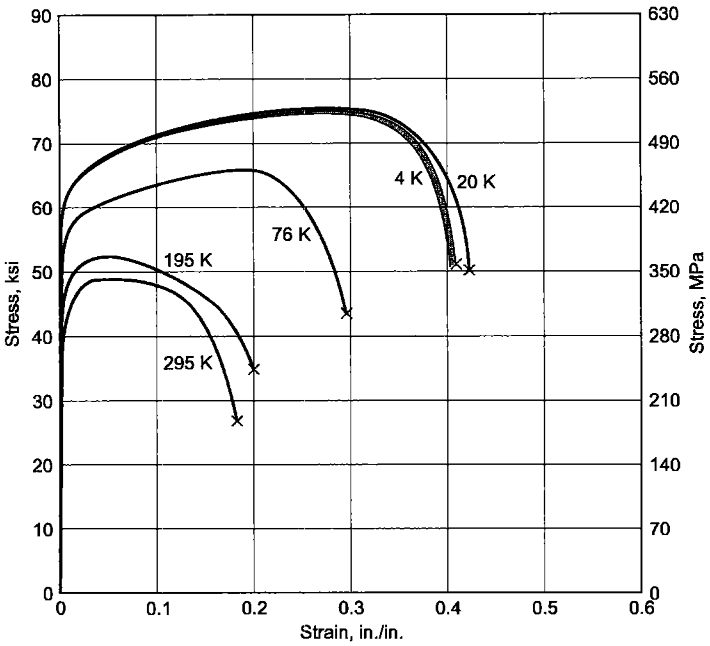


LA.022 7475-T761 aluminum alloy, aramid-fiber-reinforced sheet laminate (AMS 4302), 5/4 lay-up, typical tensile stress-strain curves (full range)

Thickness, 2.39 mm (0.094 in.). Ultimate tensile strength: longitudinal, 800 MPa (116 ksi); long transverse, 331 MPa (48 ksi). Tensile yield strength: longitudinal, 579 MPa (84 ksi); long transverse, 276 MPa (40 ksi)

Source: *MIL-HDBK-5H,* Dec 1998, p 7–48

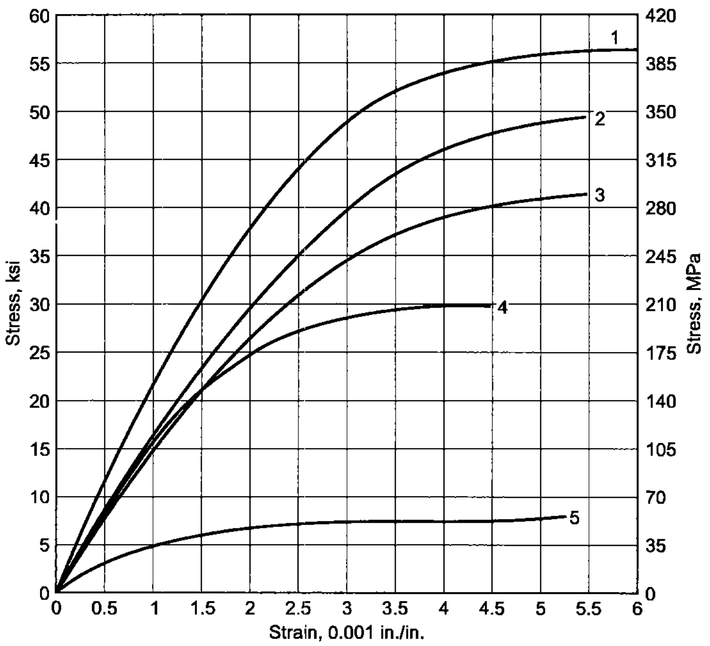
Copper (Cu)



Cu.001 Oxygen-free copper (UNS C10200) bar, stress-strain curves showing effect of low temperatures

Cold drawn 60%. Bar thickness: 19 mm (3/4 in.)

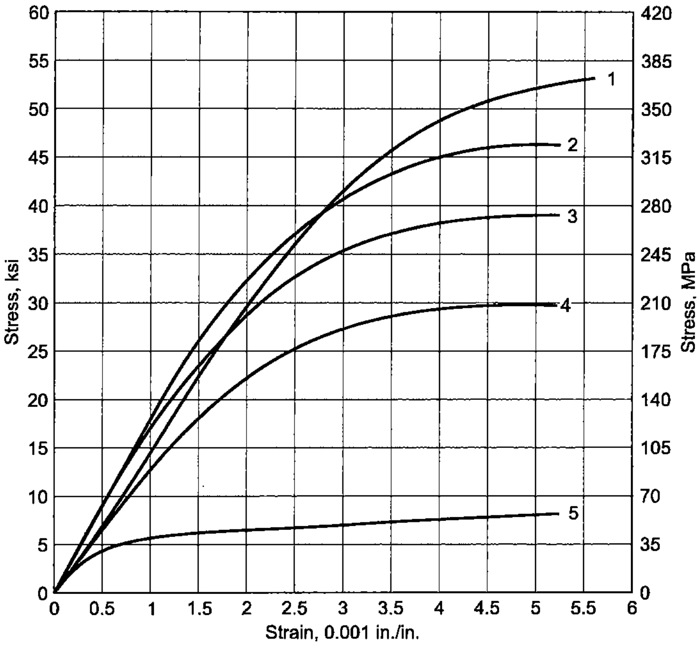
Source: *R.P. Reed and R.P. Mikesell, Low Temperature Mechanical Properties of Copper and Selected Copper Alloys*, NBS Monograph 101, Institute for Materials Research, National Bureau of Standards, 1967



Cu.002 Electrolytic tough-pitch copper (UNS C11000) strip, stress-strain curves showing effect of cold rolling

Copper strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 371 °C (700 °F) for 1 h

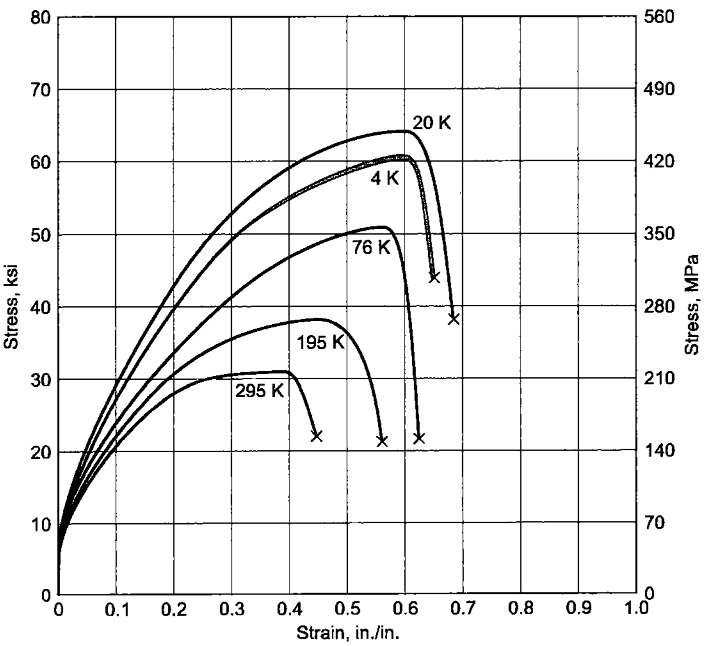
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 7



Cu.003 Electrolytic tough-pitch copper (UNS C11000) strip, stress-strain curves showing effect of cold rolling

Copper strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.045 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 427 °C (800 °F) for 1 h

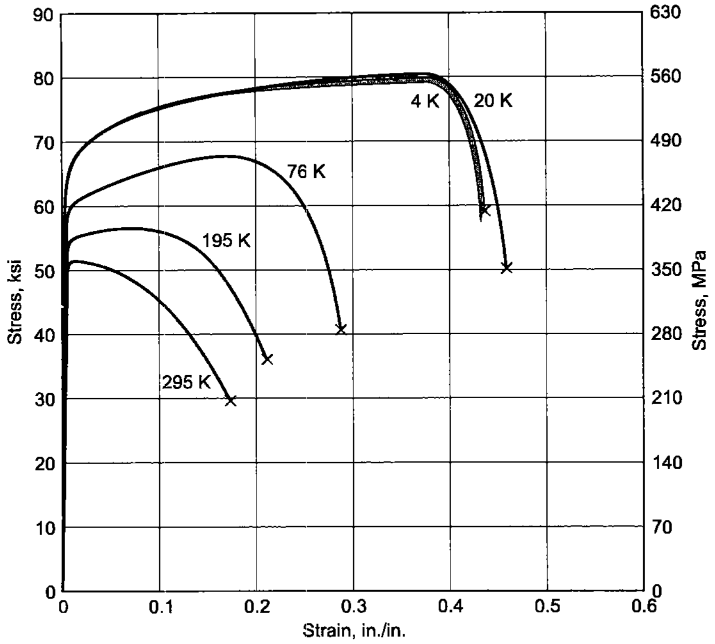
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 7



Cu.004 Phosphorus-deoxidized, high residual phosphorus (UNS C12200) bar, stress-strain curves showing effect of low temperatures

Bar in annealed condition. Bar thickness: 19 mm (3/4 in.)

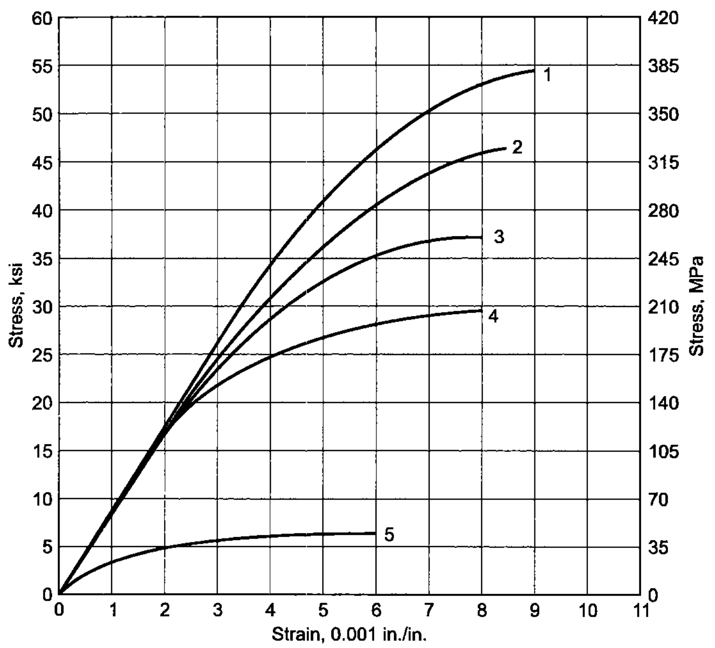
Source: R.P. Reed and R.P. Mikesell, *Low Temperature Mechanical Properties of Copper and Selected Copper Alloys*, NBS Monograph 101, Institute for Materials Research, National Bureau of Standards, 1967



Cu.005 Phosphorus-deoxidized, high residual phosphorus (UNS C12200) bar, stress-strain curves showing effect of low temperatures

Bar cold drawn 26% and aged.
Bar thickness: 19 mm (3/4 in.)

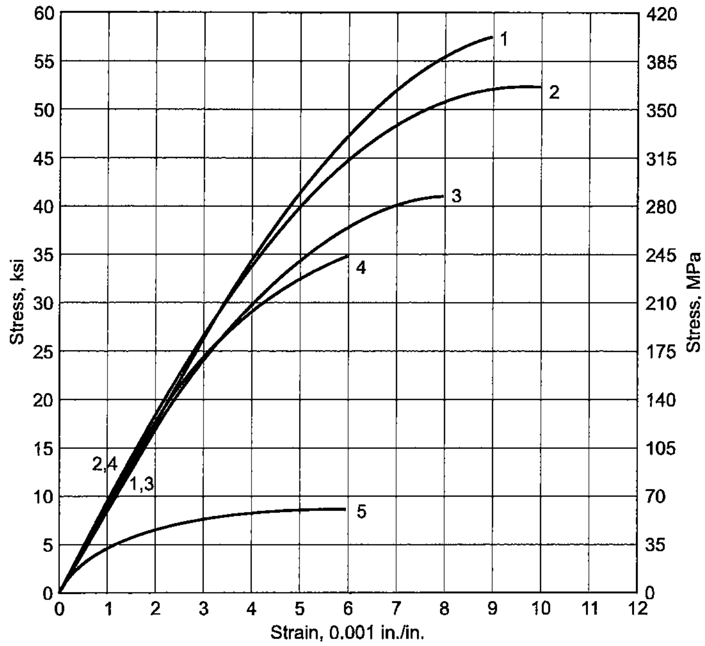
Source: R.P. Reed and R.P. Mikesell, *Low Temperature Mechanical Properties of Copper and Selected Copper Alloys*, NBS Monograph 101, Institute for Materials Research, National Bureau of Standards, 1967



Cu.006 Arsenical tough-pitch copper (UNS C14200) strip, stress-strain curves showing effect of cold rolling

Copper (99.50% Cu, 0.45% As) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.050 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA). It was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%, temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 704 °C (1300 °F) for 1 h

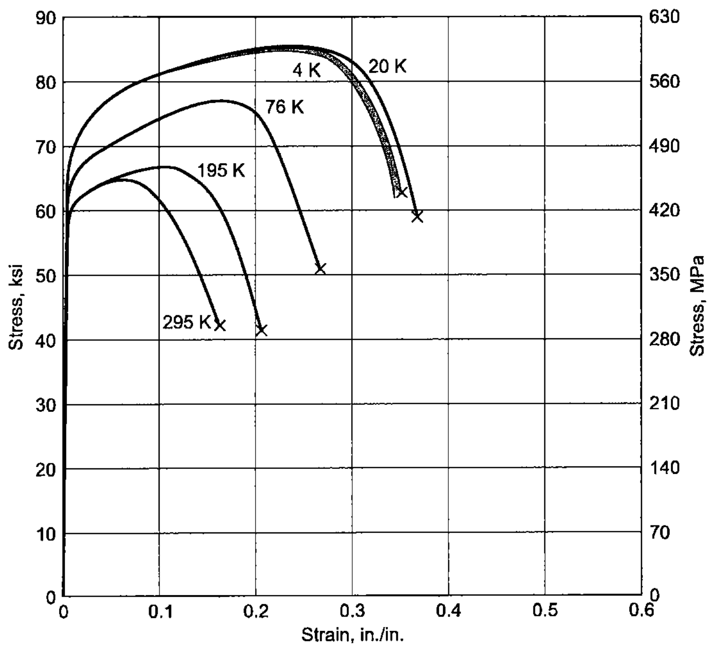
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 21



Cu.007 Arsenical tough-pitch copper (UNS C14200) strip, stress-strain curves showing effect of cold rolling

Copper (99.50% Cu, 0.45% As) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.020 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 µm (10 µin.) were used. Tested in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each curve was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage units and the reduction in area (RA) and assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed 371 ° C (700 °F) for 1 h

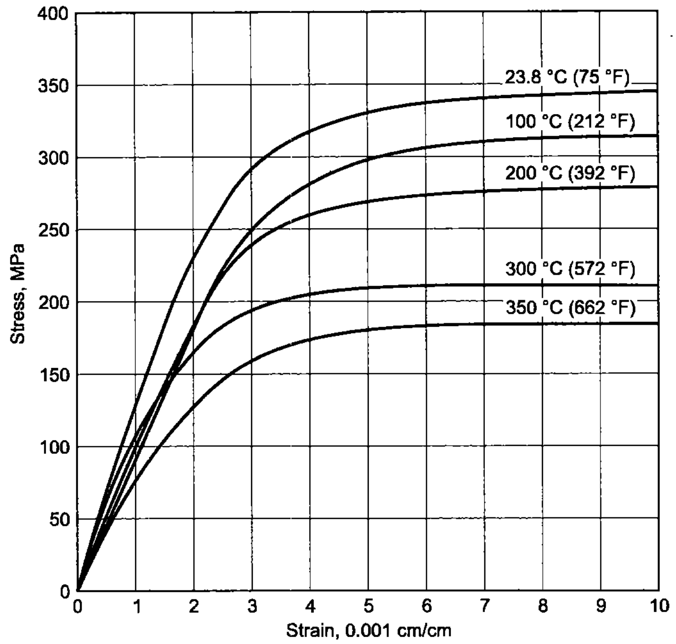
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 21



Cu.008 Zirconium copper (UNS C15000) bar, stress-strain curves showing effect of low temperatures

Bar cold drawn and aged. Bar thickness: 19 mm (3/4 in.). Composition: 0.18% Zr

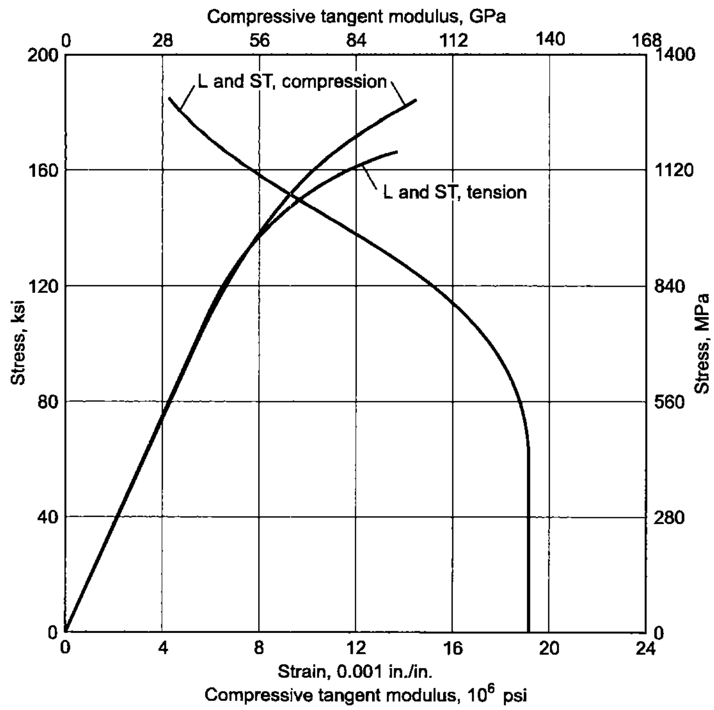
Source: R.P. Reed and R.P. Mikesell, *Low Temperature Mechanical Properties of Copper and Selected Copper Alloys*, NBS Monograph 101, Institute for Materials Research, National Bureau of Standards, 1967



Cu.009 Dispersion strengthened copper (UNS C15725) plate, engineering stress-strain showing effects of temperature

Dispersion strengthened (DS) copper AL25, LOX-80 plate (99.43 Cu, 0.25 Al, aluminum oxide 0.48% by weight). Plate 2.5 × 102 × 102 cm (1 × 40 × 40 in.), extruded and cross rolled, annealed at 1000 °C.

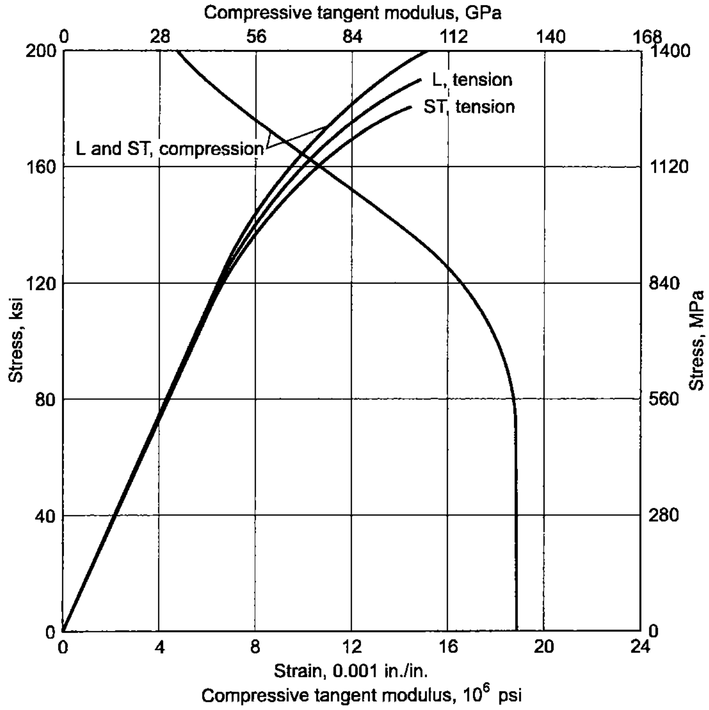
Source: J.W. Davis, *ITER Material Properties Handbook*, aries.ucsd.edu web site, May 2002



Cu.010 Copper beryllium (UNS C17200) bar and rod, TF00 temper, tensile and compressive stress-strain and compressive tangent modulus curves

Typical for bar and rod 41.27–101.6 mm (1.625–4.000 in.) thick. Test direction: L, longitudinal; ST, short transverse. Ramberg-Osgood parameters: n(L, tension) = 11, n(ST, tension) = 9.6, n(L, compression) = 7.1, n(ST, compression) = 6.7

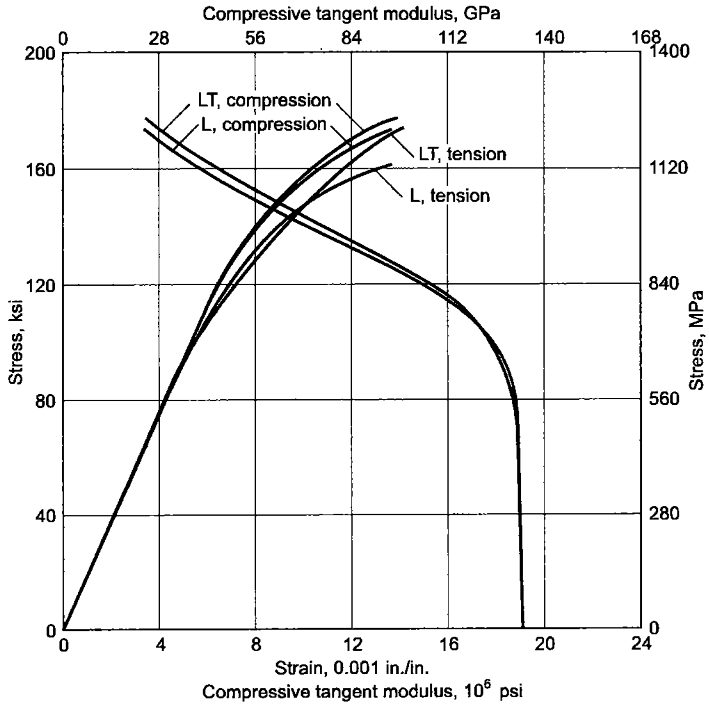
Source: *MIL-HDBK-5H*, Dec 1998, p 7–18



Cu.011 Copper beryllium (UNS C17200) bar and rod, TH04 temper, tensile and compressive stress-strain and compressive tangent modulus curves

Typical for bar and rod 12.7–76.20 mm (0.500–3.000 in.) thick. Test direction: L, longitudinal; ST, short transverse. Ramberg-Osgood parameters: n(L, tension) = 8.0, n(ST, tension) = 7.9, n(L, compression) = 6.8, n(ST, compression) = 7.5

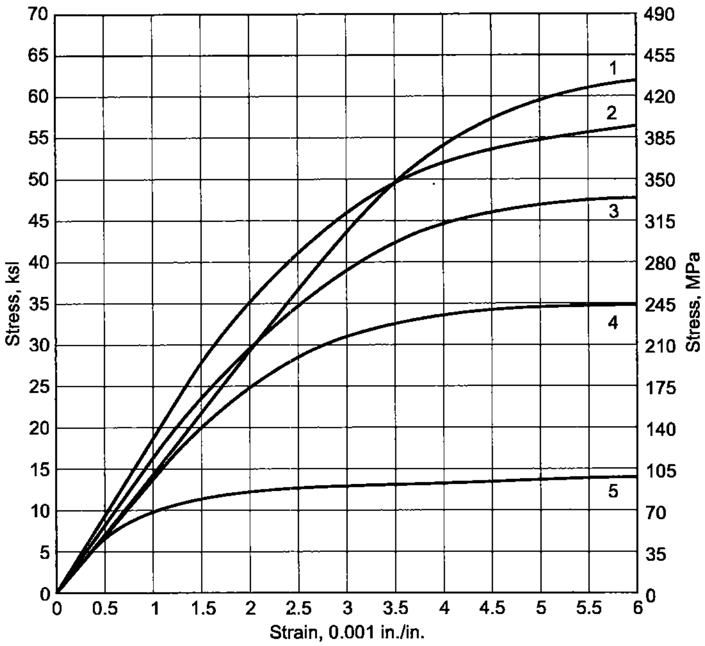
Source: *MIL-HDBK-5H*, Dec 1998, p 7–19



Cu.012 Copper beryllium (UNS C17200) tubing, TF00 temper, tensile and compressive stress-strain and compressive tangent modulus curves

Typical for mechanical tubing with wall thickness 19.05–41.27 mm (0.750–1.625 in.). Test direction: L, longitudinal; ST, short transverse. Ramberg-Osgood parameters: n(L, tension) = 8.2, n(ST, tension) = 5.1, n(L, compression) = 8.6, n(ST, compression) = 8.5

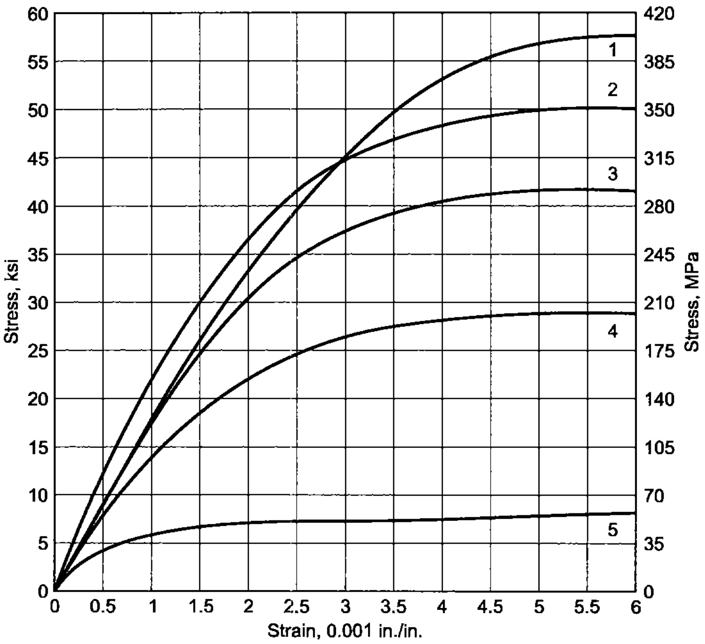
Source: *MIL-HDBK-5H*, Dec 1998, p 7–19



Cu.013 Copper gilding-metal (UNS C21000), stress-strain curves showing effect of cold working

Gilding-metal (94.59% Cu) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each curve was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage units and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed 482 °C (900 °F) for 1 h

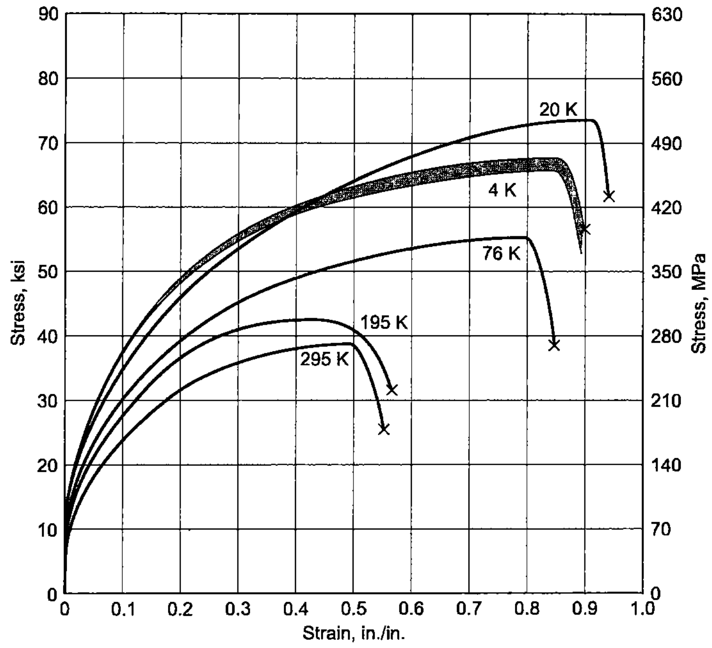
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 33



Cu.014 Copper gilding-metal (UNS C21000) strip, stress-strain curves showing effect of cold working

Gilding-metal (94.59% Cu) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.070 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. Composition: 94.59% copper. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 538 °C (1000 °F) for 1 h

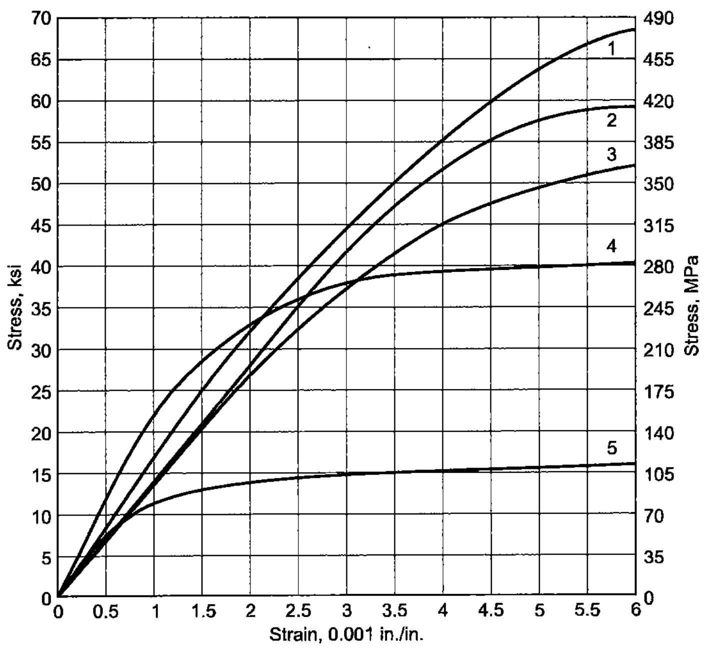
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 33



Cu.015 Commercial bronze (UNS C22000) bar, stress-strain curves showing effect of low temperatures

Bar was annealed. Bar thickness: 19 mm (3/4 in.)

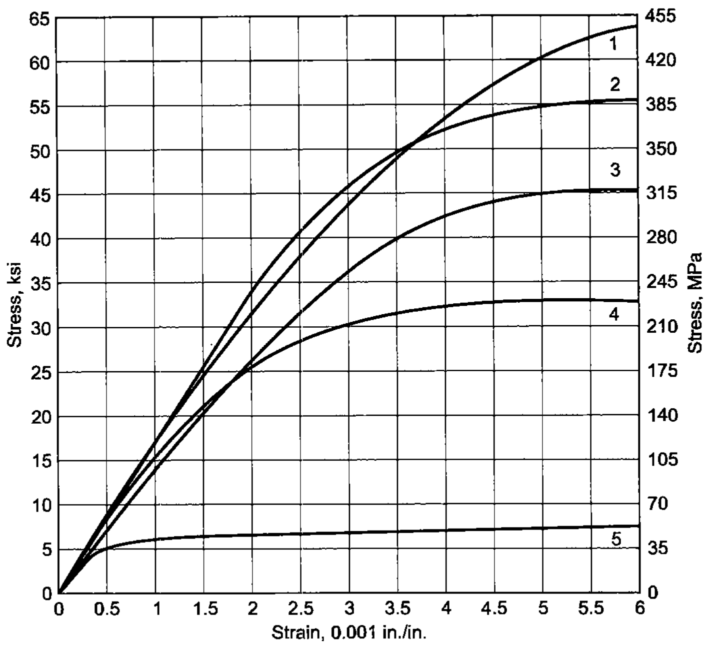
Source: R.P. Reed and R.P. Mikesell, *Low Temperature Mechanical Properties of Copper and Selected Copper Alloys*, NBS Monograph 101, Institute for Materials Research, National Bureau of Standards, 1967



Cu.016 Commercial bronze (UNS C22000) strip, stress-strain curves showing effect of cold working

Commercial bronze (government-gilding) (89.74% Cu) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 482 °C (900 °F) for 1 h

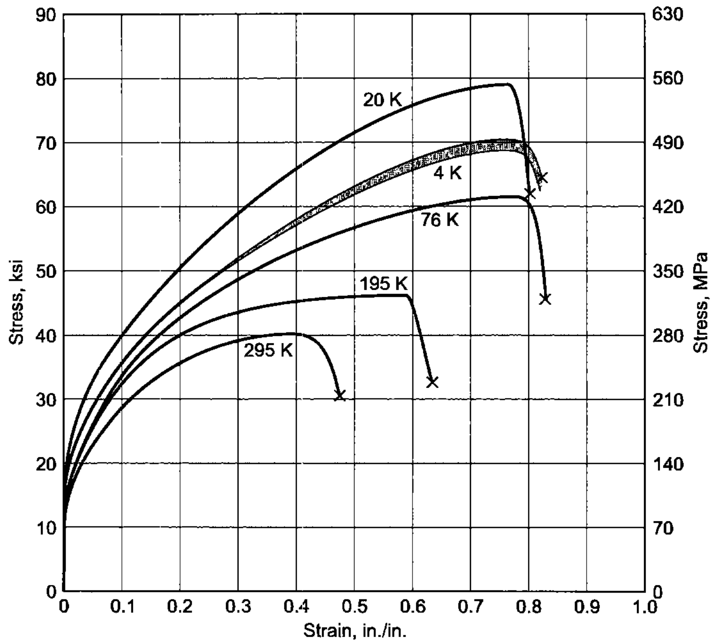
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p. 37



Cu.017 Commercial bronze (UNS C22000) strip, stress-strain curves showing effect of cold working

Commercial bronze (government-gilding) (89.74% Cu) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.070 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer 0.254 μm (10 μin.) accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 760 °C (1400 °F) for 1 h

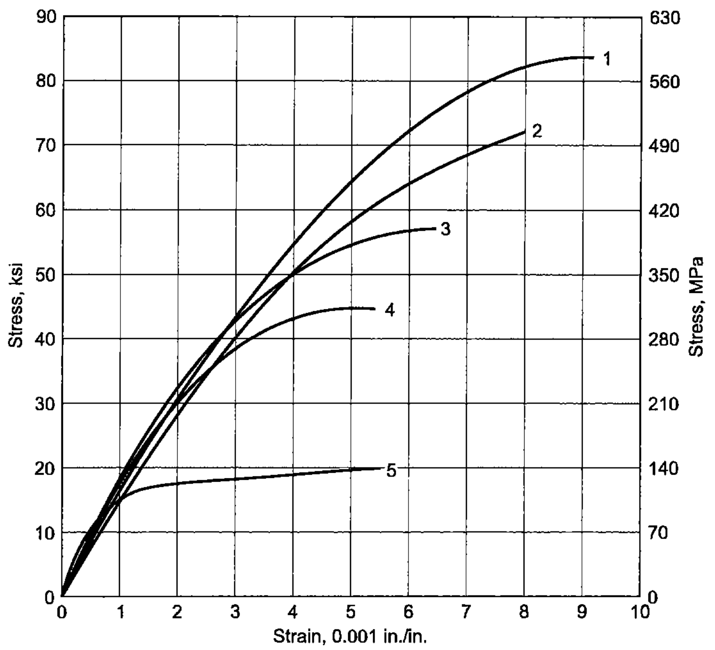
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 38



Cu.018 Red-brass (UNS C23000) bar, stress-strain curves showing effect of low temperatures

Bar cold drawn 14%. Bar thickness: 19 mm (3/4 in.). Red brass (85% Cu, 15% Zn)

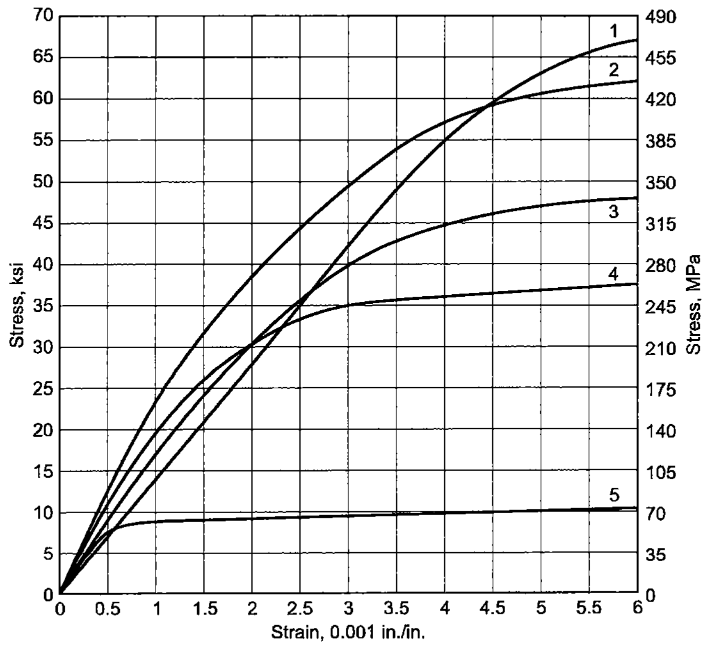
Source: R.P. Reed and R.P. Mikesell, *Low Temperature Mechanical Properties of Copper and Selected Copper Alloys*, NBS Monograph 101, Institute for Materials Research, National Bureau of Standards, 1967



Cu.019 Red-brass (UNS C23000) strip, stress-strain curves showing effect of cold working

Red-brass (85.42% Cu) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 µm (10 µin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 427 °C (800 °F) for 1 h

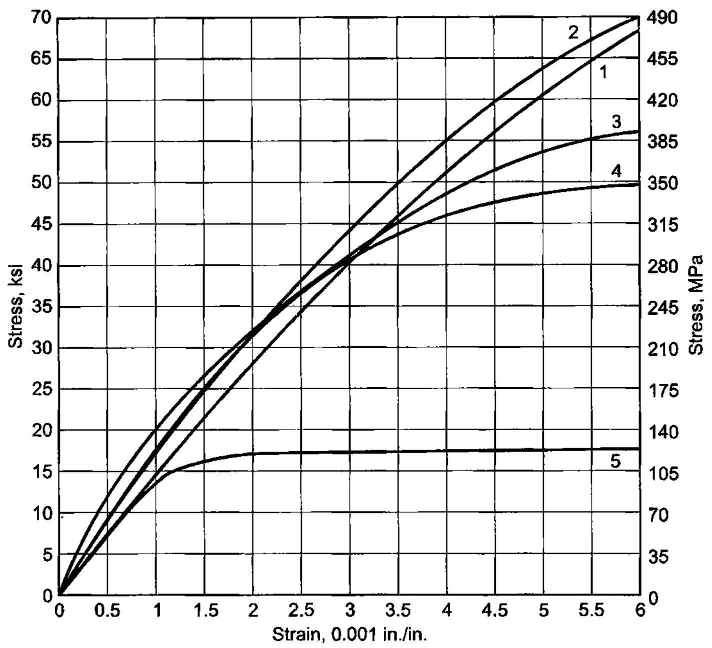
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 44



Cu.020 Red-brass (UNS C23000) strip, stress-strain curves showing effect of cold working

Red-brass (85.42% Cu) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.070 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 µm (10 µin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 593 °C (1100 °F) for 1 h

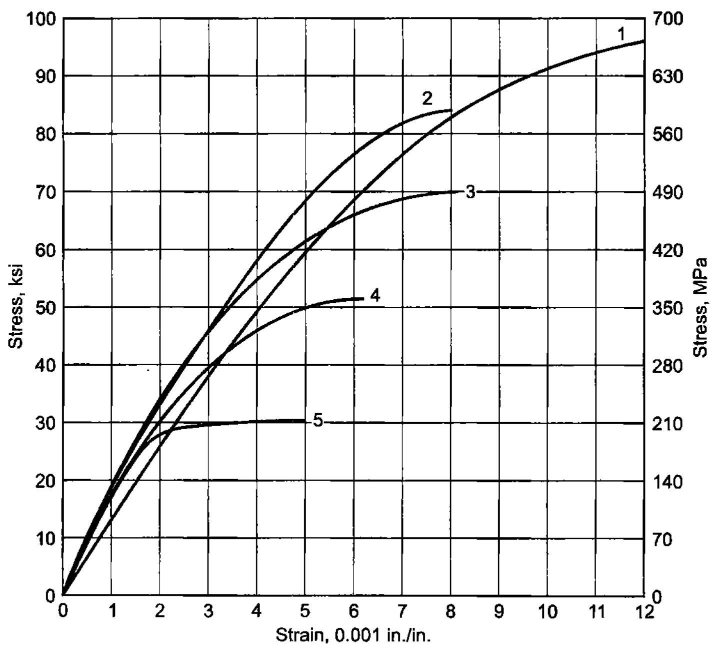
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 44



Cu.021 Low-brass (UNS C24000) strip, stress-strain curves showing effect of cold working

80-20 low-brass (80.41% Cu) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.020 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 427 °C (800 °F) for 1 h

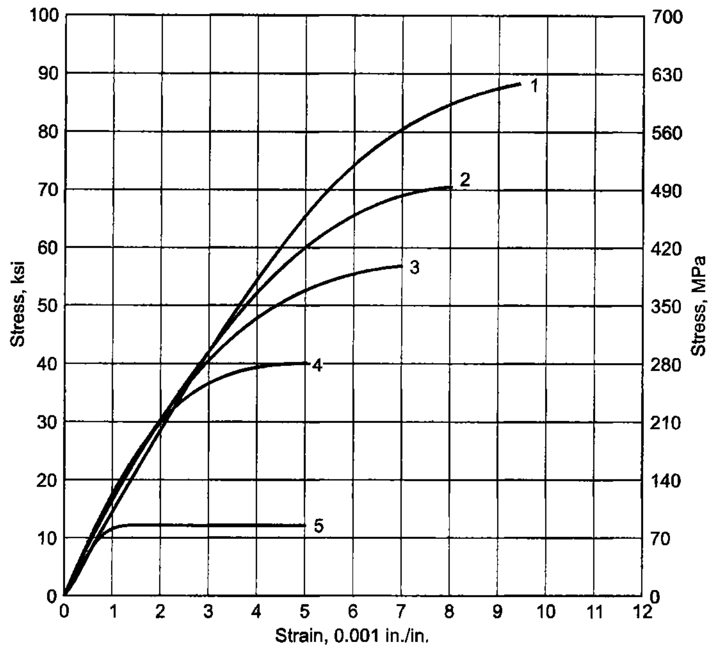
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 50



Cu.022 Spring-brass (UNS C25600) strip, stress-strain curves showing effect of cold rolling

Special spring-brass (74.69% Cu) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the spring brass composition is similar to C25600. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 427 °C (800 °F) for 1 h

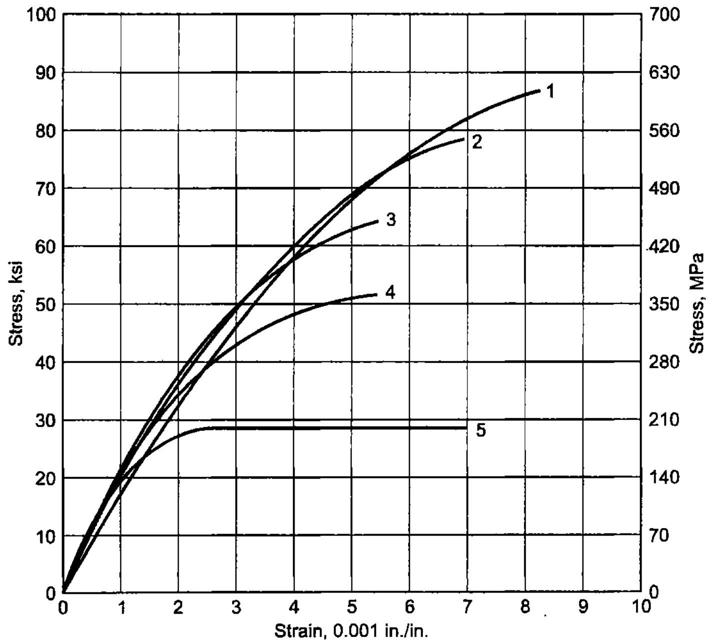
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 57



Cu.023 Spring-brass (UNS C25600) strip, stress-strain curves showing effect of cold rolling

Special spring-brass strip (74.69% Cu) 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.095 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 593 °C (1100 °F) for 1 h

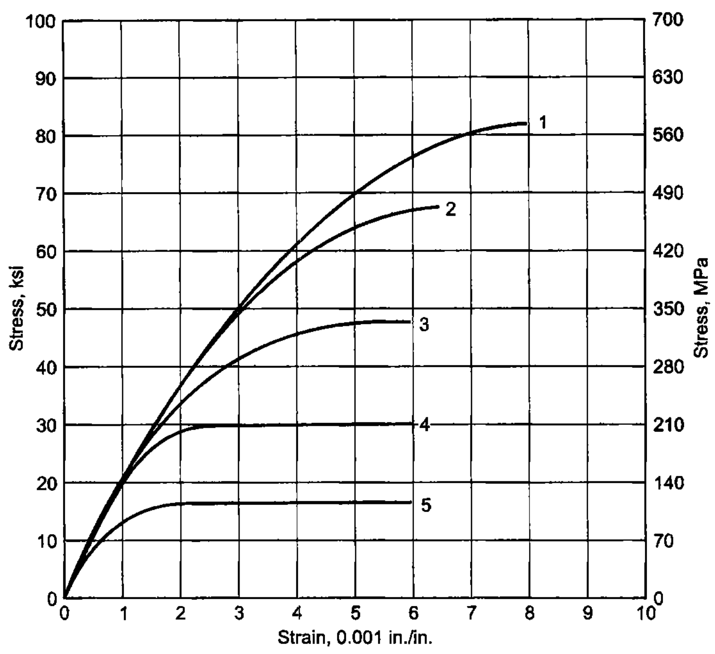
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 57



Cu.024 Cartridge brass (UNS C26000) strip, stress-strain curves showing effect of cold working

70-30 cartridge brass (69.83% Cu) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used: These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 482 °C (900 °F) for 1 h

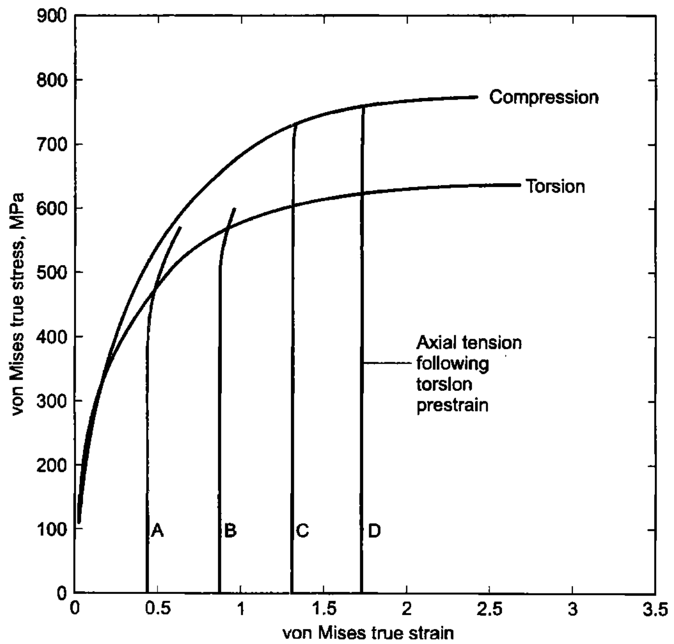
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 62



Cu.025 Cartridge brass (UNS C26000) strip, stress-strain curves showing effect of cold working

70-30 cartridge brass (69.83% Cu) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.070 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 704 °C (1300 °F) for 1 h

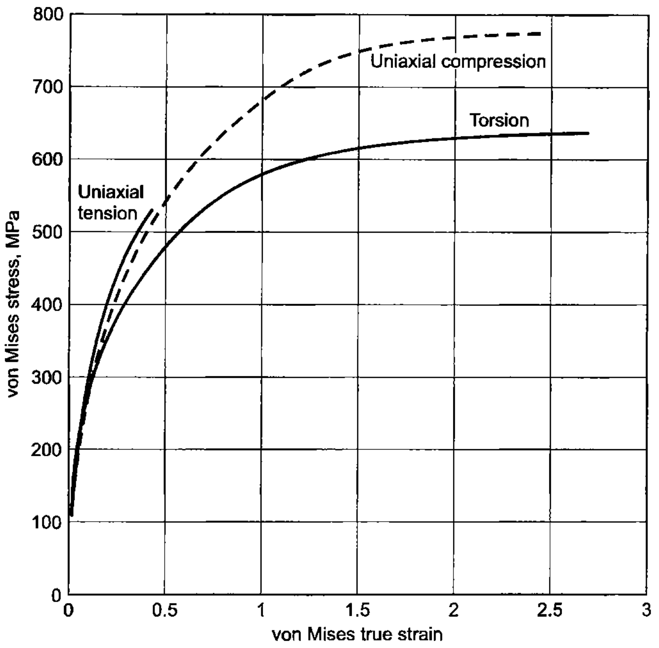
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 62



Cu.026 Cartridge brass (UNS C26000) thin-wall tubes, von Mises true stress-strain curves

Results of path-change experiments on 70-30 brass. Curves (A) through (D) represent axial tension in thin-wall tubes following torsional prestraining to von Mises strains indicated. A series of experiments were conducted by prestraining in torsion followed by uniaxial tension. All specimens were thin-wall tubes. Test sections were 25.4 mm (1 in.) long, 12.14 mm (0.48 in.) in diameter, and 0.589 mm (0.023 in.) in wall thickness. Specimens were carefully machined, annealed, and electropolished before twisting. After twisting, they were unloaded, re-electropolished, and strain gaged for tension testing. The resulting tensile curves are shown superimposed on the previous torsion and compression curves. The two curves at smaller prestrains showed little uniform elongation; most of the deformation occurred in a localized neck. Hence, these flow curves are questionable. The two curves for large prestrains definitely show that significant plastic flow in tension following torsional prestraining takes much higher stresses than does continued torsion. In fact, the flow curves are very close to that observed for compression at the same von Mises strain level.

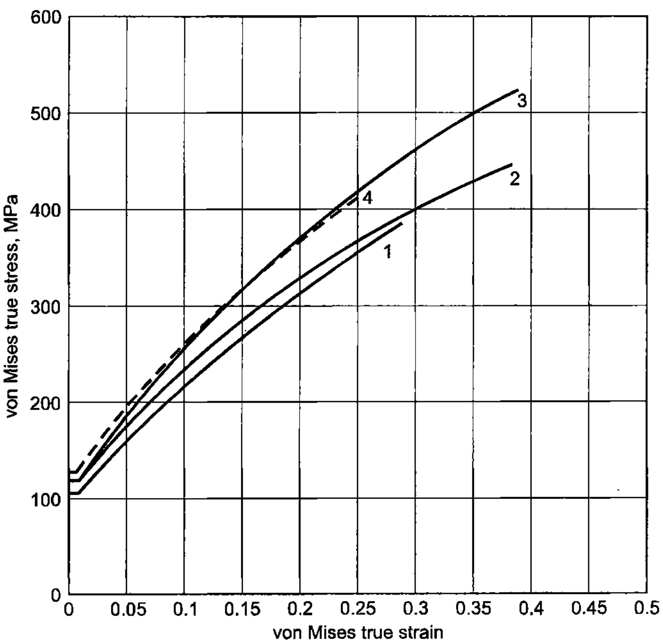
Source: G. Krauss, Ed., *Deformation, Processing, and Structure*, papers presented at the ASM Materials Science Seminar, 23 Oct 1982 (St. Louis MO), American Society for Metals, 1984, p 12



Cu.027 Cartridge brass (UNS C26000) thin-wall tubes, von Mises true stress-strain curves

Thin-wall tubes, 25.4 mm (1.00 in.) long, 12.14 mm (0.48 in.) diameter, 0.589 mm (0.023 in.) wall thickness. Comparison of stress-strain curves for 70-30 brass for uniaxial tension, uniaxial compression, and torsion. Tension and torsion were carried out on identical thin-wall tubes. Compression was carried out on solid rod, which was remachined often to avoid barreling.

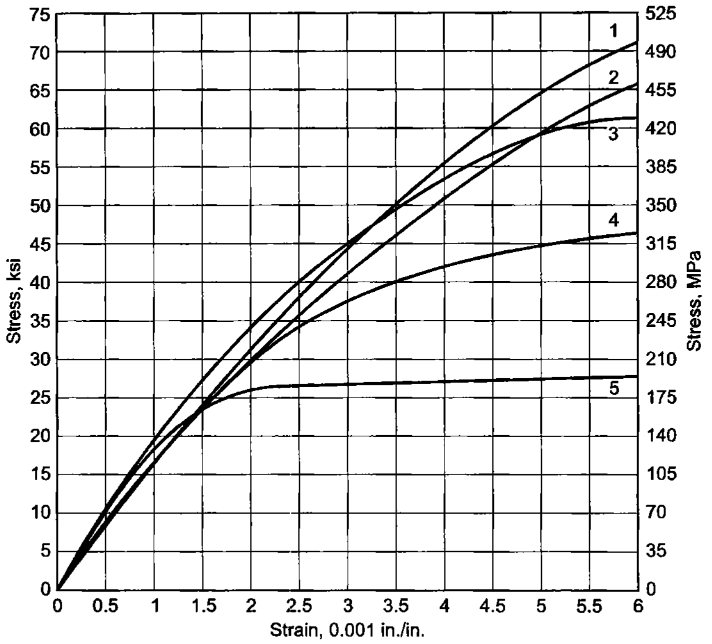
Source: G. Krauss, Ed., *Deformation, Processing, and Structure*, papers presented at the ASM Materials Science Seminar, 23 Oct 1982 (St. Louis MO), American Society for Metals, 1984, p 7



Cu.028 Cartridge brass (UNS C26000) thin-wall tubes, von Mises true stress-strain curves

Thin-wall tubes, 25.4 mm (1.00 in.) long, 12.14 mm (0.48 in.) diam, 0.589 mm (0.023 in.) wall thickness. Comparison of stress-strain curves for thin-wall 70-30 brass tubes. Curve 1: uniaxial hoop tension. Curve 2: the results for three different stress states—torsion, plane strain with no length change ($\varepsilon_z = 0$), and plane strain with no diameter change ($\varepsilon_\theta = 0$). Curve 3: uniaxial tension. Curve 4: balanced biaxial tension

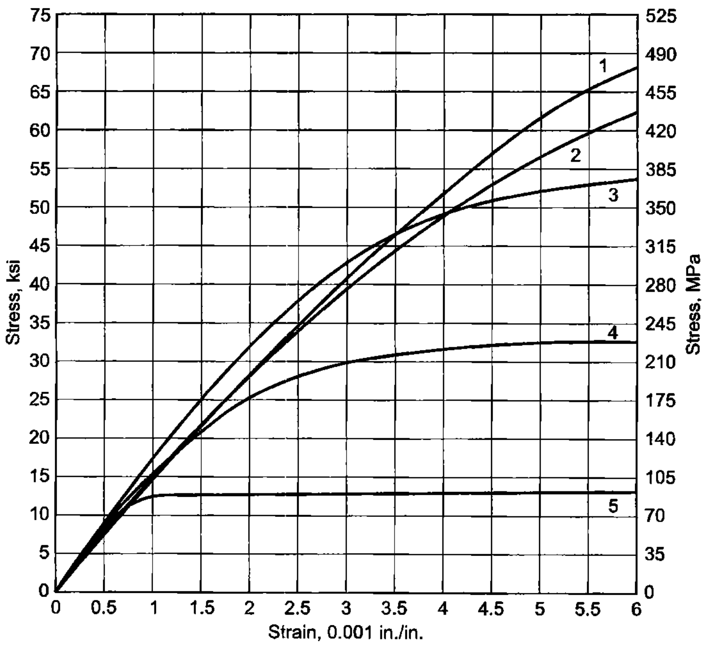
Source: G. Krauss, Ed., *Deformation, Processing, and Structure*, papers presented at the ASM Materials Science Seminar, 23 Oct 1982 (St. Louis MO), American Society for Metals, 1984, p 8



Cu.029 High-brass (UNS C27000) strip, stress-strain curves showing effect of cold rolling

Common high-brass (66.49% Cu) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 371 °C (700 °F) for 1 h

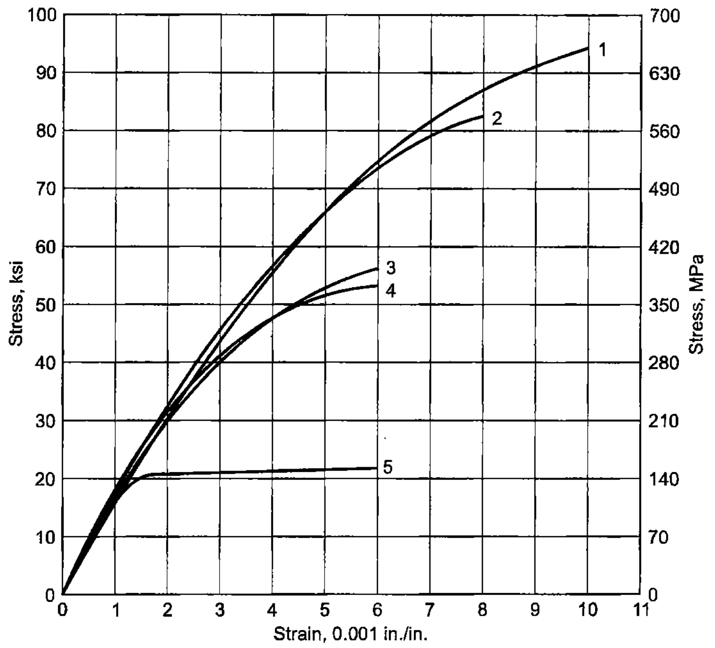
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 72



Cu.030 High-brass (UNS C27000) strip, stress-strain curves showing effect of cold rolling

Common high-brass (66.49% Cu) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.070 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 538 °C (1000 °F) for 1 h

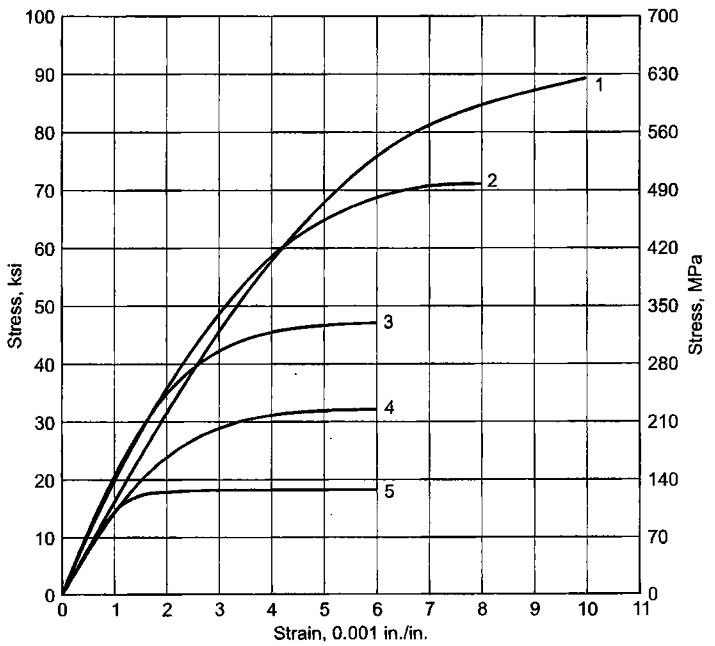
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 72



Cu.031 Muntz metal copper (UNS C28000) strip, stress-strain curves showing effect of cold rolling

Muntz metal (60.50% Cu) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 482 °C (900 °F) for 1 h

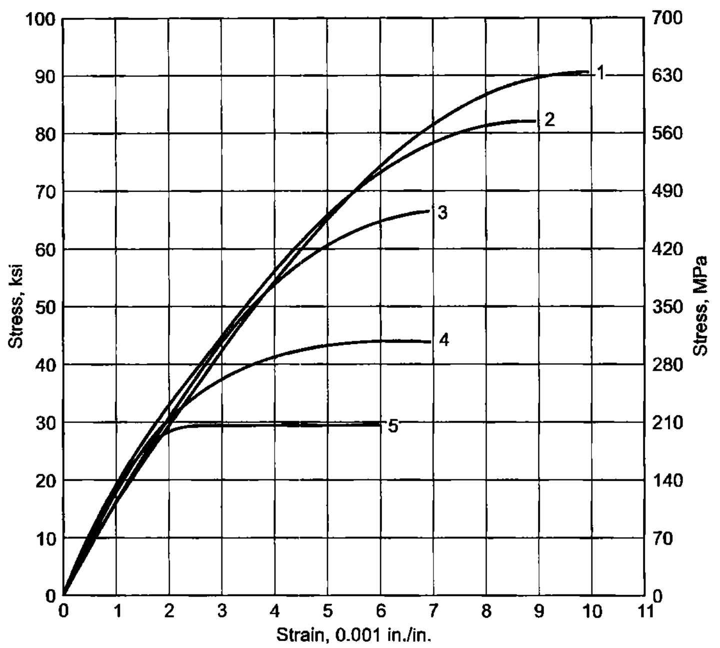
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 82



Cu.032 Muntz metal copper (UNS C28000) strip, stress-strain curves showing effect of cold rolling

Muntz metal (60.50% Cu) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.045 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 538 °C (1000 °F) for 1 h

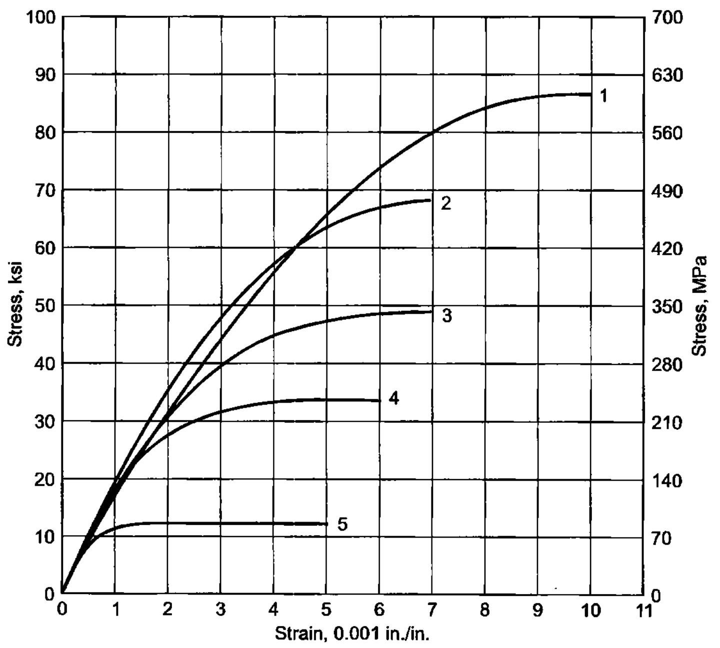
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 82



Cu.033 High leaded brass (UNS C33200) strip, stress-strain curves showing effect of cold rolling

High leaded brass (65.19% Cu, 1.09% Pb, balance Zn) strip 1.0 mm (0.040 in.) stock, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest in composition current designation is given for reference. (C33200 is for tube.) The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 427 °C (800 °F) for 1 h

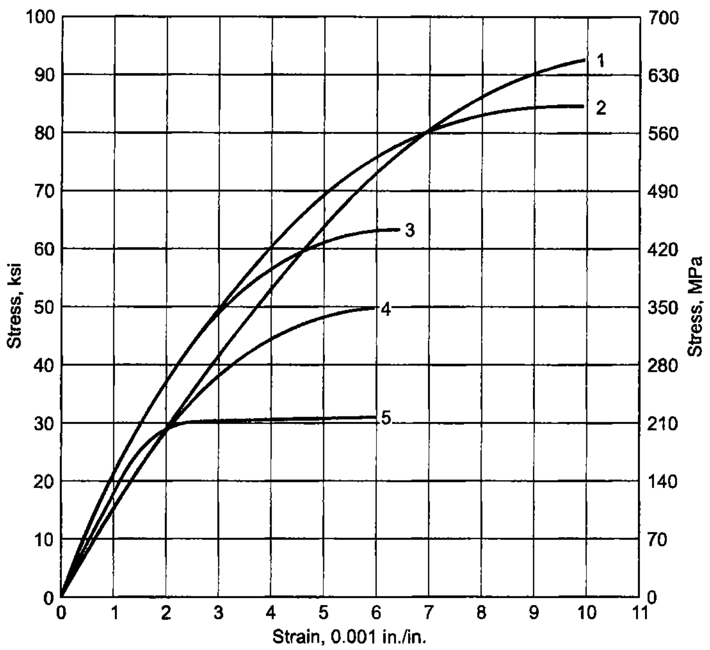
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 100



Cu.034 High leaded brass (UNS C33200) strip, stress-strain curves showing effect of cold rolling

High leaded brass (65.19% Cu, 1.09% Pb, balance Zn) strip 1.0 mm (0.040 in.) stock, having a ready-to-finish grain size of 0.080 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation in composition is given for reference. C33200 is for tube. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 649 °C (1200 °F) for 1 h

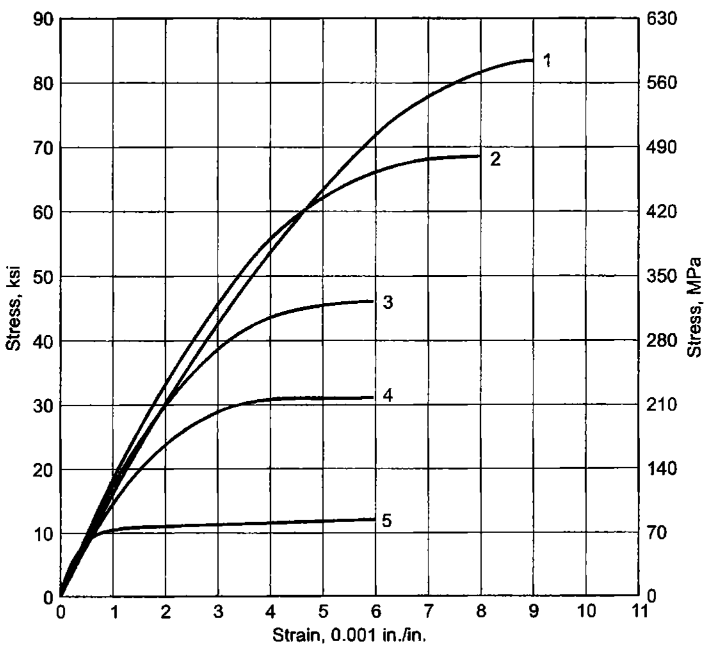
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 100



Cu.035 High leaded brass (UNS C34200) strip, stress-strain curves showing effect of cold rolling

High leaded brass (63.35% Cu, 2.79% Pb, balance Zn) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 427 °C (800 °F) for 1 h

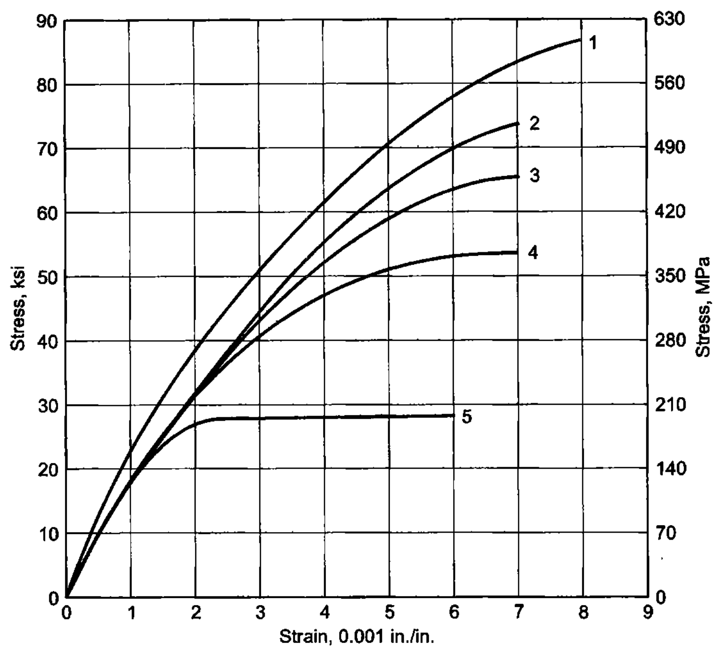
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 106



Cu.036 High leaded brass (UNS C34200) strip, stress-strain curves showing effect of cold rolling

High leaded brass (63.35% Cu, 2.79% Pb, balance Zn) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.080 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 760 °C (1400 °F) for 1 h

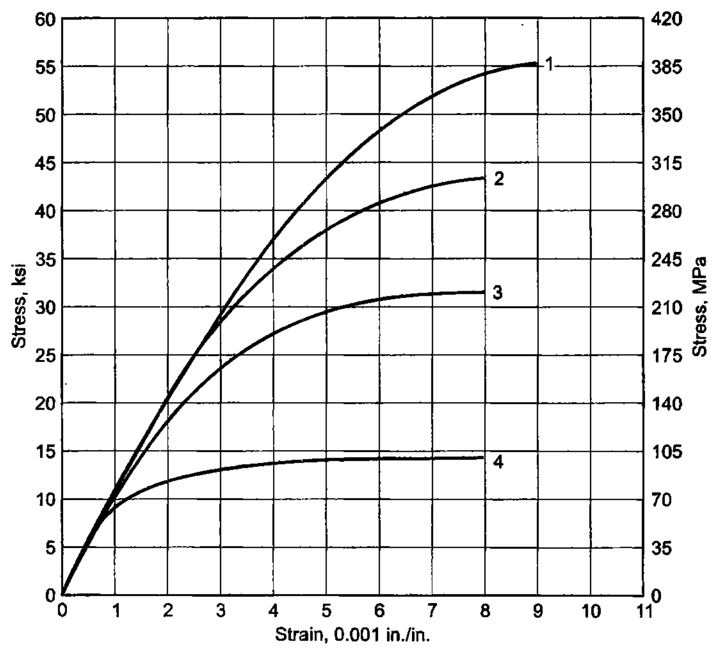
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 106



Cu.037 Lancashire brass strip, stress-strain curves showing effect of cold rolling

Lancashire brass (73.53% Cu, 2.24% Pb, balance Zn) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 427 °C (800 °F) for 1 h

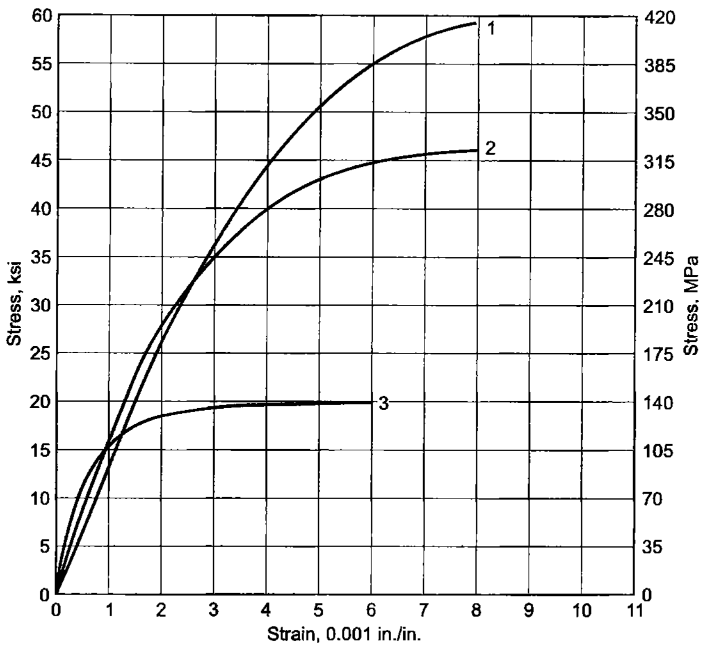
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 96



Cu.038 Deep-drilling copper (UNS C35330) rod, stress-strain curves showing effect of cold drawing

Deep-drilling copper (62.11% Cu, 4.00% Pb, balance Zn) rod less than 25.4 mm (1 in.) in diameter, previously extruded to a grain size of 0.050 mm. A 45,359 kg (100,000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the reduction in area: curve 1, 32%; curve 2, 19.5%; curve 3, 10%; curve 4, 32%, also annealed at 649 °C (1200 °F) for 1 h

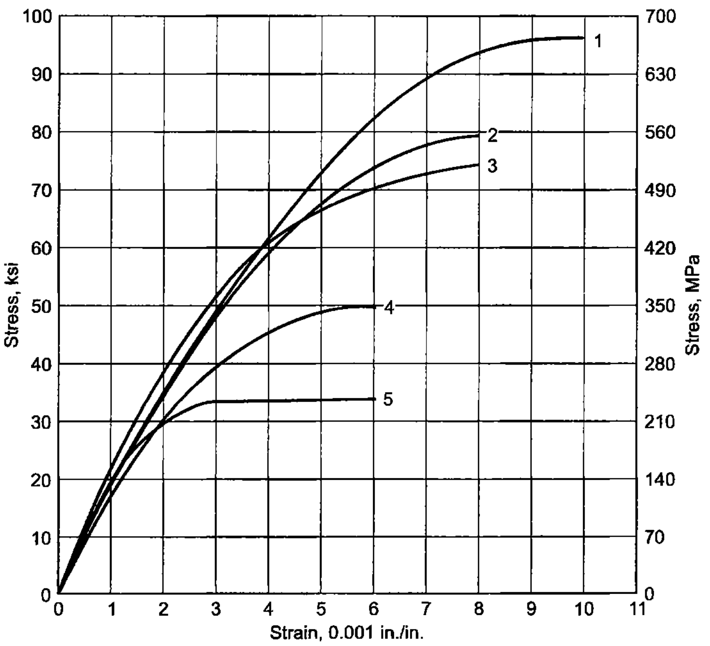
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 122



Cu.039 Forging brass (UNS C37700) forged rod, stress-strain curves showing effect of cold drawing

Standard brass (60.05% Cu, 2.12% Pb, balance Zn) forging rod less than 25.4 mm (1 in.) in diameter, previously extruded to a grain size of 0.010 mm. A 45,359 kg (100,000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the reduction in area: curve 1, 17.5%; curve 2, 8.5%; curve 3, 17.5%, also annealed at 482 °C (900 °F) for 1 h

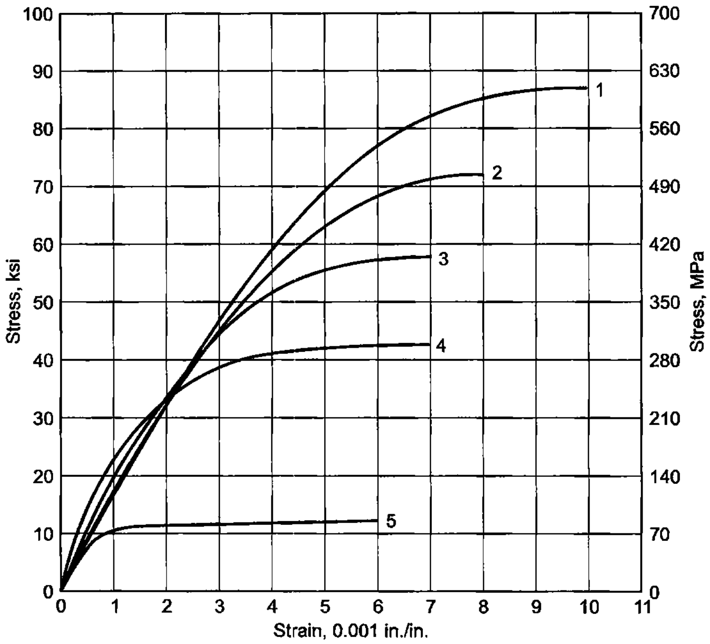
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 124



Cu.040 Pen-metal copper strip, stress-strain curves showing effect of cold rolling

Pen-metal copper (83.32% Cu, 1.32% Sn, balance Zn) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, this alloy is in the family of Cu-Zn-Sn tin brasses. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 538 °C (1000 °F) for 1 h

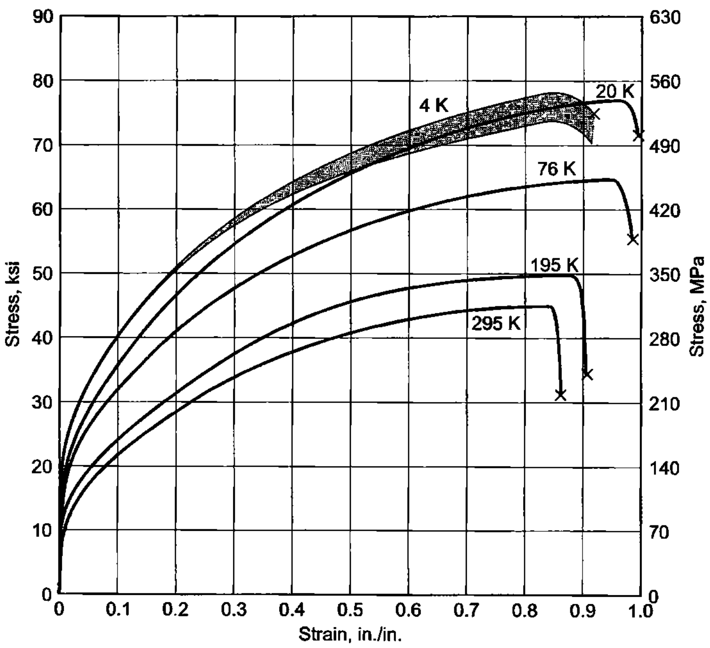
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 143



Cu.041 Pen-metal copper strip, stress-strain curves showing effect of cold rolling

Pen-metal copper (83.32% Cu, 1.32% Sn, balance Zn) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.080 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, this alloy is in the family of Cu-Zn-Sn tin brasses. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 704 °C (1300 °F) for 1 h

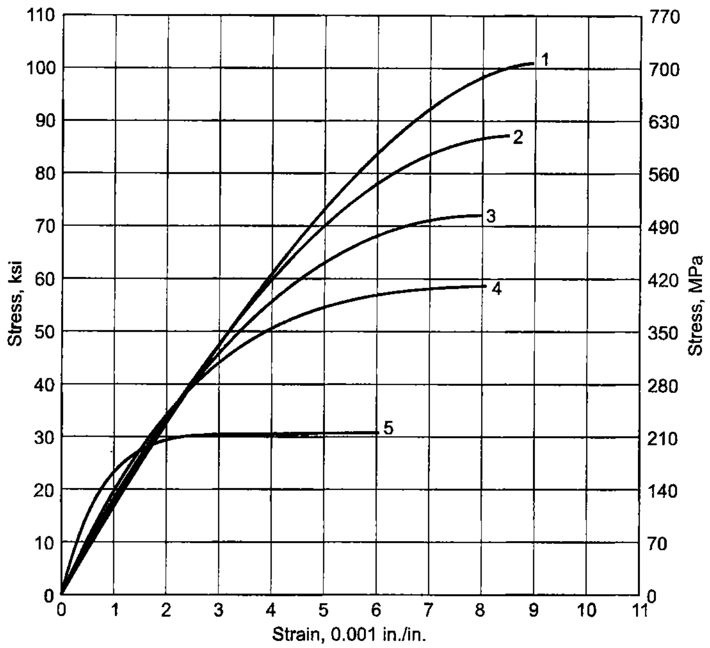
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 143



Cu.042 Admiralty brass (arsenical) (UNS C44300) bar, stress-strain curves showing effect of low temperatures

Bar in annealed condition. Bar thickness: 19 mm (3/4 in.)

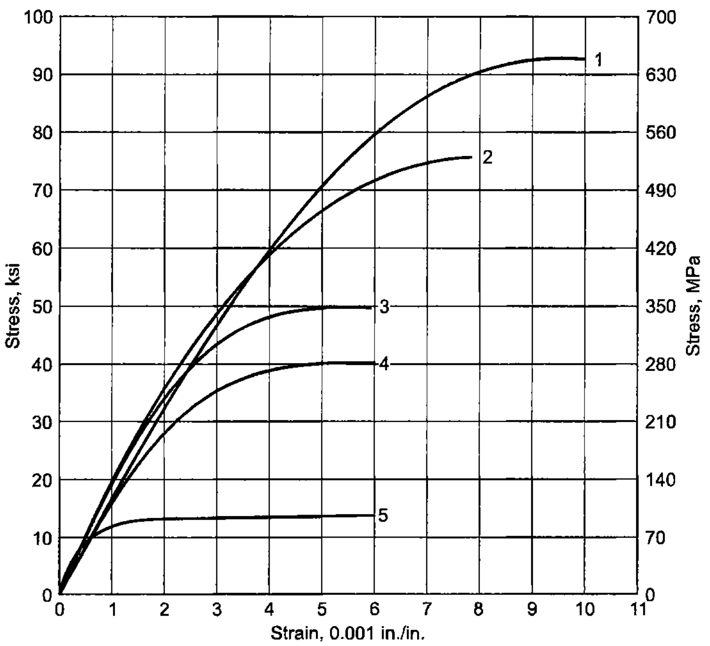
Source: R.P. Reed and R.P. Mikesell, *Low Temperature Mechanical Properties of Copper and Selected Copper Alloys*, NBS Monograph 101, Institute for Materials Research, National Bureau of Standards, 1967



Cu.043 Admiralty brass (antimonial) (UNS C44400) strip, stress-strain curves showing effect of cold rolling

Admiralty brass (70.37% Cu, 1.01% Sn, balance Zn) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 427 °C (800 °F) for 1 h

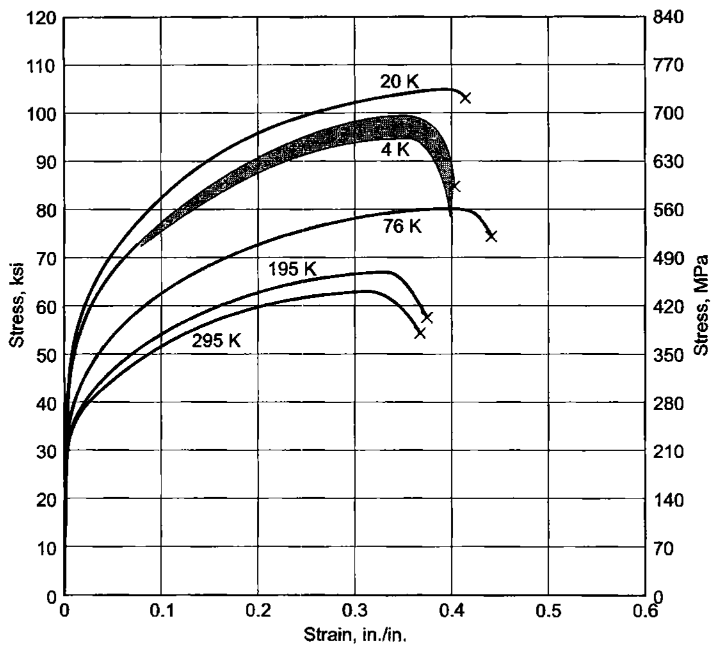
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 147



Cu.044 Admiralty brass (antimonial) (UNS C44400) strip, stress-strain curves showing effect of cold rolling

Admiralty brass (70.37% Cu, 1.01% Sn, balance Zn) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.080 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 649 °C (1200 °F) for 1 h

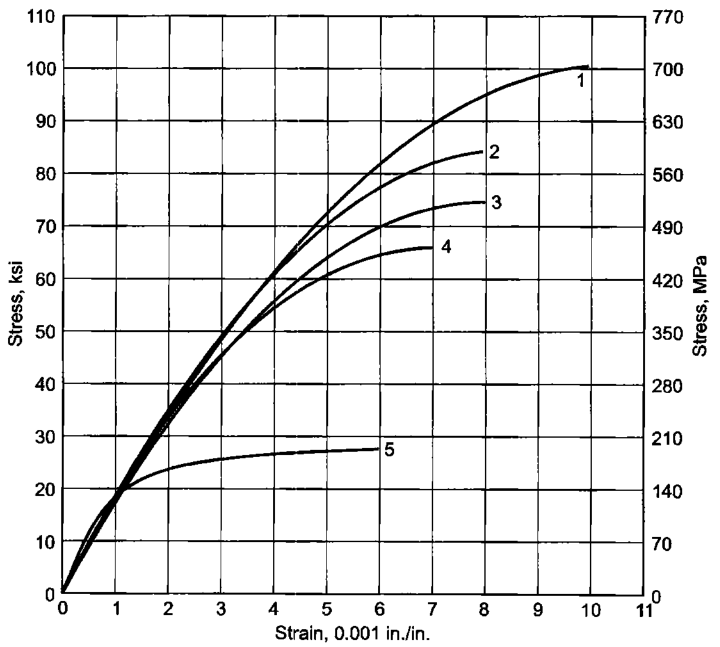
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 147



Cu.045 Naval brass (UNS C46400) bar, stress-strain curves showing effect of low temperatures

Bar in annealed condition. Bar thickness: 19 mm (3/4 in.)

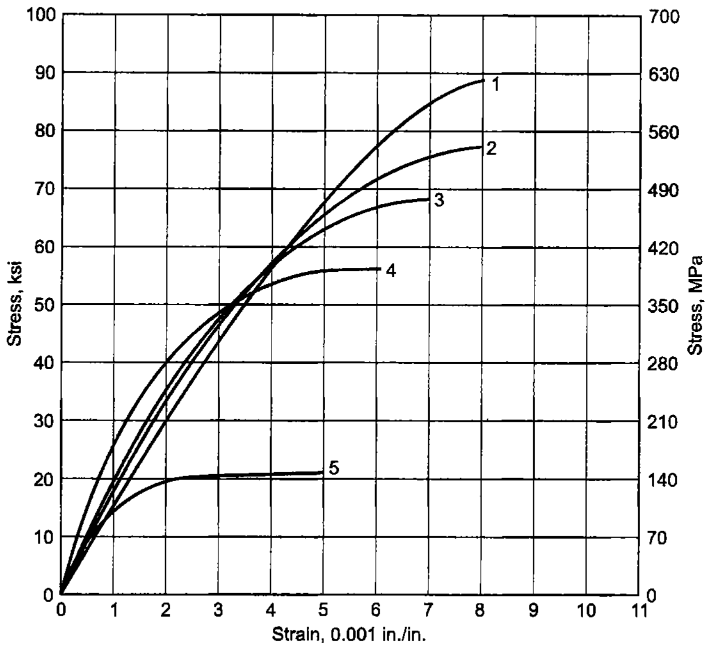
Source: R.P. Reed and R.P. Mikesell, *Low Temperature Mechanical Properties of Copper and Selected Copper Alloys*, NBS Monograph 101, Institute for Materials Research, National Bureau of Standards, 1967



Cu.046 Naval brass (UNS C46400) strip, stress-strain curves showing effect of cold rolling

Naval brass (61.51% Cu, 0.57% Sn, balance Zn) strip 1 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 482 °C (900 °F) for 1 h

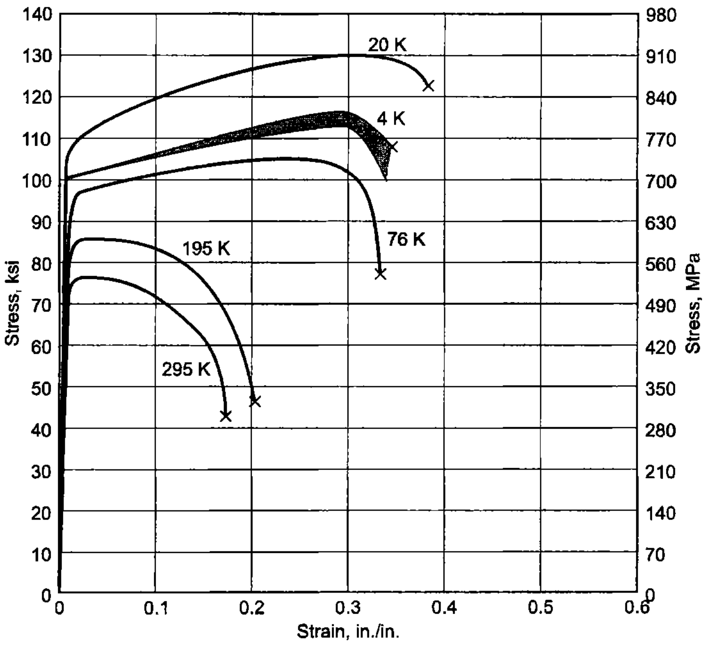
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 155



Cu.047 Naval brass (UNS C46400) strip, stress-strain curves showing effect of cold rolling

Naval brass (61.51% Cu, 0.57% Sn, balance Zn) strip 1 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.080 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 649 °C (1200 °F) for 1 h

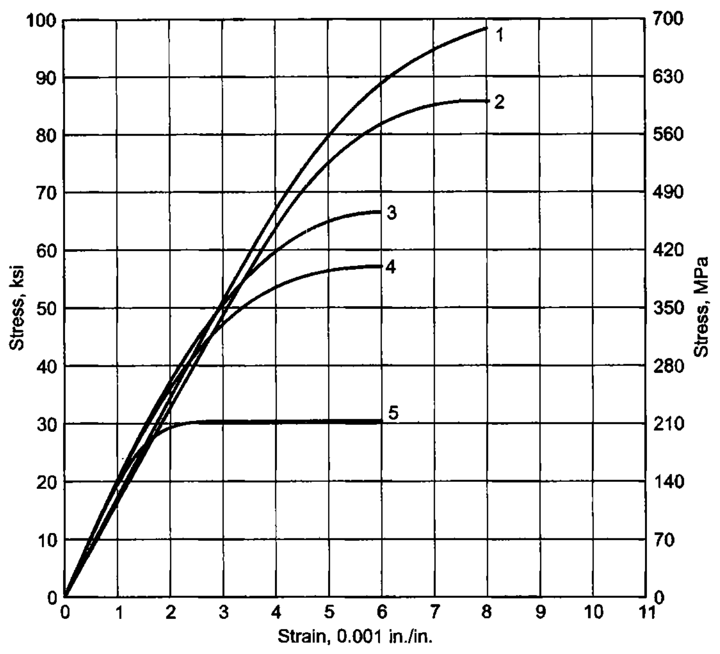
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 155



Cu.048 Phosphor bronze (UNS C51000) 5% grade A bar, stress-strain curves showing effect of low temperatures

Copper alloy No. 510 cold drawn 85%.
Bar thickness: 19 mm (3/4 in.)

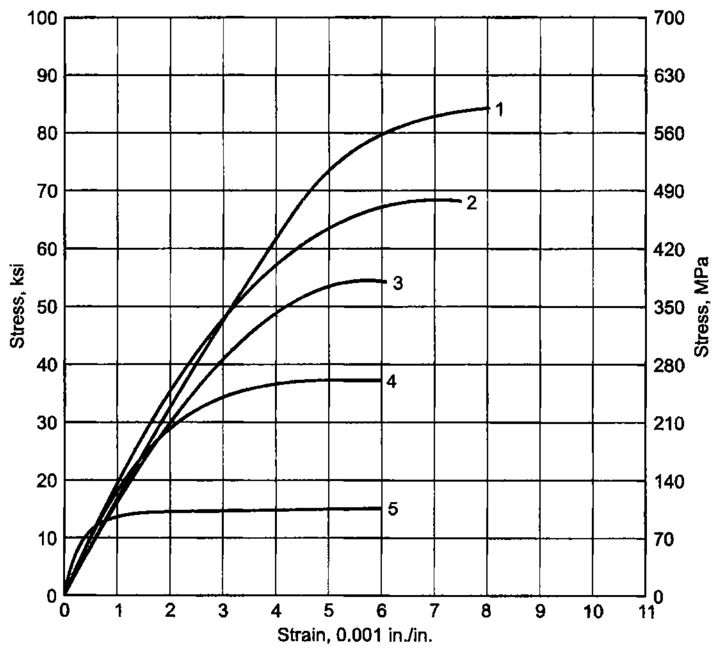
Source: R.P. Reed and R.P. Mikesell, *Low Temperature Mechanical Properties of Copper and Selected Copper Alloys*, NBS Monograph 101, Institute for Materials Research, National Bureau of Standards, 1967



Cu.049 Phosphor bronze (UNS C51000) 5% grade A strip, stress-strain curves showing effect of cold rolling

5% grade A phosphor bronze (4.09% Sn, 0.035% P, balance Cu) 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 538 °C (1000 °F) for 1 h

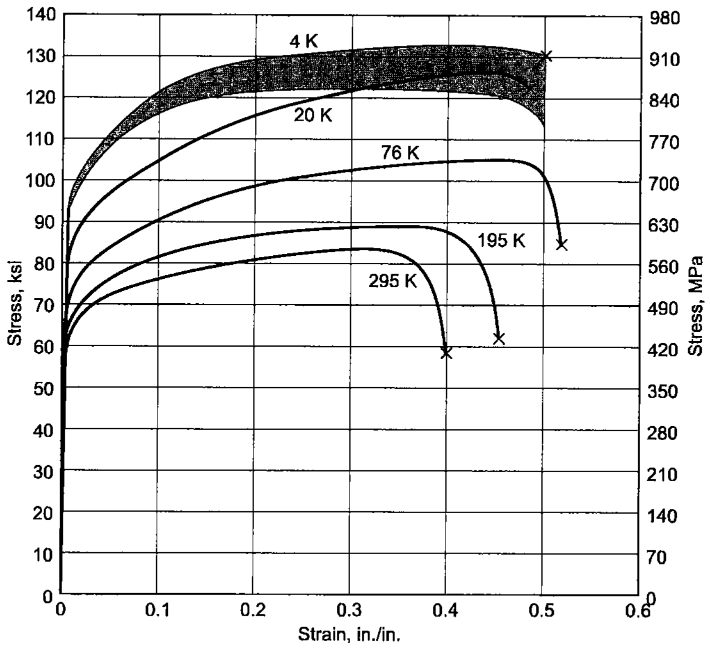
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 269



Cu.050 Phosphor bronze (UNS C51000) 5% grade A strip, stress-strain curves showing effect of cold rolling

5% grade A phosphor bronze (4.09% Sn, 0.035% P, balance Cu) 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.070 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 760 °C (1400 °F) for 1 h

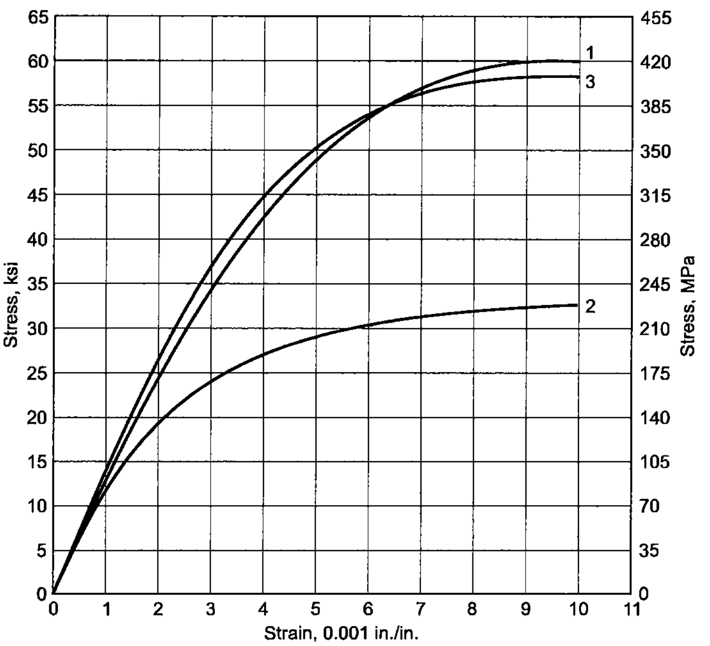
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 269



Cu.051 Aluminum bronze D (UNS C61400) bar, stress-strain curves showing effect of low temperatures

Bar in annealed condition. Bar thickness: 19 mm (3/4 in.)

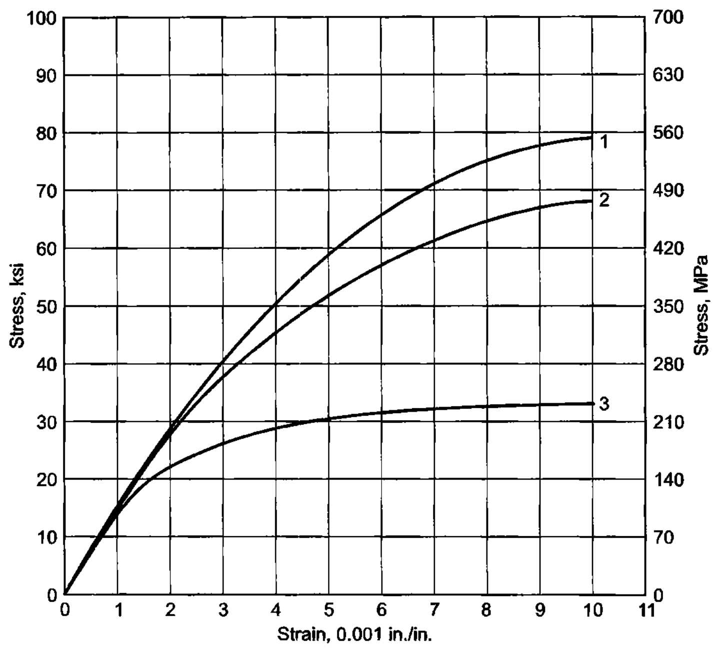
Source: R.P. Reed and R.P. Mikesell, *Low Temperature Mechanical Properties of Copper and Selected Copper Alloys*, NBS Monograph 101, Institute for Materials Research, National Bureau of Standards, 1967



Cu.052 Aluminum bronze (UNS C63000) extruded rod, stress-strain curves showing effect of cold working and annealing

10% aluminum bronze (88.83% Cu, 10.02% Al, 0.77% Fe, 0.31% Mn) previously extruded rod. Applicable to rod less than 25.4 mm (1.00 in.) diameter. A 45,350 kg (100,000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the reduction in area: curve 1, 5%; curve 2, 0% as extruded 25.4 mm (1 in.) diam; curve 3, 5%, also annealed at 260 °C (500 °F) for 1 h

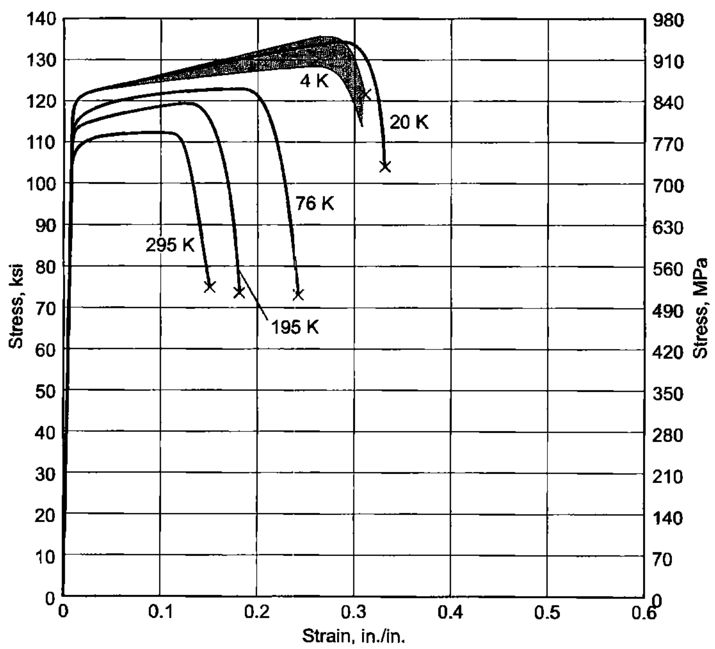
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 262



Cu.053 Silicon aluminum bronze (UNS C64210) rod, stress-strain curves showing effect of cold working and annealing

Silicon aluminum bronze (7.01% Al, 1.98% Si, balance Cu) previously extruded rod. Applicable to rod less than 25.4 mm (1 in.) in diameter. A 45,359 kg (100,000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the reduction in area: curve 1, 10.5%; curve 2, 8%; curve 3, 10.5%, also annealed at 649 °C (1200 °F) for 1 h

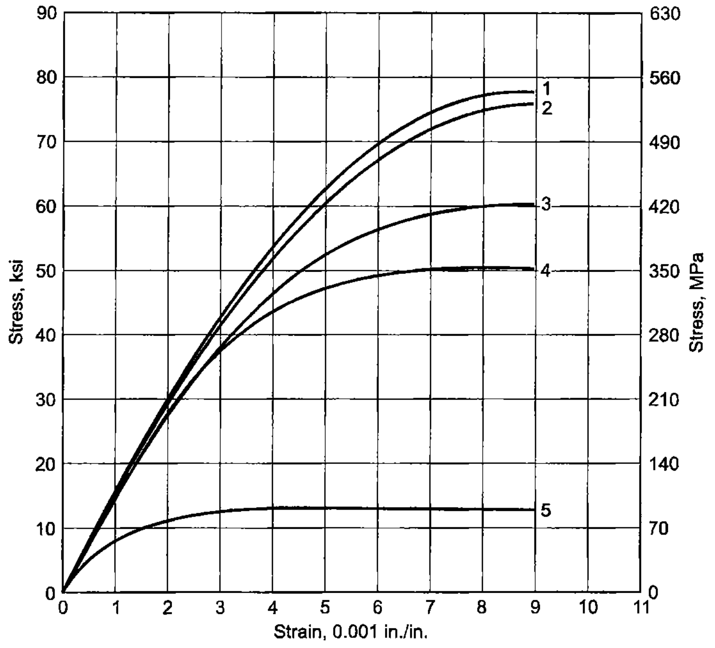
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 265



Cu.054 Copper-nickel-silicon (UNS C64700) bar, stress-strain curves showing effect of low temperatures

Bar thickness: 19 mm (3/4 in.). Aged at 450 °C (842 °F) for 2 h. This alloy was the strongest tested in this series of low-temperature tests.

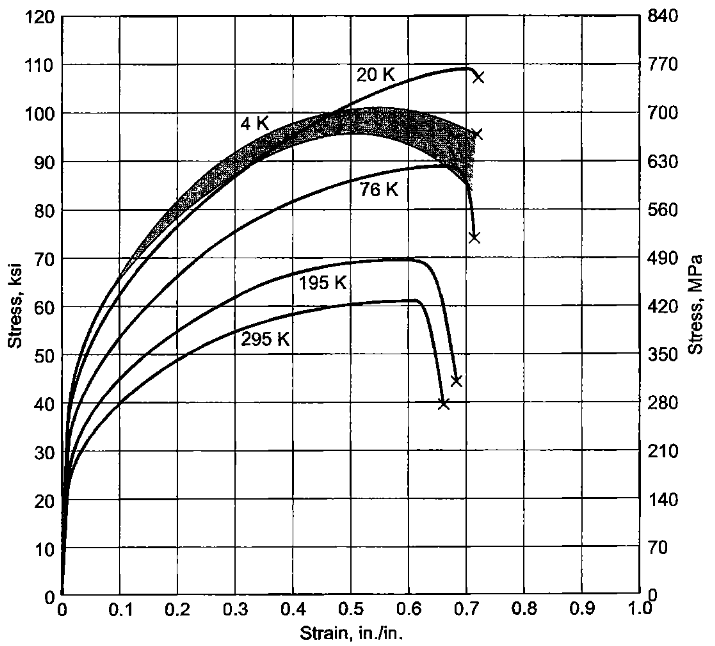
Source: R.P. Reed and R.P. Mikesell, *Low Temperature Mechanical Properties of Copper and Selected Copper Alloys*, NBS Monograph 101, Institute for Materials Research, National Bureau of Standards, 1967



Cu.055 Low-silicon bronze type B (UNS C65100) rod, stress-strain curves showing effect of cold drawing

Type B silicon bronze rod less than 25.4 mm (1 in.) diameter, (1.76% Si, 0.35% Mn, balance Cu) having a ready-to-finish grain size of 0.115 mm. A 45,359 kg (100,000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 649 °C (1200 °F) for 1 h

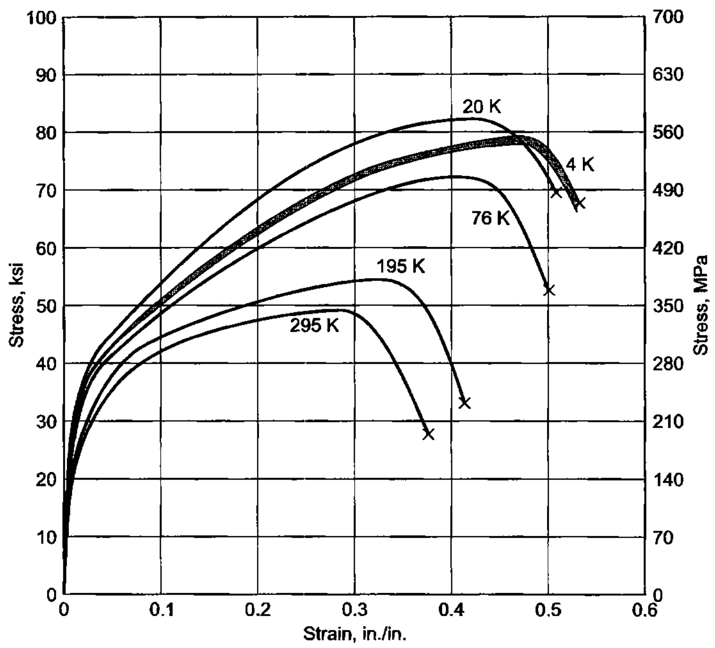
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 248



Cu.056 High-silicon bronze A (UNS C65500) bar, stress-strain curves showing effect of low temperatures

Specimen in annealed condition.
Bar thickness: 19 mm (3/4 in.)

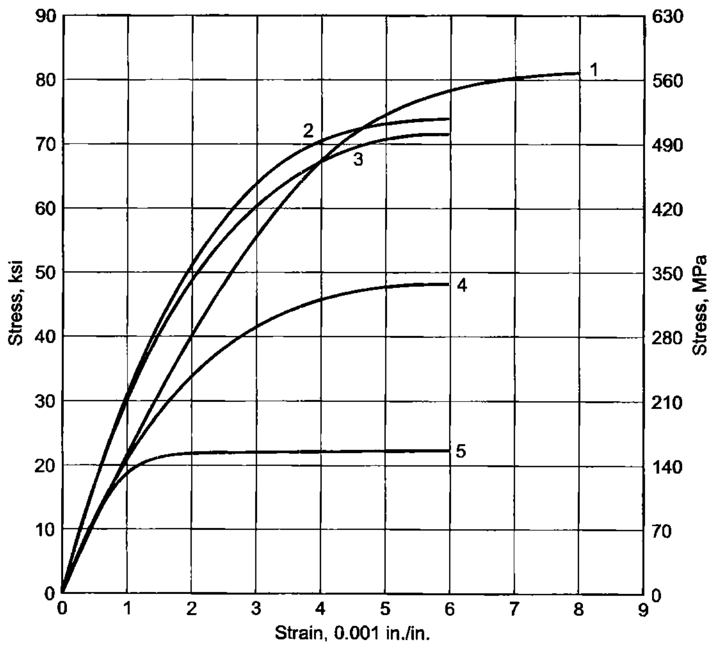
Source: R.P. Reed and R.P. Mikesell, *Low Temperature Mechanical Properties of Copper and Selected Copper Alloys*, NBS Monograph 101, Institute for Materials Research, National Bureau of Standards, 1967



Cu.057 Copper-nickel 10% (UNS C70600) bar, stress-strain curves showing effect of low temperatures

Specimen in annealed condition.
Bar thickness: 19 mm (3/4 in.)

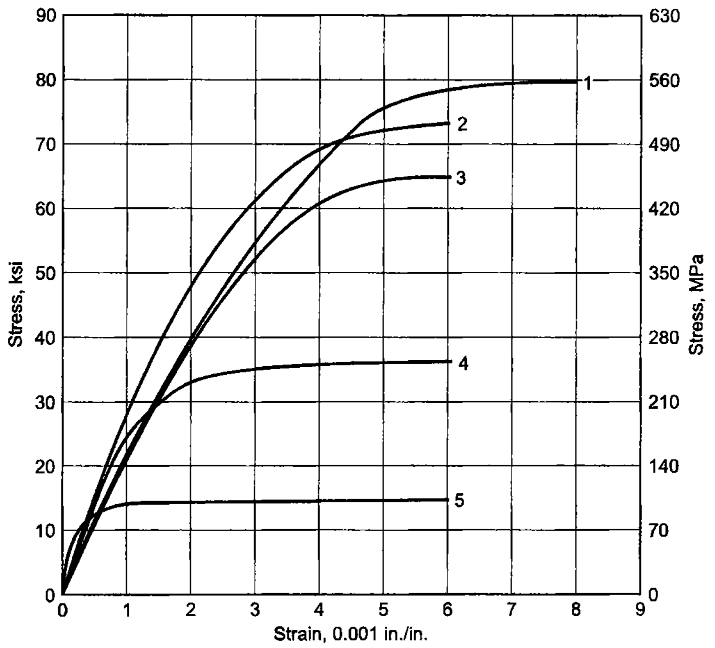
Source: R.P. Reed and R.P. Mikesell, *Low Temperature Mechanical Properties of Copper and Selected Copper Alloys*, NBS Monograph 101, Institute for Materials Research, National Bureau of Standards, 1967



Cu.058 Copper-nickel 20% (UNS C71000) strip, stress-strain curves showing effect of cold rolling

80-20 copper-nickel (78.18% Cu, 20.65% Ni, 0.51% Mn) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 649 °C (1200 °F) for 1 h.

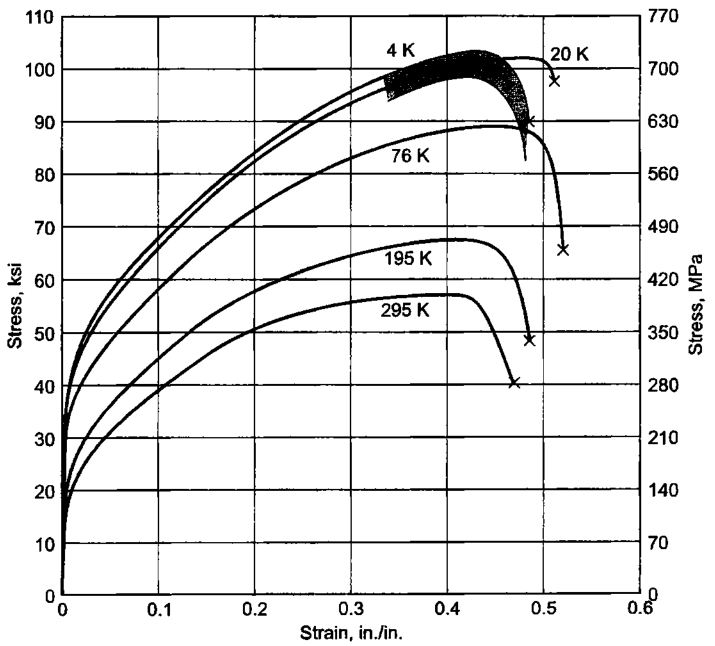
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 237



Cu.059 Copper-nickel 20% (UNS C71000) strip, stress-strain curves showing effect of cold rolling

80-20 copper-nickel (78.18% Cu, 20.65% Ni, 0.51% Mn) strip 1 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.055 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 871 °C (1600 °F) for 1 h

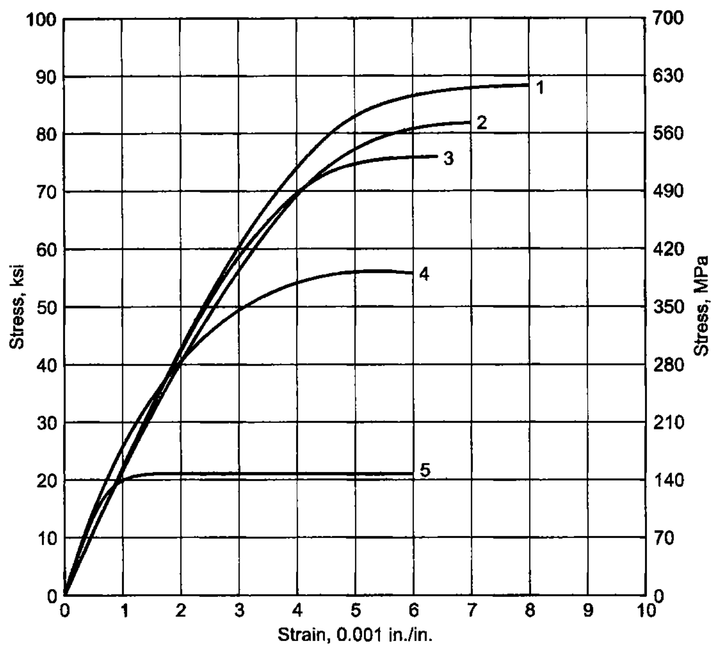
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 237



Cu.060 Copper-nickel 30% (UNS C71500) bar, stress-strain curves showing effect of low temperatures

Specimen in annealed condition.
Bar thickness: 19 mm (3/4 in.)

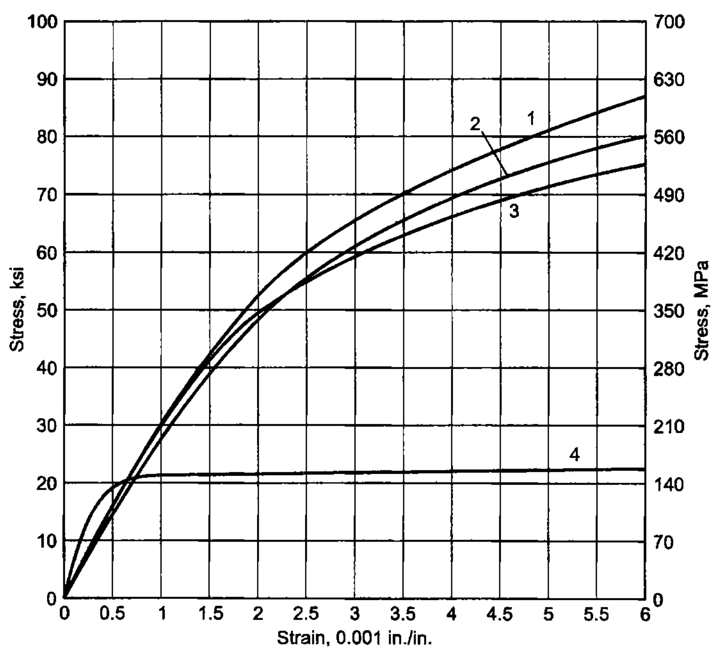
Source: R.P. Reed and R.P. Mikesell, *Low Temperature Mechanical Properties of Copper and Selected Copper Alloys*, NBS Monograph 101, Institute for Materials Research, National Bureau of Standards, 1967



Cu.061 Copper-nickel 30% (UNS C71500) strip, stress-strain curves showing effect of cold rolling

70-30 copper-nickel (68.94% Cu, 29.61% Ni) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 704 °C (1300 °F) for 1 h

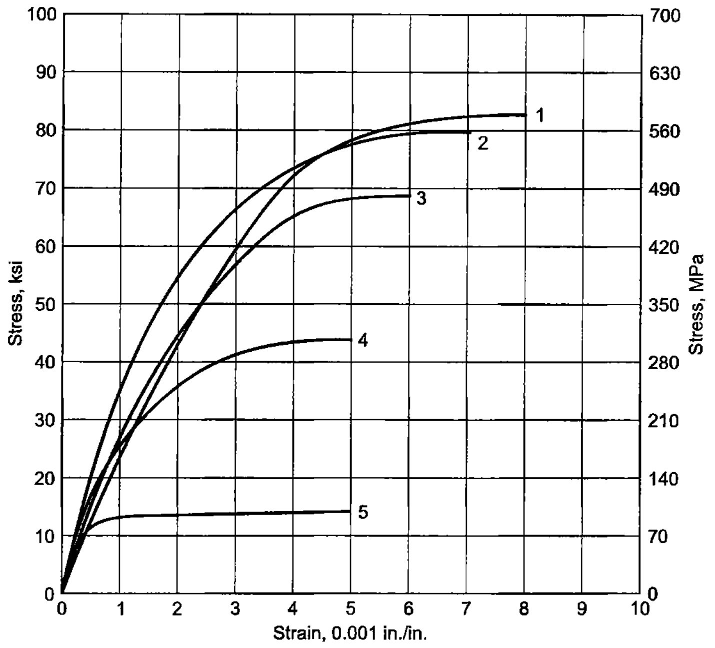
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 230



Cu.062 Copper-nickel 30% (UNS C71500) rod, stress-strain curves showing effect of cold drawing

70-30 copper-nickel (68.56% Cu, 30.48% Ni, 0.39% Fe, 0.57% Mn) rod, having a ready-to-finish grain size of 0.035 mm. A 45,359 kg (100,000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 704 °C (1300 °F) for 1 h

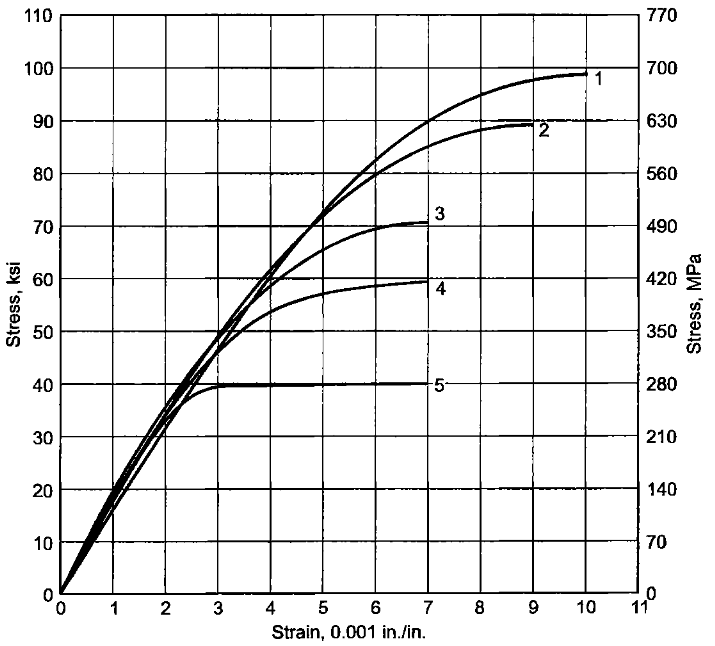
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 233



Cu.063 Copper-nickel 30% (UNS C71500) strip, stress-strain curves showing effect of cold rolling

70-30 copper-nickel (68.94% Cu, 29.61% Ni) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.070 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 871 °C (1600 °F) for 1 h

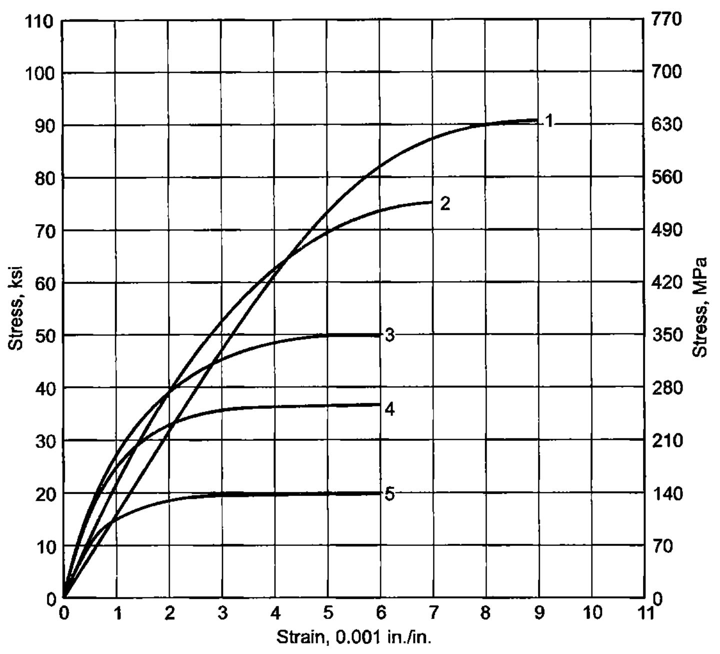
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 230



Cu.064 Nickel silver (UNS C74400) strip, stress-strain curves showing effect of cold rolling

5% nickel silver (63.55% Cu, 5.14% Ni, balance Zn) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 482°C (900 °F) for 1 h

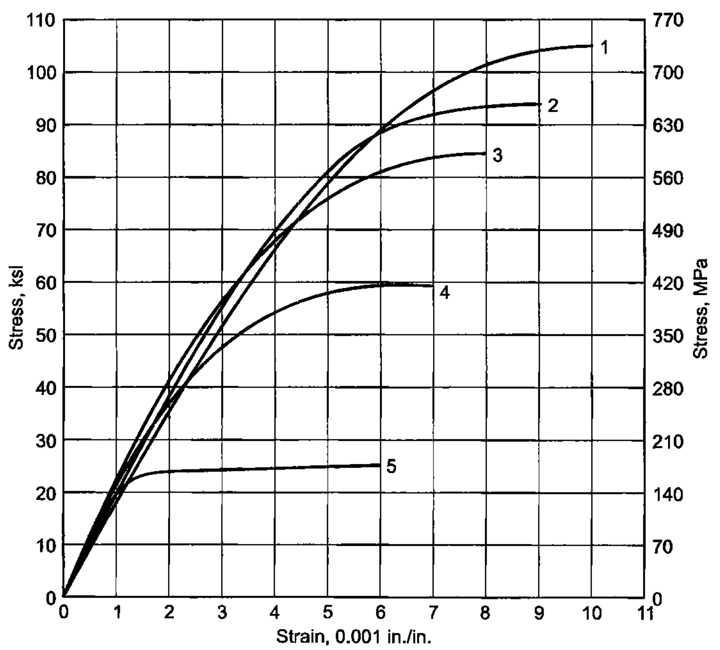
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 220



Cu.065 Nickel silver (UNS C74400) strip, stress-strain curves showing effect of cold rolling

5% nickel silver (63.55% Cu, 5.14% Ni, balance Zn) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.110 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 760 °C (1400 °F) for 1 h

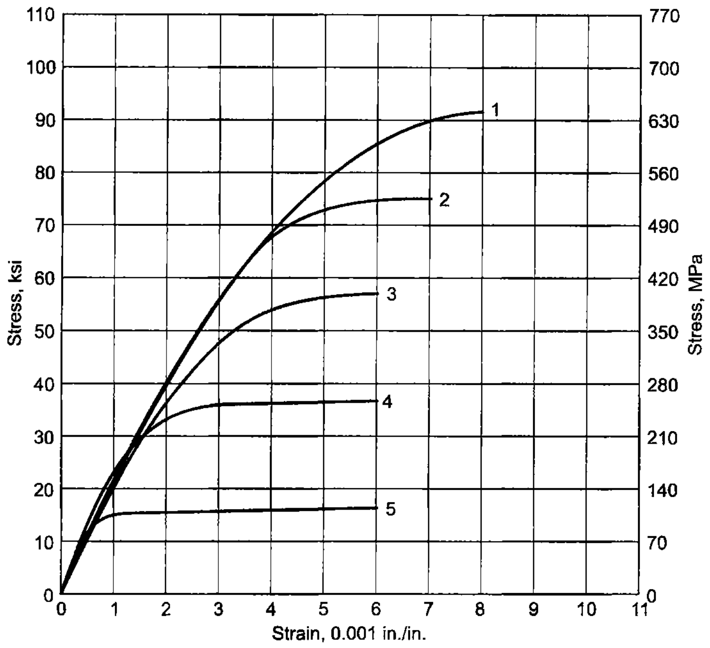
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 220



Cu.066 Nickel silver (UNS C74500) strip, stress-strain curves showing effect of cold rolling

10% nickel silver (66.02% Cu, 10.73% Ni, balance zinc) strip, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 593 °C (1100 °F) for 1 h

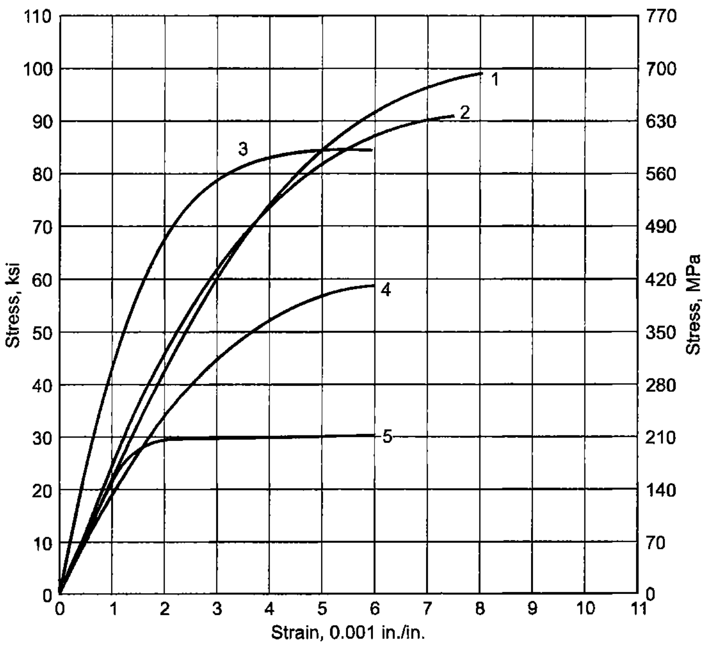
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 215



Cu.067 Nickel silver (UNS C74500) strip, stress-strain curves showing effect of cold rolling

10% nickel silver (66.02% Cu, 10.73% Ni, balance zinc) strip, having a ready-to-finish grain size of 0.080 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 704 °C (1300 °F) for 1 h

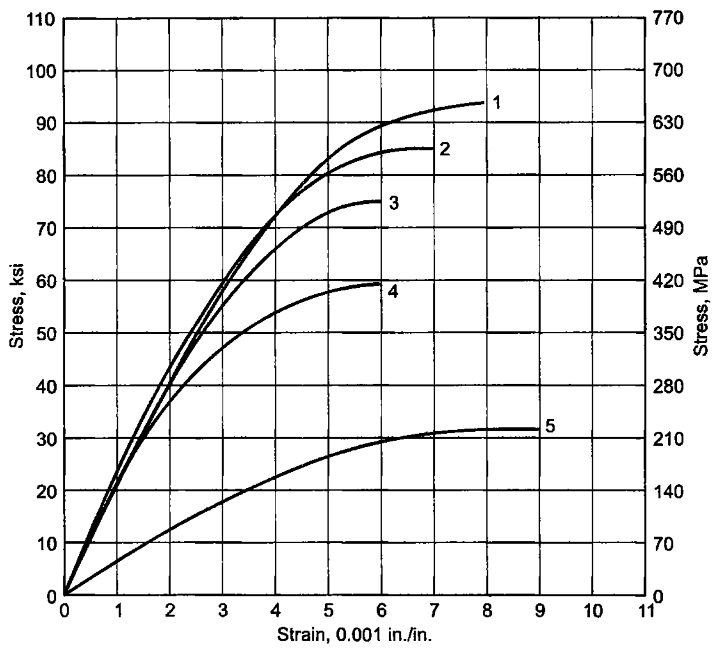
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 215



Cu.068 Nickel silver 65-18 (UNS C75200) strip, stress-strain curves showing effect of cold rolling

18% deep-drawing nickel silver (66.00% Cu, 18.00% Ni, balance Zn) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 593 °C (1100 °F) for 1 h

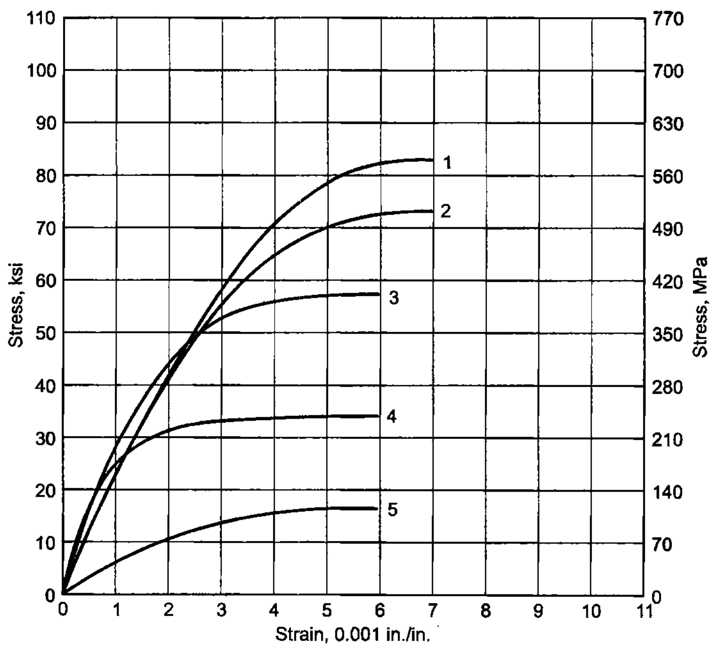
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 200



Cu.069 Nickel silver (UNS C75400) strip, stress-strain curves showing effect of cold rolling

15% nickel silver (66.18% Cu, 15.05% Ni, balance Zn) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 593 °C (1100 °F) for 1 h

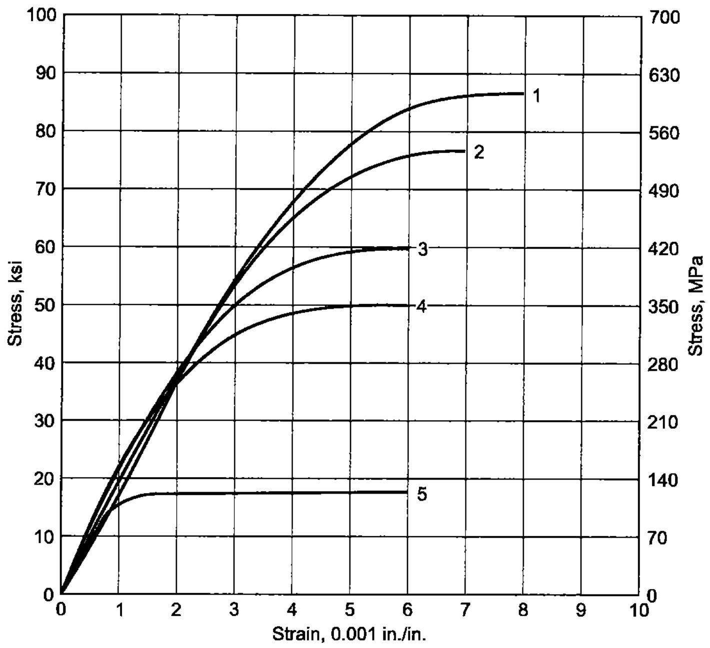
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 208



Cu.070 Nickel silver (UNS C75400) strip, stress-strain curves showing effect of cold rolling

15% nickel silver (66.18% Cu, 15.05% Ni, balance Zn) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.100 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 760 °C (1400 °F) for 1 h

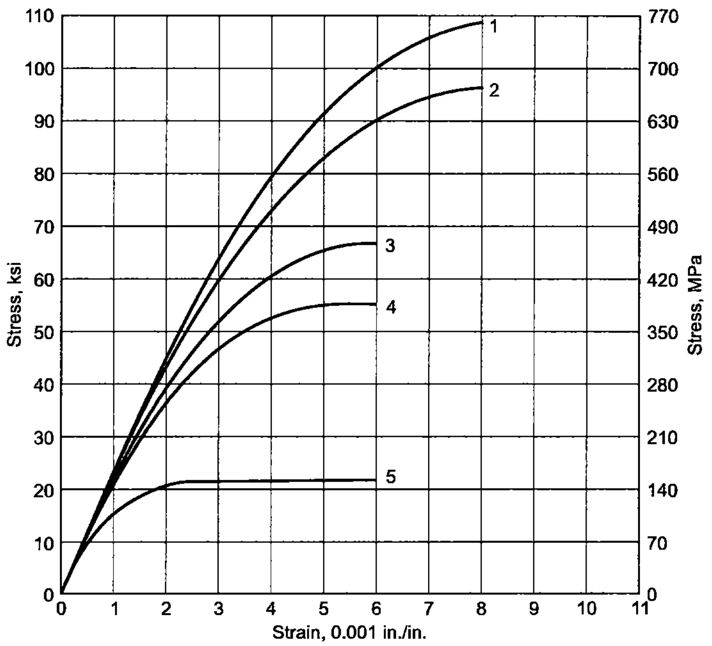
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 208



Cu.071 Nickel silver 65-12 (UNS C75700) strip, stress-strain curves showing effect of cold rolling

12% nickel silver (66.24% Cu, 11.57% Ni, balance Zn) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.080 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 760 °C (1400 °F) for 1 h

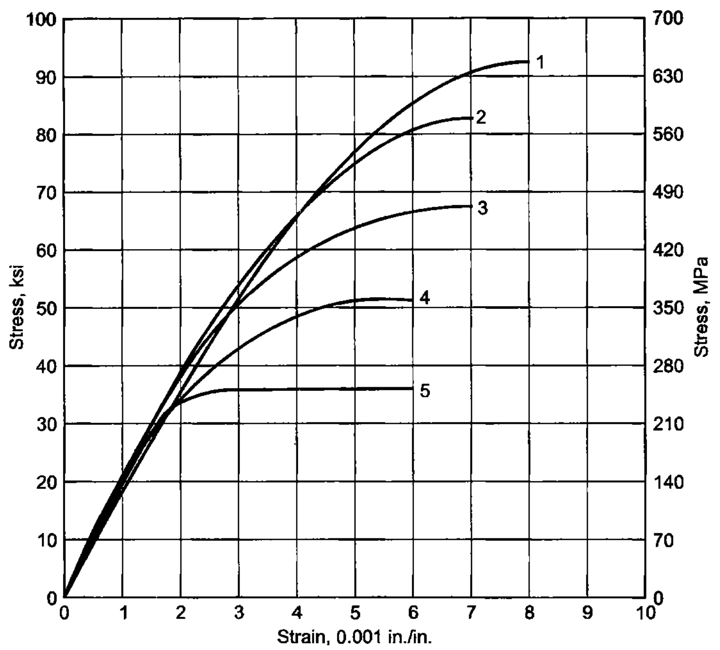
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 212



Cu.072 Nickel silver 55-18 (UNS C77000) strip, stress-strain curves showing effect of cold rolling

18% spring-stock nickel silver (56.56% Cu, 17.77% Ni, balance Zn) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.080 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 760 °C (1400 °F) for 1 h

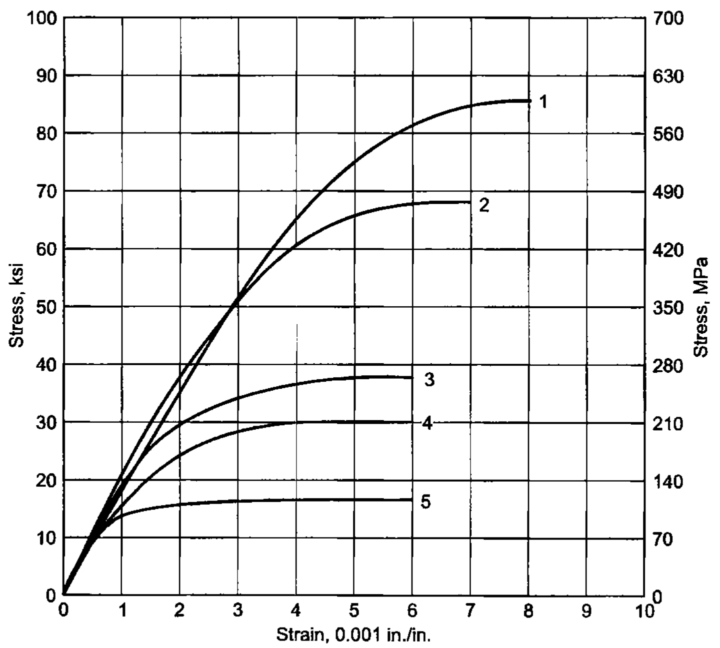
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 203



Cu.073 Leaded nickel silver (UNS C79000) strip, stress-strain curves showing effect of cold working

Leaded 12% nickel silver (65.49% Cu, 12.11% Ni, 1.96% Pb, balance Zn), strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60..5; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 538 °C (1000 °F) for 1 h

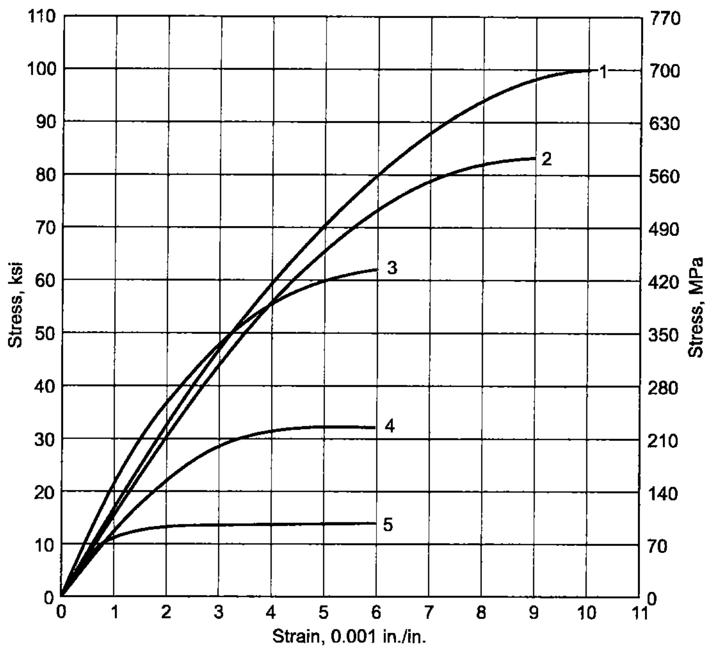
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 225



Cu.074 Leaded nickel silver (UNS C79000) strip, stress-strain curves showing effect of cold working

Leaded 12% nickel silver (65.49% Cu, 12.11% Ni, 1.96% Pb, balance Zn) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.060 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The tests predate the UNS designations, but the closest current designation is given for reference. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 816 °C (1500 °F) for 1 h

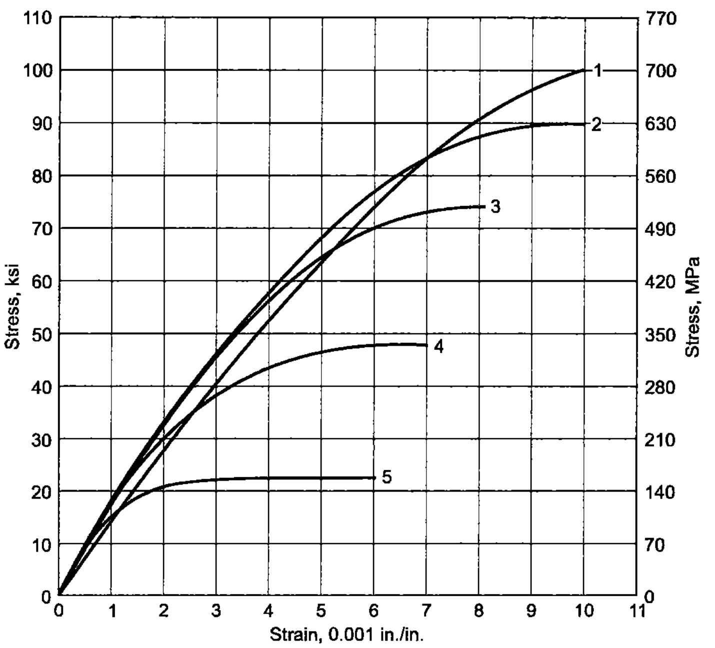
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 225



Cu.075 Silicon brass No. 1 strip, stress-strain curves showing effect of cold rolling

Silicon brass No. 1 (77.74% Cu, 1.30% Si, balance Zn) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.090 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used These tests were conducted in accordance with ASTM E 8. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 704 °C (1300 °F) for 1 h

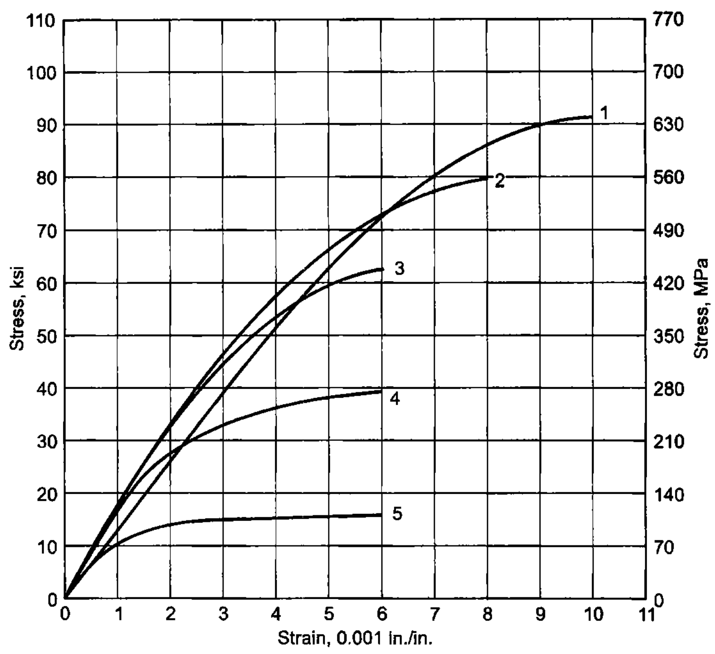
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 181



Cu.076 Silicon brass No. 2 strip, stress-strain curves showing effect of cold rolling

Silicon brass No. 2 (72.36% Cu, 0.47% Si, balance Zn) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.015 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 538 °C (1000 °F) for 1 h

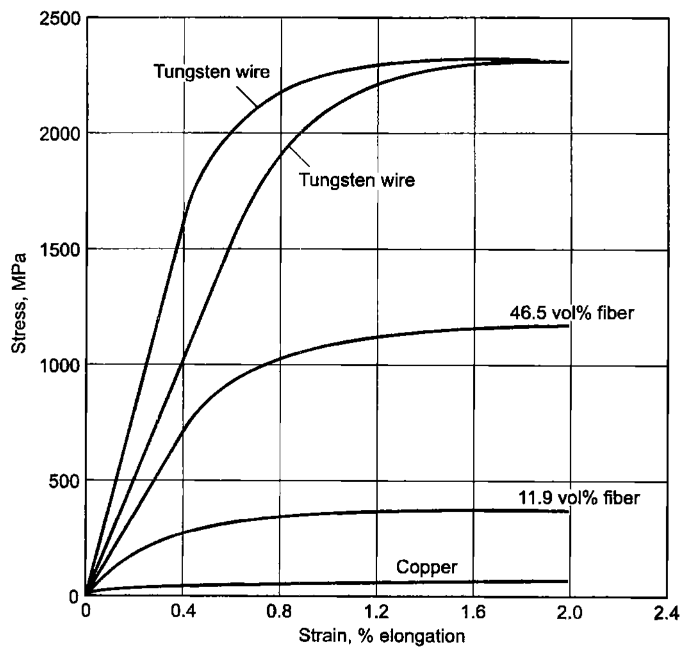
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 185



Cu.077 Silicon brass No. 2 strip, stress-strain curves showing effect of cold rolling

Silicon brass No. 2 (72.36% Cu, 0.47% Si, balance Zn) strip 1.0 mm (0.040 in.) thick, having a ready-to-finish grain size of 0.080 mm. A 2268 kg (5000 lb) capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.254 μm (10 μin.) were used. These tests were conducted in accordance with ASTM E 8. The cold working of each specimen was defined by the change in strip thickness based on the Brown and Sharpe (B&S) wire gage and the reduction in area (RA) and was then assigned a commercial temper designation. Curve 1: B&S, 8; RA, 60.5%; temper, spring. Curve 2: B&S, 4; RA, 37.2%; temper, hard. Curve 3: B&S, 2; RA, 20.7%; temper, half hard. Curve 4: B&S, 1; RA, 11.0%; temper, quarter hard. Curve 5: B&S, 6; RA, 50.0%; temper, extra hard; annealed at 649 °C (1200 °F) for 1 h

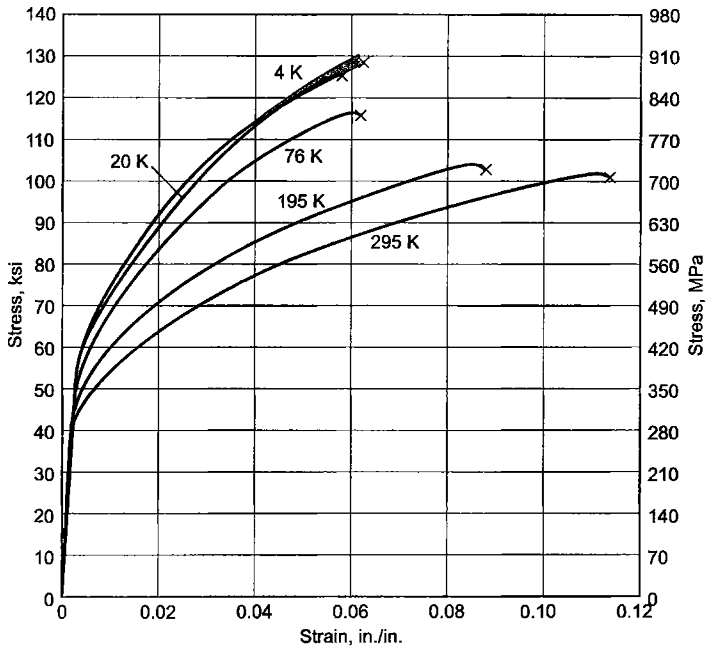
Source: R.A. Wilkins and E.S. Bunn, *Copper and Copper Base Alloys*, McGraw-Hill, 1943, p 185



Cu.078 Tungsten copper composite wires, comparison of stress-strain curves

Experimental composites with tungsten wires in a copper matrix at the volume percentage shown.

Source: R.W.K. Honeycombe, *The Plastic Deformation of Metals*, 2nd ed., American Society for Metals, 1984, p 260 (After D.L. McDanels, R.W. Jech, and J.W. Weeton, *Metal Progress*, Vol 78, Dec 1960, p 118)

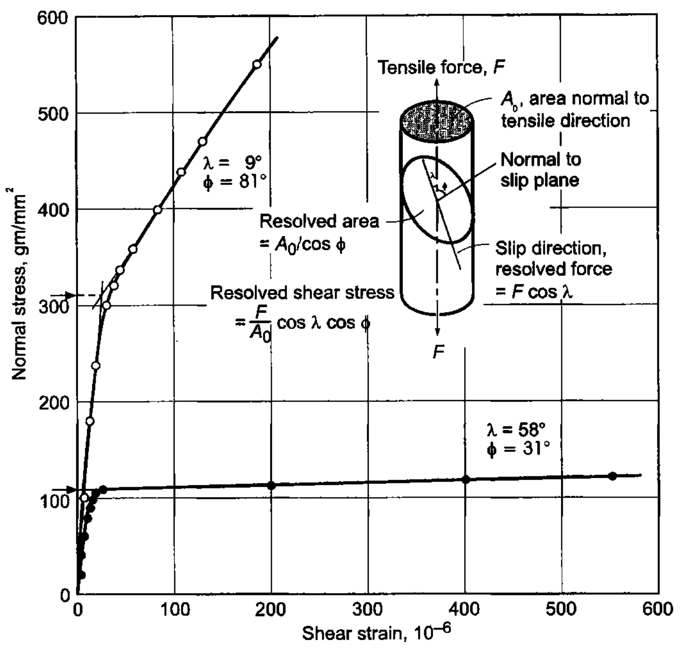


Cu.079 Copper-nickel-aluminum sand cast billet, stress-strain curves showing effect of low temperatures

As cast. Brittle at low temperature. Composition: 9.95% Al, 5.20% Ni, 3.35% Fe, 0.3% Mn, balance Cu

Source: R.P. Reed and R.P. Mikesell, *Low Temperature Mechanical Properties of Copper and Selected Copper Alloys*, NBS Monograph 101, Institute for Materials Research, National Bureau of Standards, 1967

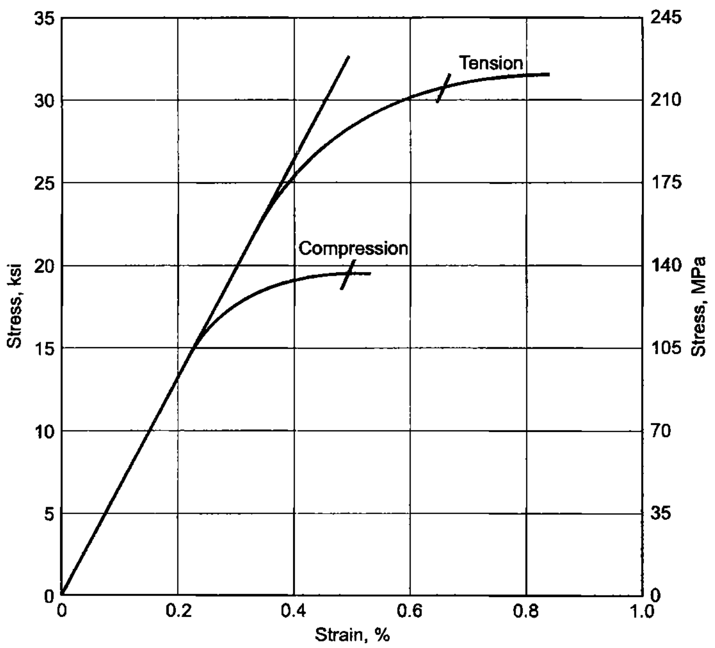
Magnesium (Mg)



Mg.001 Magnesium single crystal, stress-strain curves

Arrows indicate yield strengths. Relationship between specimen and slip plane orientation is shown.

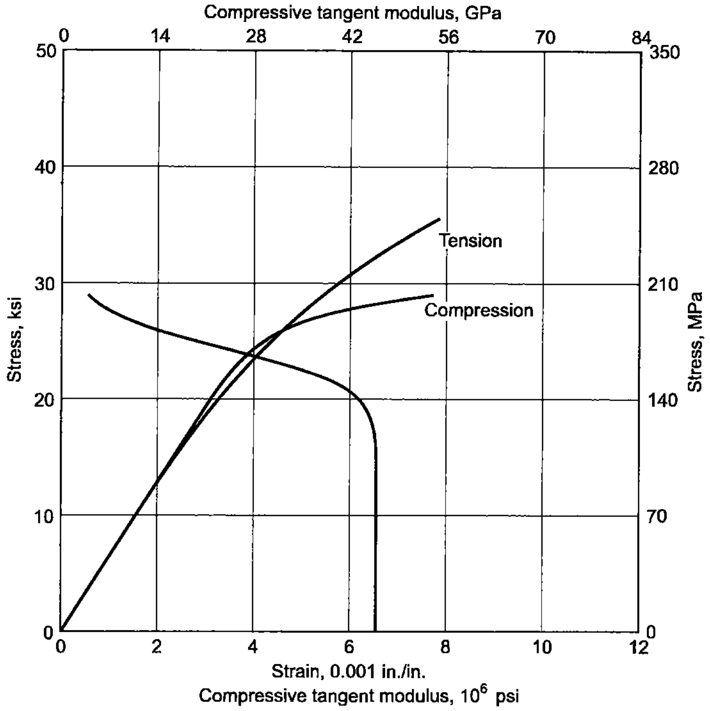
Source: C.R. Brooks, *Heat Treatment, Structure, and Properties of Nonferrous Alloys,* American Society for Metals, 1982, p 6 (as published in E.C. Burk and W. R. Hibbard, *Trans AIME,* Vol 194, 1952, p 295)



Mg.002 AZ31B-F magnesium alloy extrusion, tensile and compressive stress-strain curves

Composition: Mg-3Al-1Zn. UNS M11311

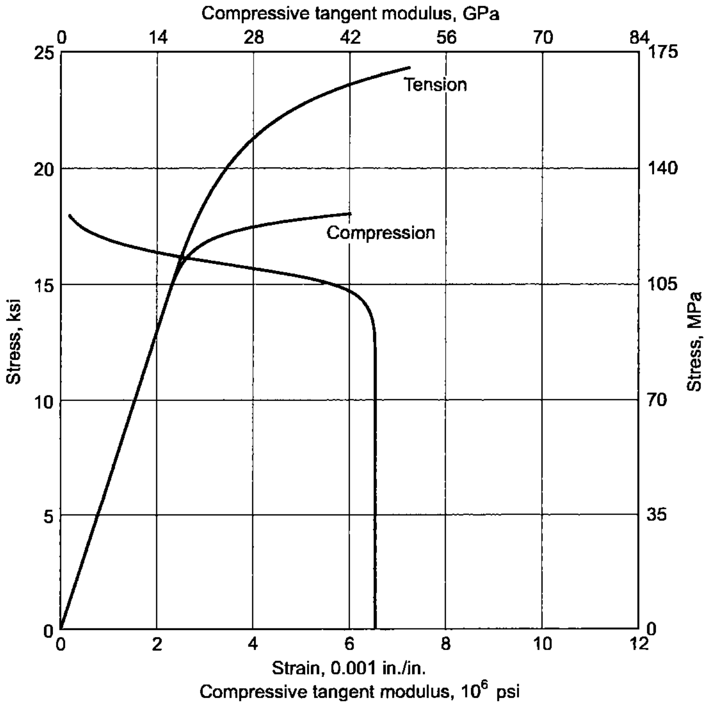
Source: *ASM Specialty Handbook, Magnesium and Magnesium Alloys,* ASM International, 1999, p 166



Mg.003 AZ31B-H24 magnesium alloy sheet, tensile and compressive stress-strain and compressive tangent modulus curves

Typical room-temperature values. Ramberg-Osgood parameter: n(tension) = 4.3; n(compression) = 15. Composition: Mg-3Al-1Zn. UNS M11311

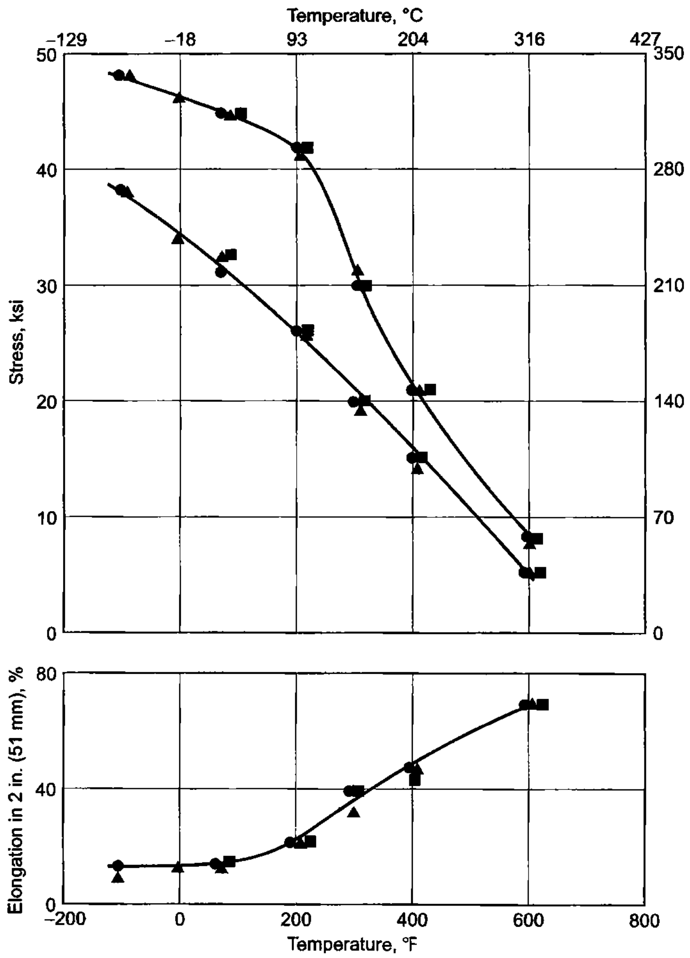
Source: *MIL-HDBK-5H,* Dec 1998, p 4–14



Mg.004 AZ31B-O magnesium alloy sheet and plate, tensile and compressive stress-strain and compressive tangent modulus curves

Typical room-temperature values. Ramberg-Osgood parameter: n(longitudinal, tension) = 12, n(longitudinal, compression) = 30. Composition: Mg-3Al-1Zn. UNS M11311

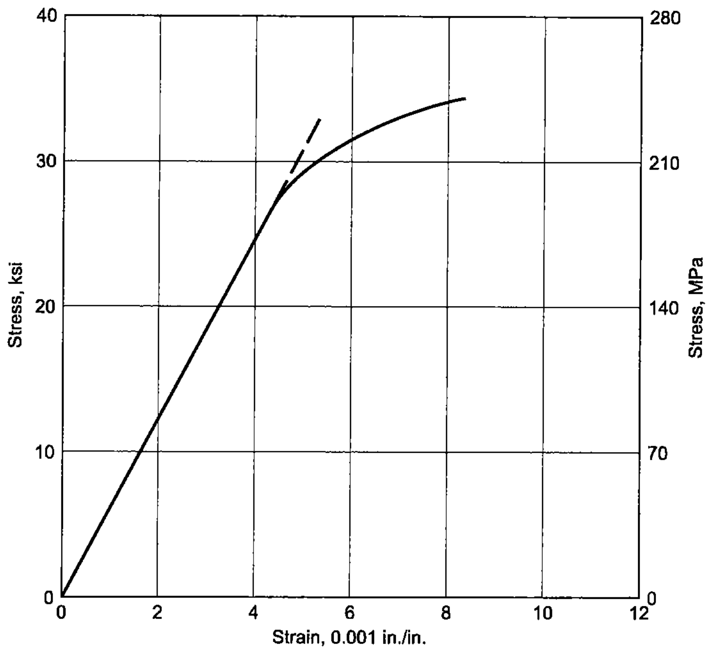
Source: *MIL-HDBK-5H,* Dec 1998, p 4–11



Mg.005 AZ61A magnesium alloy extrusion, low- and high-temperature effects on tensile properties

F_{tu}, ultimate tensile strength; F_{ty}, tensile yield strength. Composition: Mg-6Al-1Zn. UNS M11610

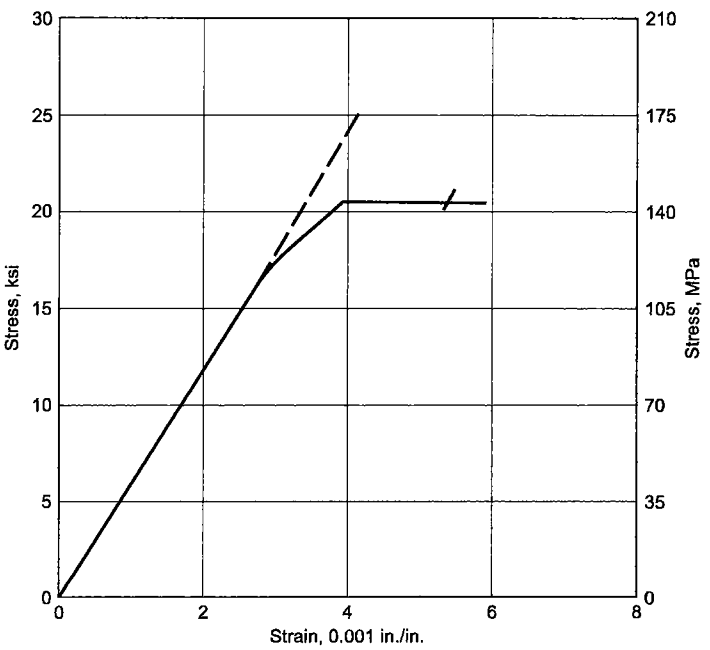
Data from three sources: circle, Mg-43, *Alloy Digest*, Aug 1959; triangle, *Properties and Selection of Metals*, Vol 1, 8th ed., *Metals Handbook*, American Society for Metals, 1961; square, C.R. Tipton, *Reactor Handbook*, Vol I, 2nd ed., Interscience Publishing, 1960. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3603, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 3



Mg.006 AZ61A magnesium alloy extrusion, tensile stress-strain curve

Composition: Mg-6Al-1Zn. UNS M11610

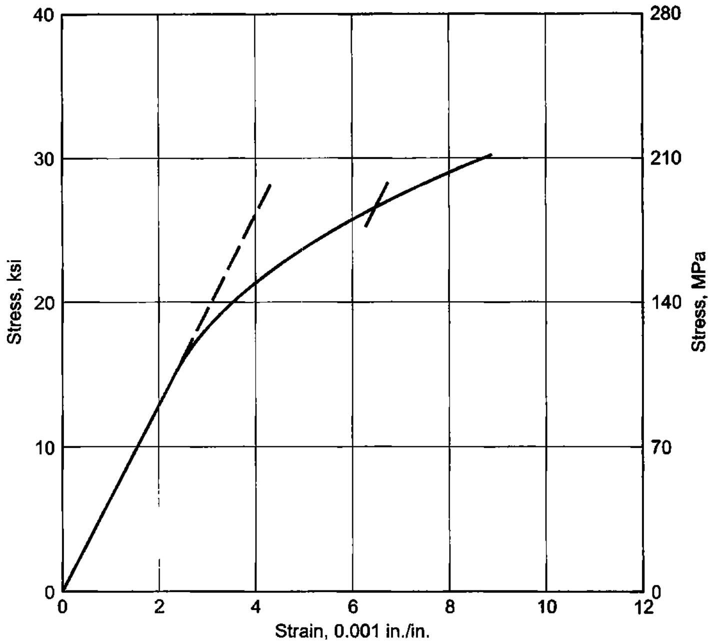
Source: "Magnesium Design," Dow Chemical Co., 1957. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3603, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 3



Mg.007 AZ61A magnesium alloy extrusion, compressive stress-strain curve

Composition: Mg-6Al-1Zn. UNS M11610

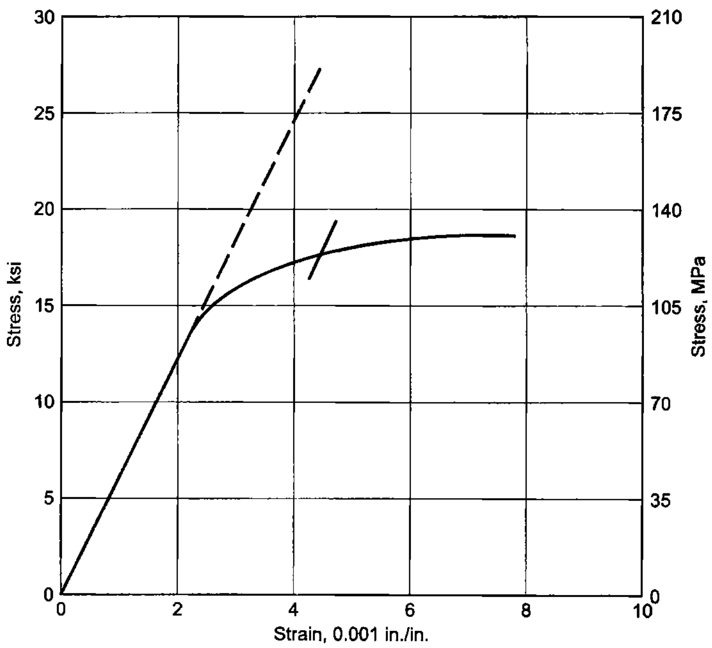
Source: "Magnesium Design," Dow Chemical Co., 1957. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3603, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 4



Mg.008 AZ61A magnesium alloy forging, tensile stress-strain curve

Composition: Mg-6Al-1Zn. UNS M11610

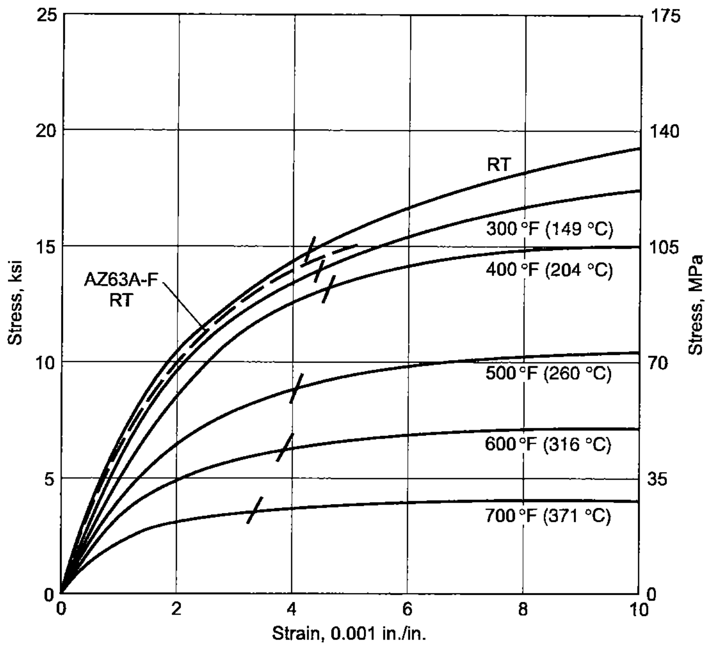
Source: "Magnesium Design," Dow Chemical Co., 1957. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3603, CINDAS/ USAF CRDA Handbooks Operation, Purdue University, 1995, p 3



Mg.009 AZ61A magnesium alloy forging, compressive stress-strain curve

Composition: Mg-6Al-1Zn. UNS M11610

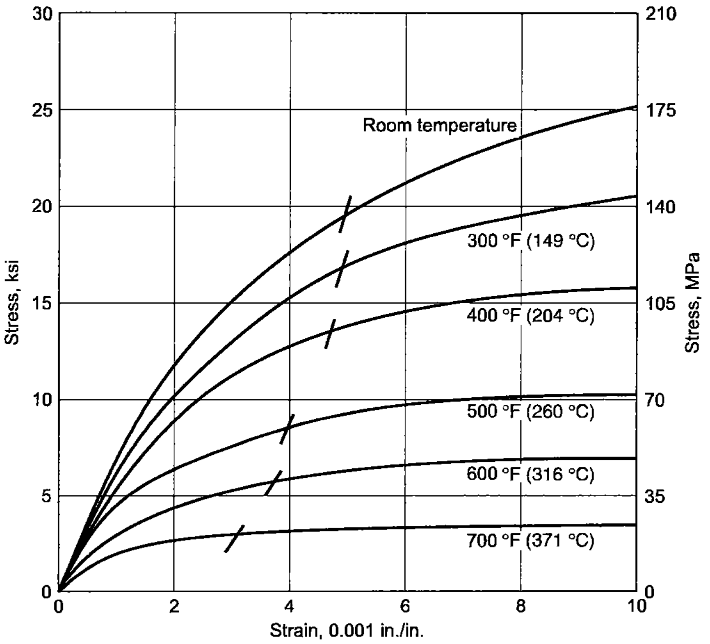
Source: "Magnesium Design," Dow Chemical Co., 1957. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3603, CINDAS/ USAF CRDA Handbooks Operation, Purdue University, 1995, p 4



Mg.010 AZ63A-F, AZ63A-T4 magnesium alloy sand cast bar, tensile stress-strain curves at room and elevated temperatures

RT, room temperature. Composition: Mg-6Al-3Zn. UNS M11630

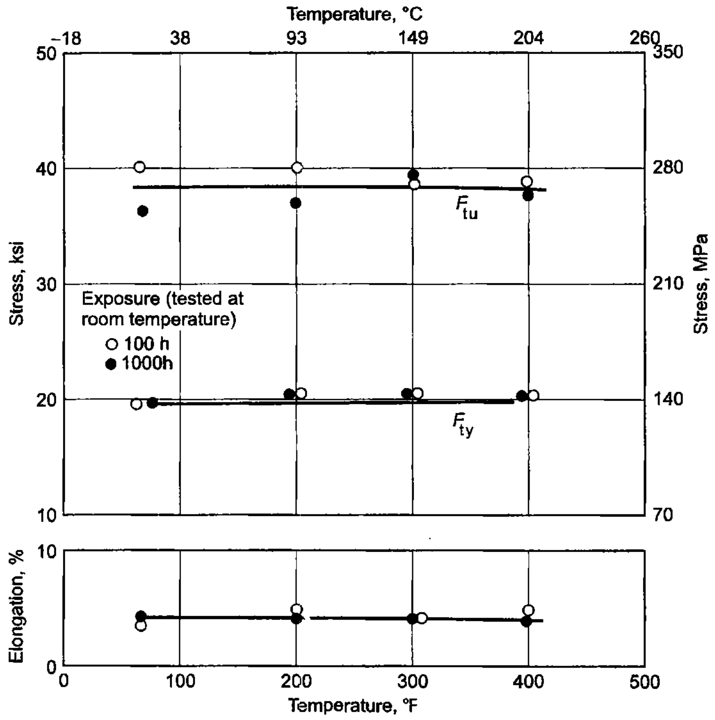
Source: "Room and Elevated Temperature Properties of Magnesium Cast Alloys," Bulletin No. 141-176, Dow Chemical Co., 1958. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3603, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 3



Mg.011 AZ63A-T6 magnesium alloy sand cast bar, tensile stress-strain curves at room and elevated temperatures

Composition: Mg-6Al-3Zn. UNS M11630

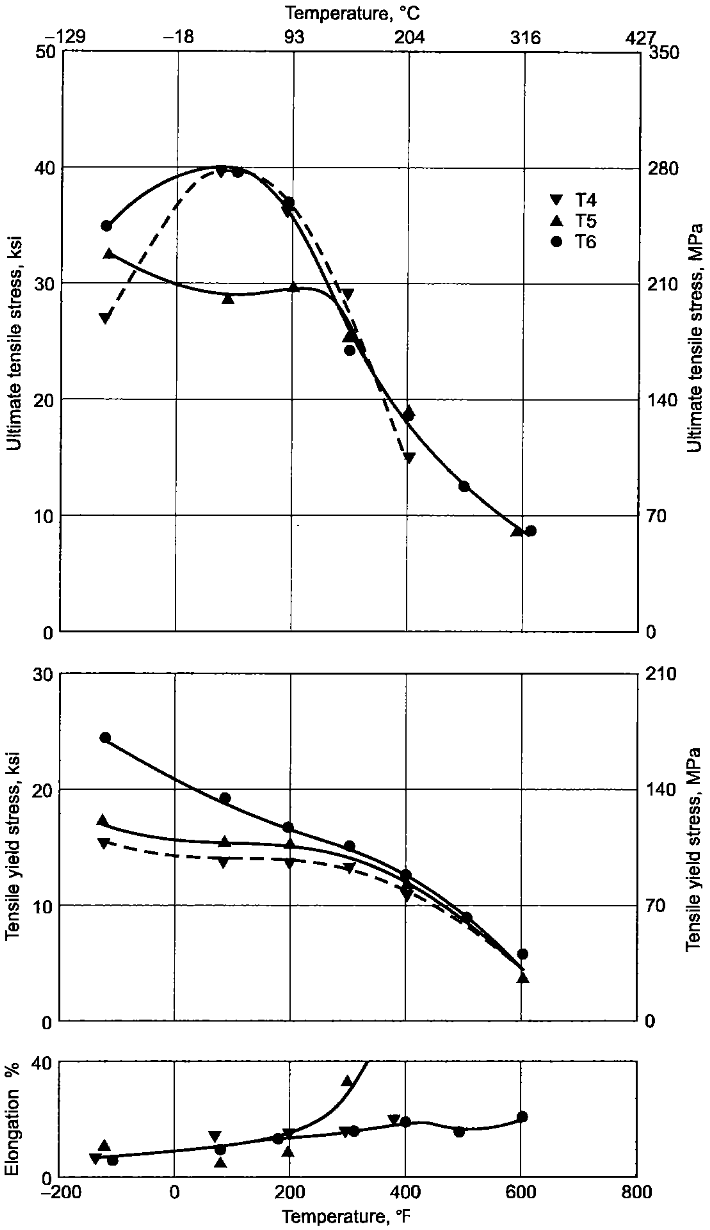
Source: "Room and Elevated Temperature Properties of Magnesium Cast Alloys," Bulletin No. 141-176, Dow Chemical Co., 1958. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3603, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 4



Mg.012 AZ63A-T6 magnesium alloy sand cast bar, high-temperature effect on tensile properties

F_{tu}, ultimate tensile strength; F_{ty}, tensile yield strength. Tested at room temperature after exposure to elevated temperatures. Composition: Mg-6Al-3Zn. UNS M11630

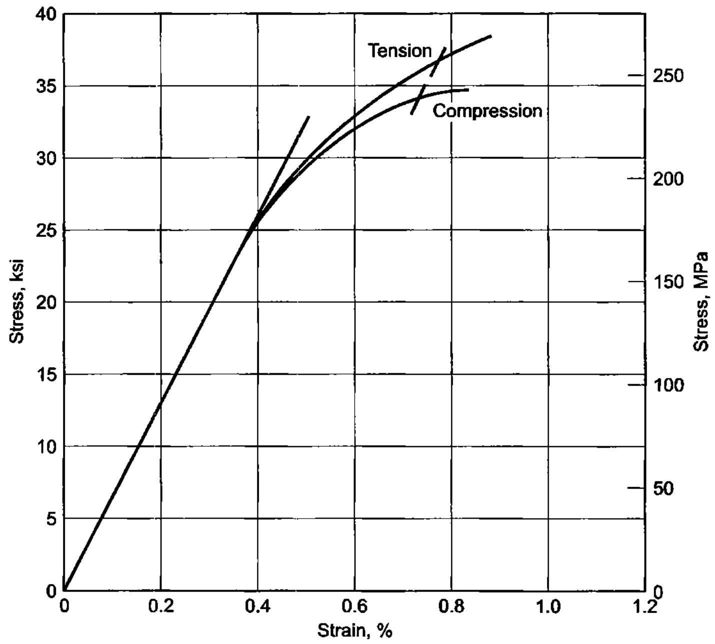
Source: "Magnesium Design," Dow Chemical Co., 1957. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3603, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 3



Mg.013 AZ63A magnesium alloy sand cast bar, high-temperature effect on tensile properties

Effect of 10 min exposure and test temperature on three tempers. Composition: Mg-6Al-3Zn. UNS M11630

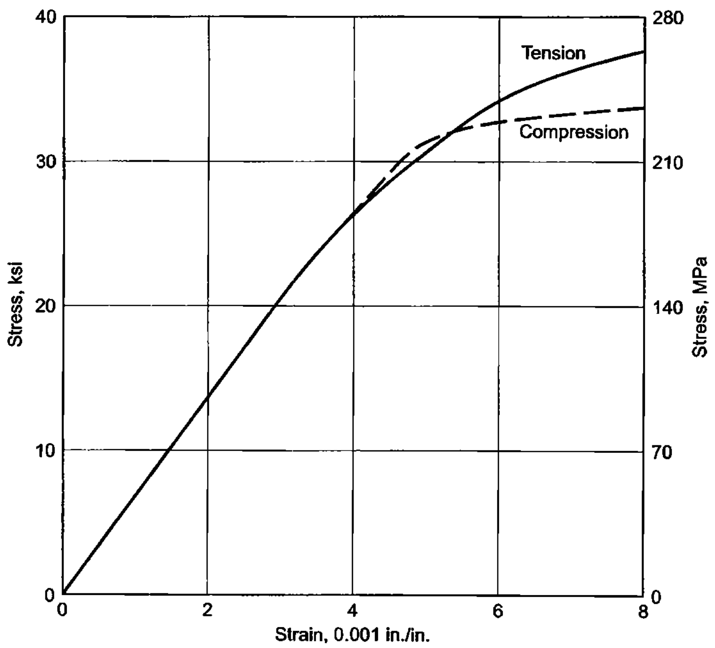
Source: "Magnesium Design," Dow Chemical Co., 1957. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3603, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 4



Mg.014 AZ80A-T5 magnesium alloy extrusion, tensile and compressive stress-strain curves

Composition: Mg-8.5Al-0.5Zn. UNS M11800

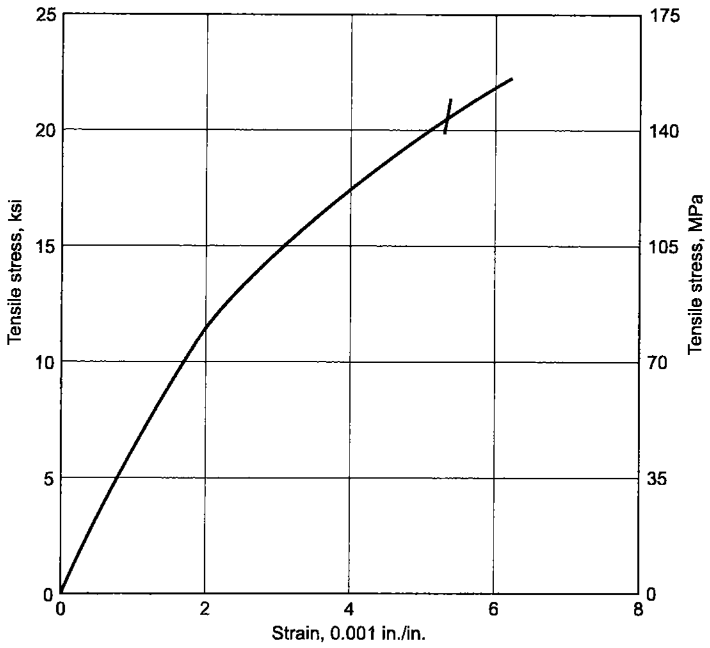
Source: *ASM Specialty Handbook, Magnesium and Magnesium Alloys,* ASM International, 1999, p 166



Mg.015 AZ80A-T5 magnesium alloy forging, tensile and compressive stress-strain curves

Composition: Mg-8.5Al-0.5Zn. UNS M11800

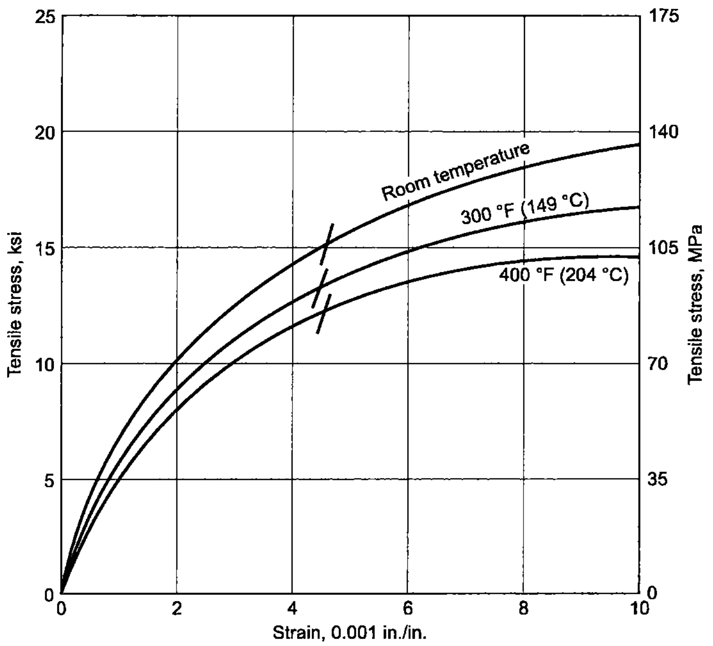
Source: "Magnesium Design," Dow Chemical Co., 1957. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3501, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 2



Mg.016 AZ91A-F magnesium alloy die-cast bar, tensile stress-strain curve

Composition: Mg-9Al-0.7Zn. UNS M11910

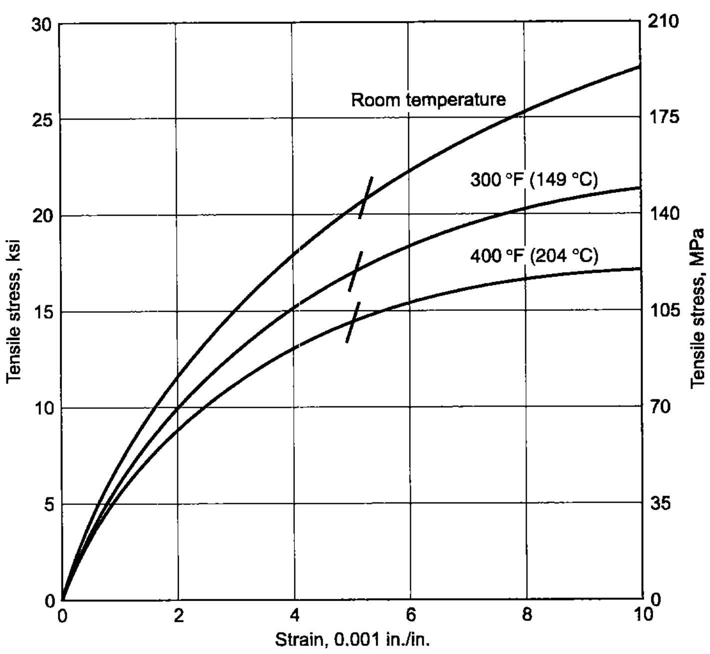
Source: "Magnesium Design," Form No. 141-91-457, Dow Chemical Co., 1957. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3402, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



Mg.017 AZ91C-T4 magnesium alloy sand cast bar, tensile stress-strain curves at room and elevated temperature

Composition: Mg-9Al-0.7Zn. UNS M11914

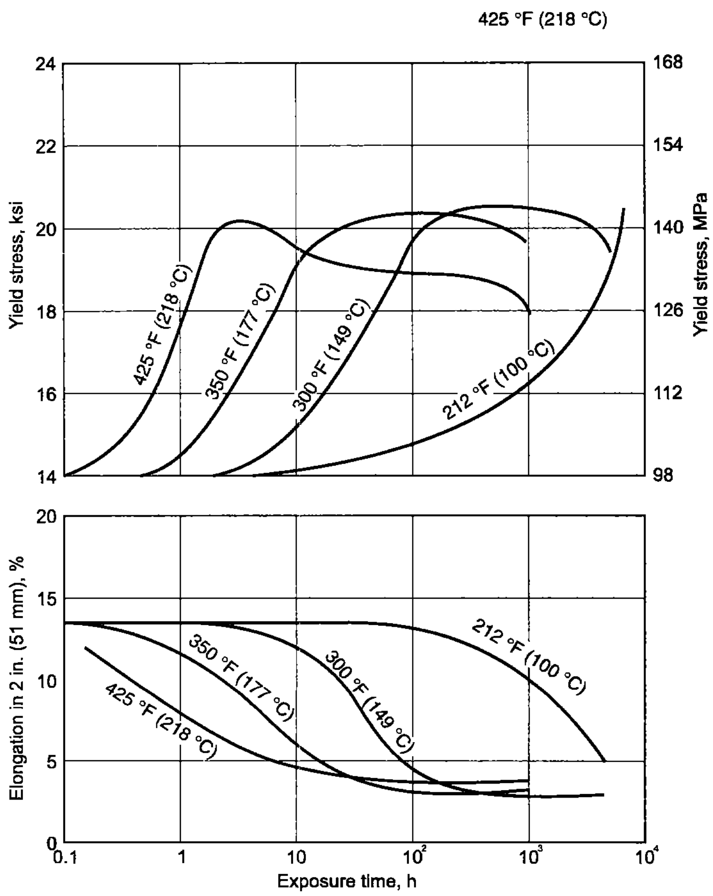
Source: "Room and Elevated Temperature Properties of Magnesium Cast Alloys," Bulletin No. 141-176, Dow Chemical Co., 1958. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3402, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



Mg.018 AZ91C-T6 magnesium alloy sand cast bar, tensile stress-strain curves at room and elevated temperature

Composition: Mg-9Al-0.7Zn. UNS M11914

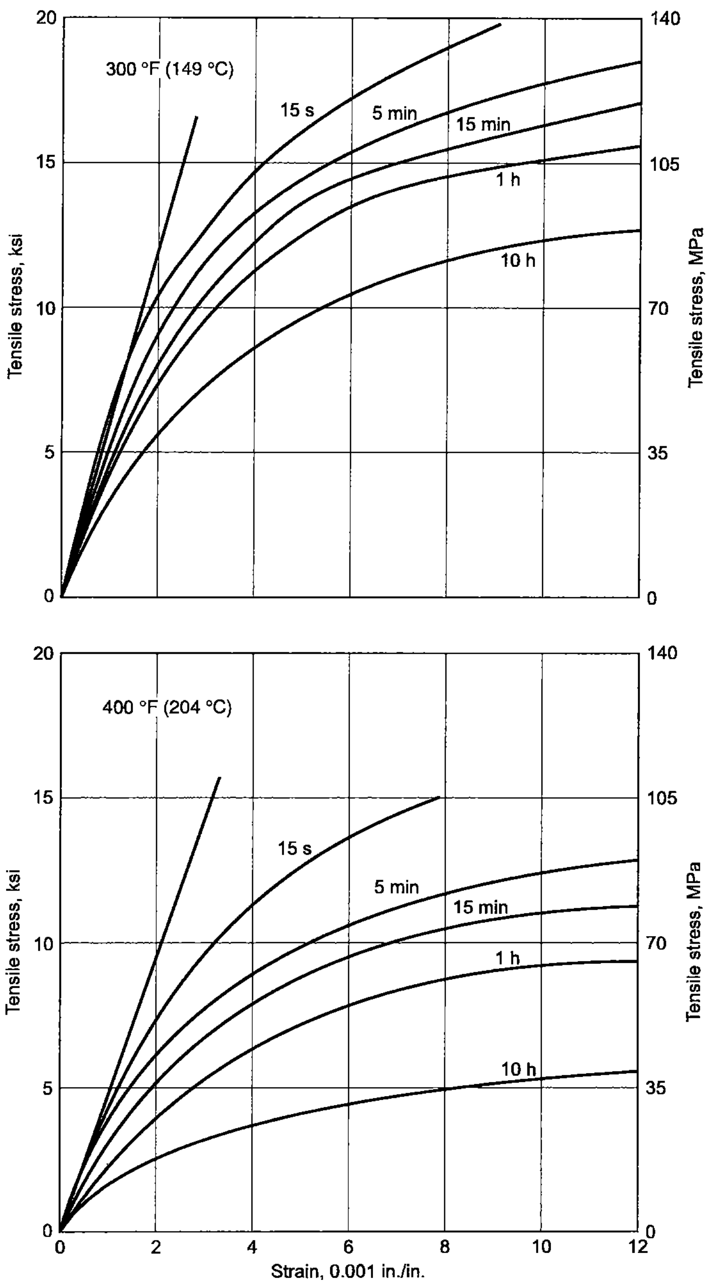
Source: "Room and Elevated Temperature Properties of Magnesium Cast Alloys," Bulletin No. 141-176, Dow Chemical Co., 1958. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3402, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



Mg.019 AZ91C-T4 magnesium alloy sand cast bar, effect of elevated temperature on room-temperature properties

Composition: Mg-9Al-0.7Zn. UNS M11914

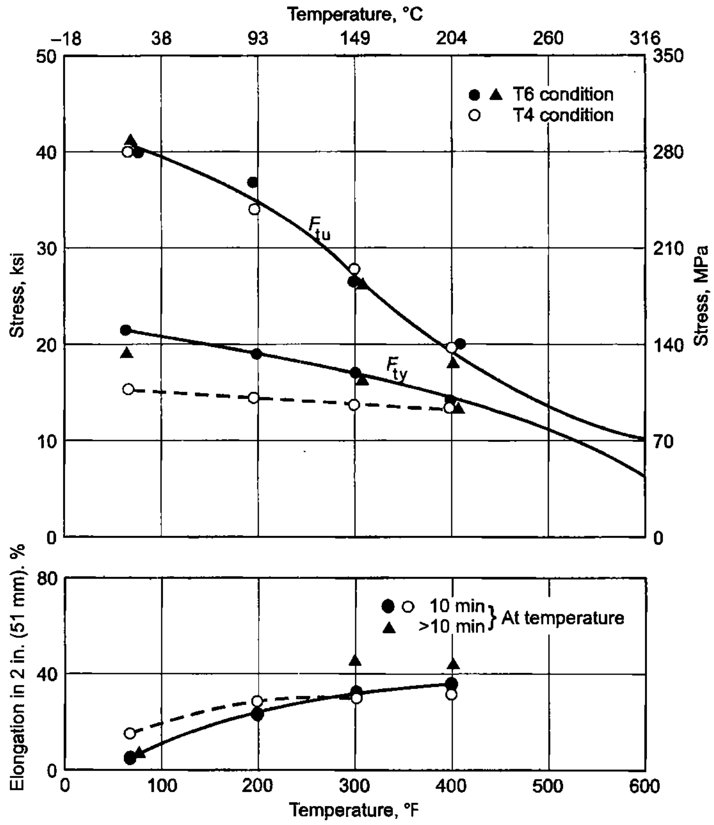
Source: "Magnesium Design," Form No. 141-91-457, Dow Chemical Co., 1957. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3402, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 16



Mg.020 AZ91C-T4 magnesium alloy sand cast bar, isochronous stress-strain curves

F_{tu}, ultimate tensile strength; F_{ty}, tensile yield strength. Composition: Mg-9Al-0.7Zn. UNS M11914

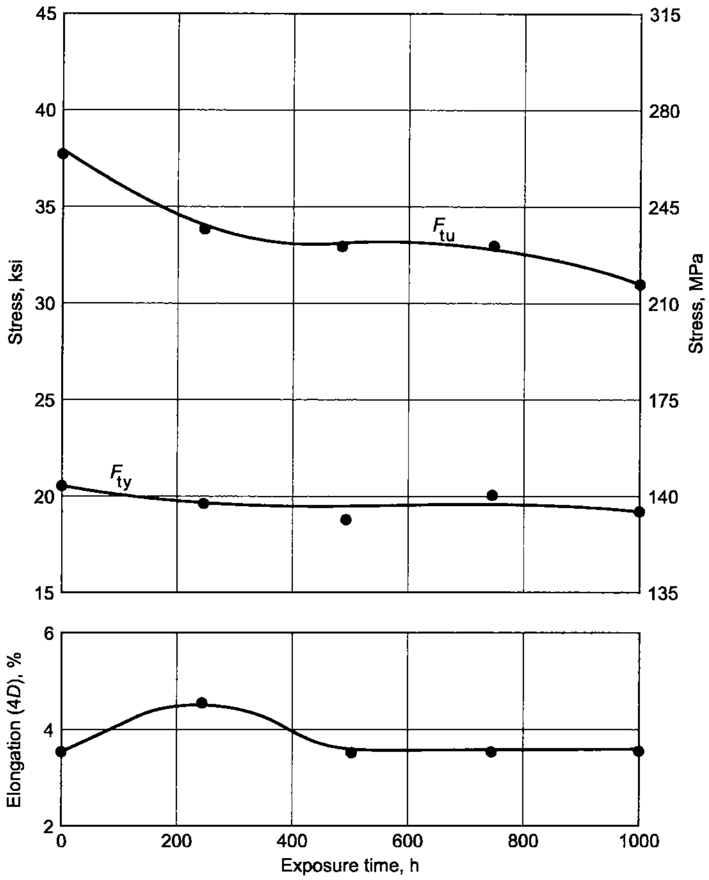
Source: "Isochronous Stress-Strain Curves of Magnesium Casting Alloys," Dow Chemical Co., 31 Oct 1958. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3402, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



Mg.021 AZ91-T4, AZ91-T6 magnesium alloy sand cast bar, tensile stress-strain curves at room and elevated temperatures

Composition: Mg-9Al-0.7Zn

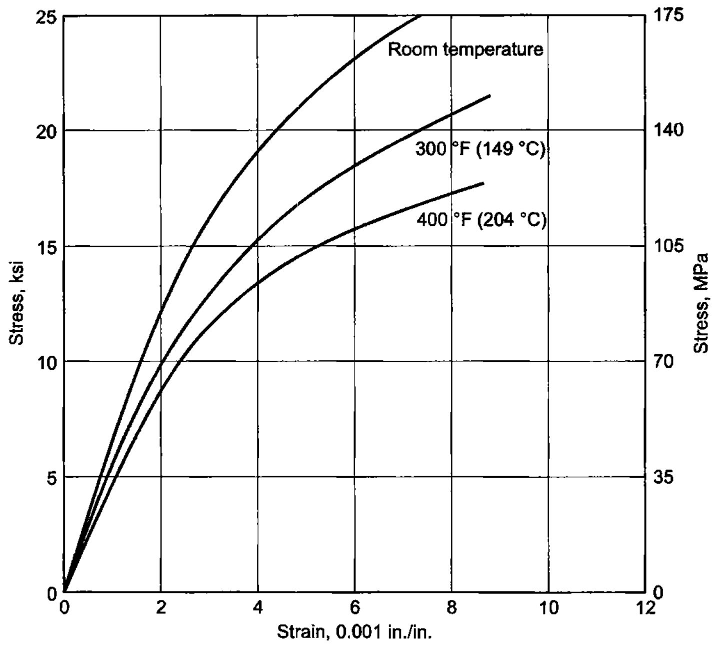
Source: "Room and Elevated Temperature Properties of Magnesium Cast Alloys," Bulletin No. 141-176, Dow Chemical Co., 1958. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3402, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 14



Mg.022 AZ91E-T6 magnesium alloy sand cast bar, effect of elevated temperature on room-temperature tensile properties

Composition: Mg-9Al-0.7Zn. UNS M11918

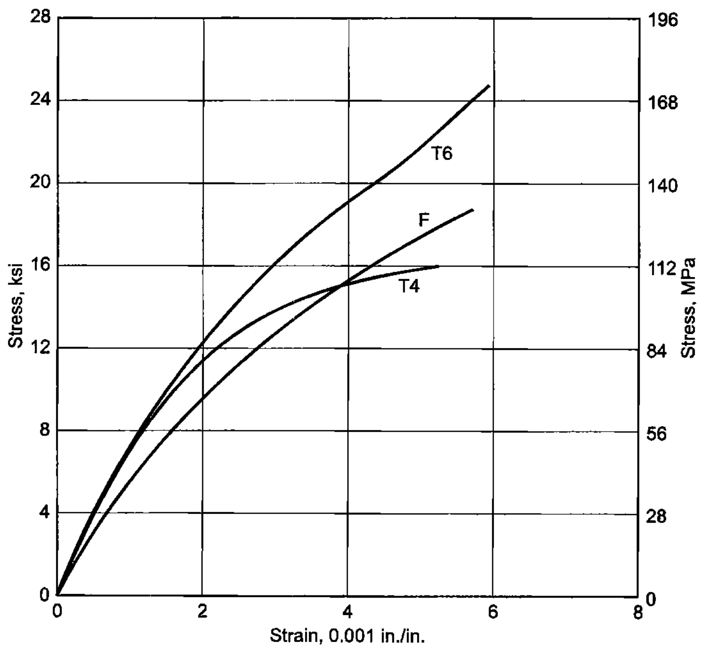
Source: B. Geary, "Corrosion Resistant Magnesium Casting Alloys," Magnesium Elektron, Ltd, Manchester, England. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3402, CINDAS/ USAF CRDA Handbooks Operation, Purdue University, 1995, p 14



Mg.023 AZ91C-T6/AZ91E-T6 magnesium alloy casting, typical tensile stress-strain curves at room and elevated temperatures

Exposure: 1/2 h. Ramberg-Osgood parameter: n(room temperature) = 4.5; n(300 °F [or 149 °C]) = 3.9; n(400 °F [or 204 °C]) = 5.3. Composition: Mg-9Al-0.7Zn. The C and E versions have similar mechanical properties. The E version is purer and more corrosion resistant. AZ91C: UNS M11914. AZ91E: UNS M11918

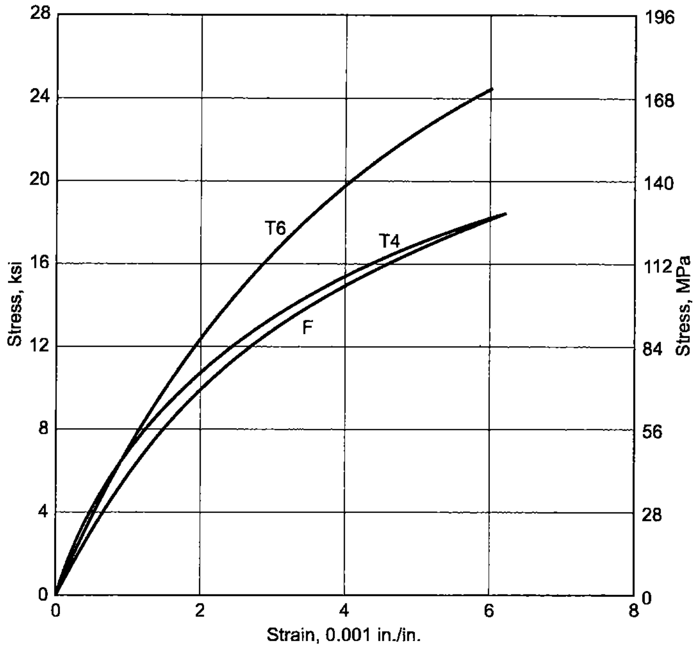
Source: *MIL-HDBK-5H*, Dec 1998, p 4–32



Mg.024 AZ92A-F, AZ92A-T4, AZ92A-T6 magnesium alloy cast bar, tensile stress-strain curves at room temperature

Composition: Mg-9Al-2Zn. UNS M11920

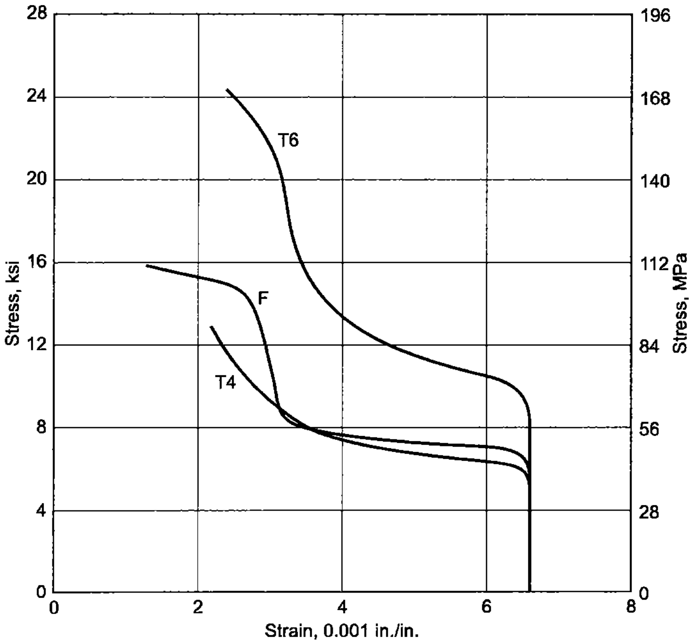
Source: *MIL-HDBK-5*, 1958. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3403, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 3



Mg.025 AZ92A-F, AZ92A-T4, AZ92A-T6 magnesium alloy cast bar, compressive stress-strain curves at room temperature

Composition: Mg-9Al-2Zn. UNS M11920

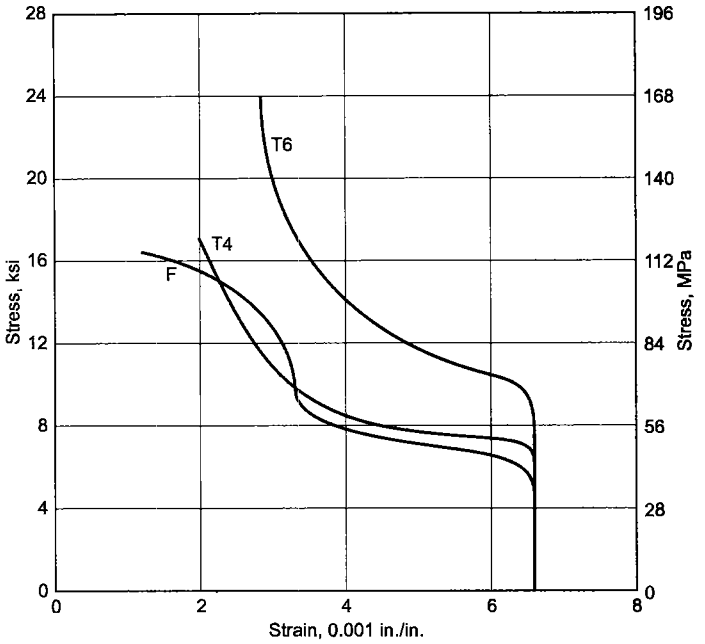
Source: *MIL-HDBK-5,* 1958. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3403, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 4



Mg.026 AZ92A-F, AZ92A-T4, AZ92A-T6 magnesium alloy cast bar, tensile tangent modulus stress-strain curves at room temperature

Composition: Mg-9Al-2Zn. UNS M11920

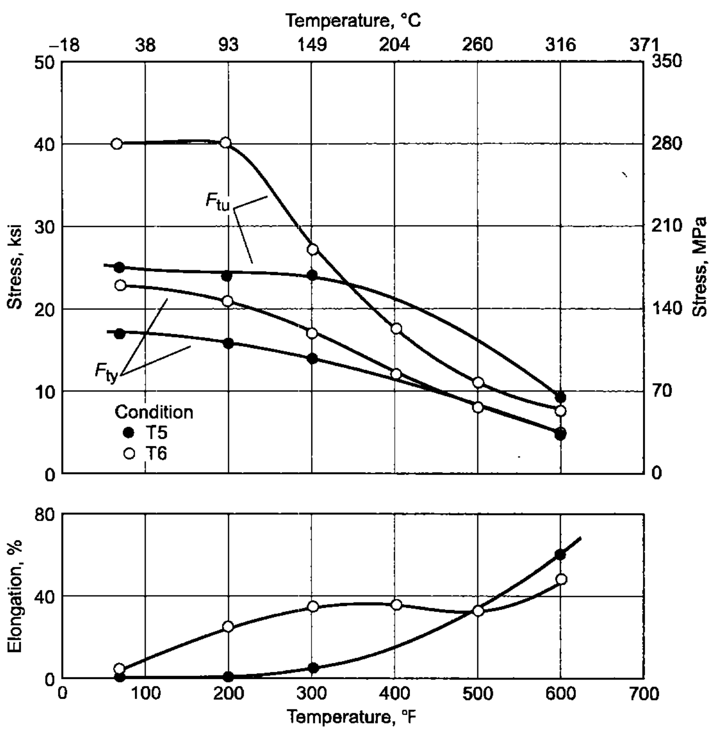
Source: *MIL-HDBK-5,* 1958. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3403, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 4



Mg.027 AZ92A-F, AZ92A-T4, AZ92A-T6 magnesium alloy cast bar, compressive tangent modulus stress-strain curves at room temperature

Composition: Mg-9Al-2Zn. UNS M11920

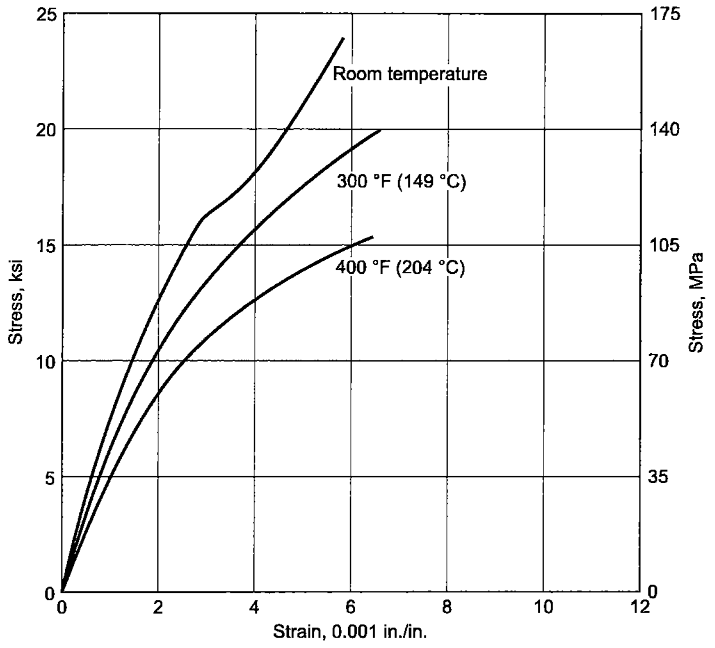
Source: *MIL-HDBK-5,* 1958. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3403, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 4



Mg.028 AZ92A-T5, AZ92A-T6 magnesium alloy cast bar, temperature effects on tensile properties

F_{tu}, ultimate tensile strength; F_{ty}, tensile yield strength. Composition: Mg-9Al-2Zn. UNS M11920

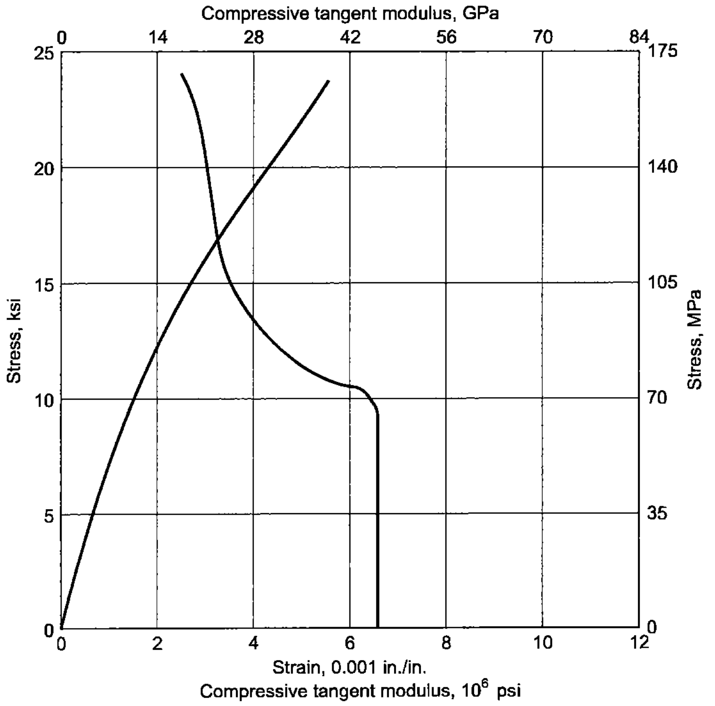
Source: "Magnesium Design," Form 141-91-57, Dow Chemical Co., 1957. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3403, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 5



Mg.029 AZ92A-T6 magnesium alloy casting, typical tensile stress-strain curves at room and elevated temperatures

Exposure: 1/2 h. Composition: Mg-9Al-2Zn. UNS M11920

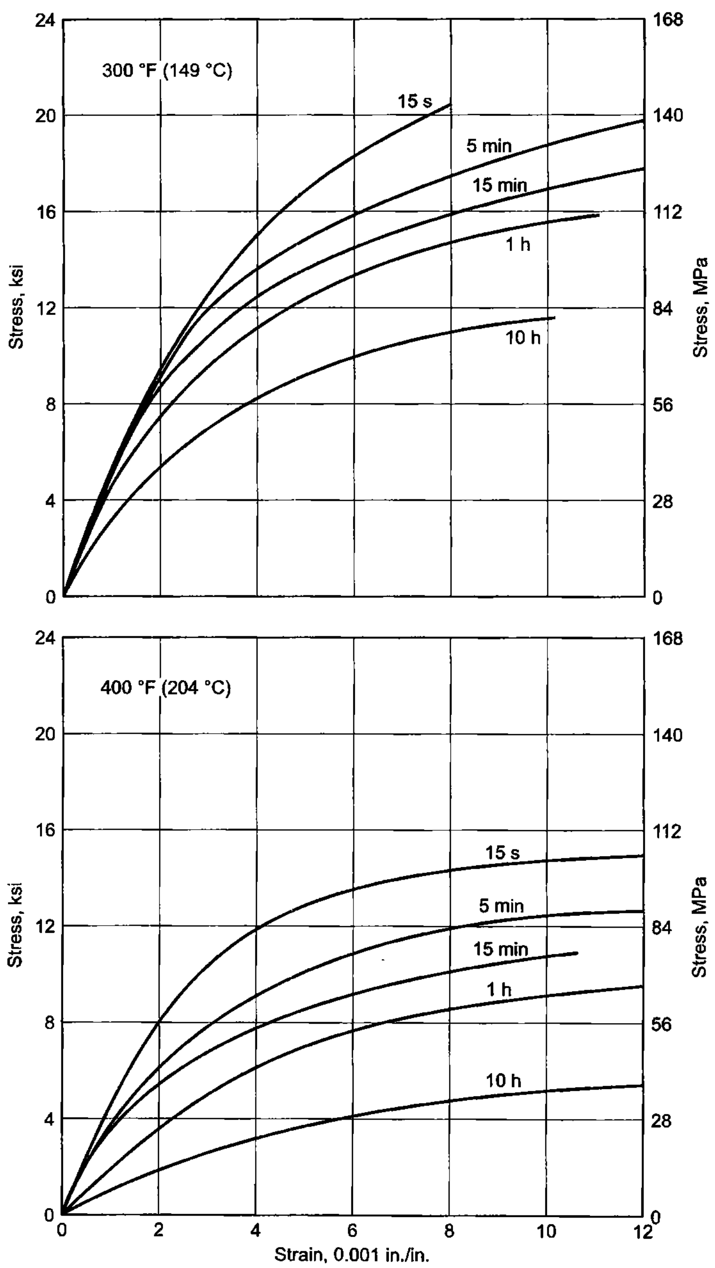
Source: *MIL-HDBK-5H,* Dec 1998, p 4–38



Mg.030 AZ92A-T6 magnesium alloy casting, typical compressive stress-strain and tangent modulus curves at room temperature

Composition: Mg-9Al-2Zn. UNS M11920

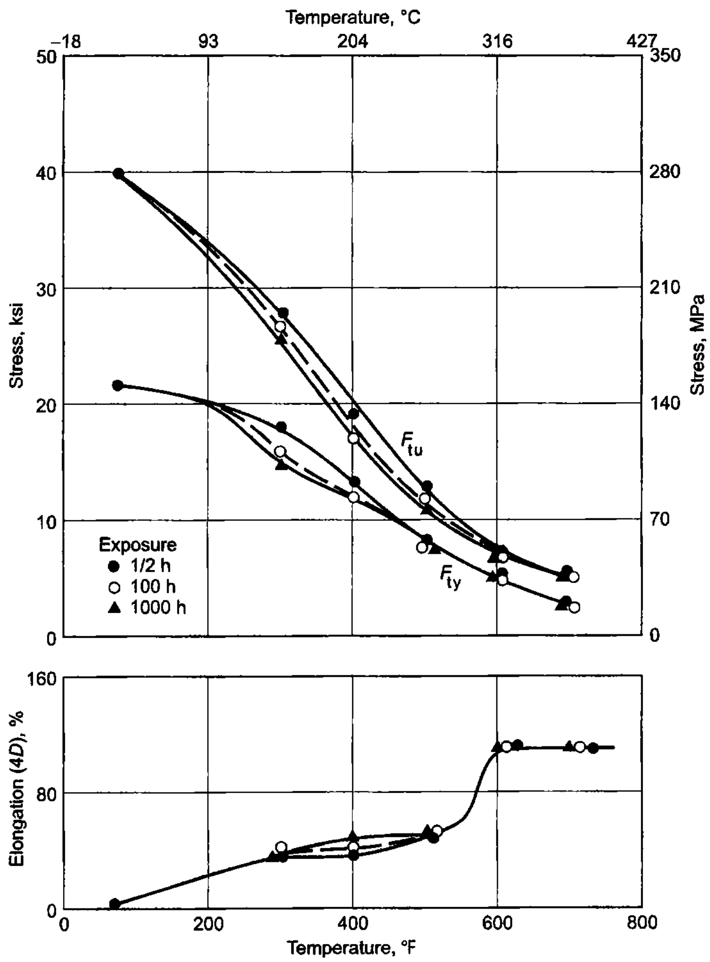
Source: *MIL-HDBK-5H,* Dec 1998, p 4–38



Mg.031 AZ92A-T6 magnesium alloy sand cast bar, isochronous stress-strain curves

Composition: Mg-9Al-2Zn. UNS M11920

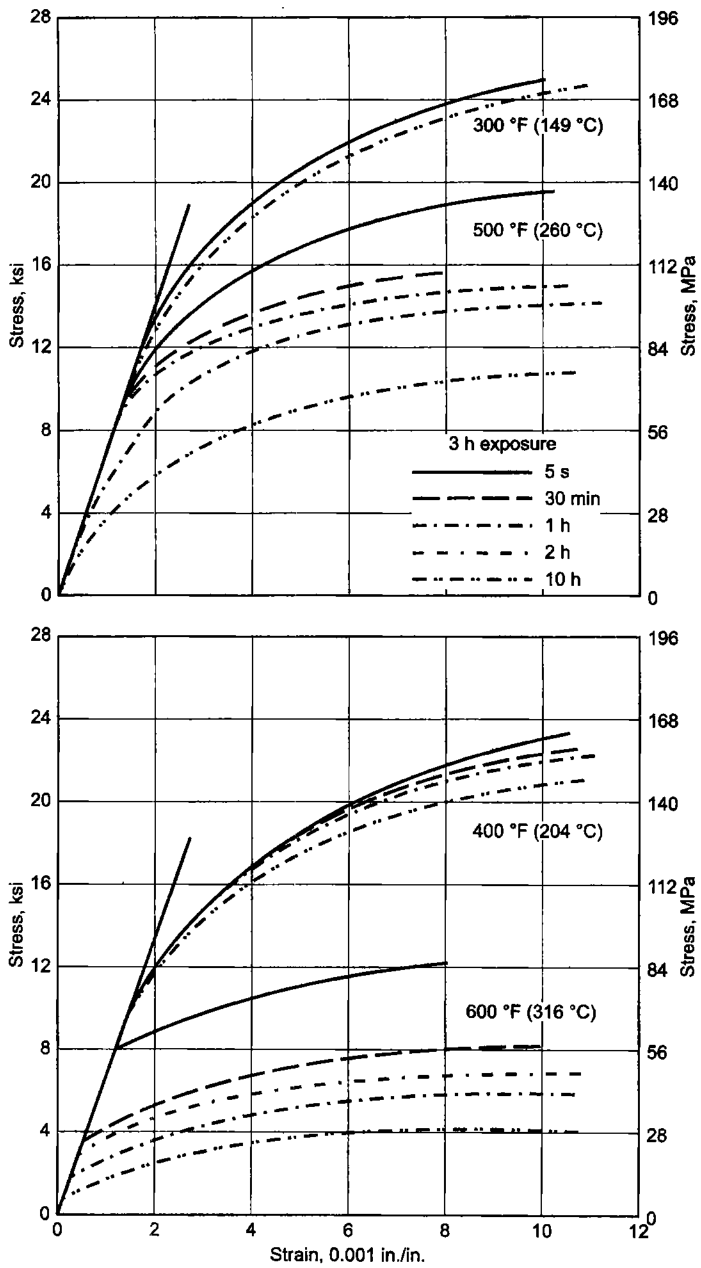
Source: "Isochronous Stress-Strain Curves of Magnesium Casting Alloys," Lett. Enc., Code 1.8 HB, Dow Chemical Co., 31 Oct 1958. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3403, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 7



Mg.032 AZ92A-T6 magnesium alloy sand cast bar, effect of exposure and test temperature on tensile properties

F_{tu}, ultimate tensile strength; F_{ty}, tensile yield strength. Composition: Mg-9Al-2Zn. UNS M11920

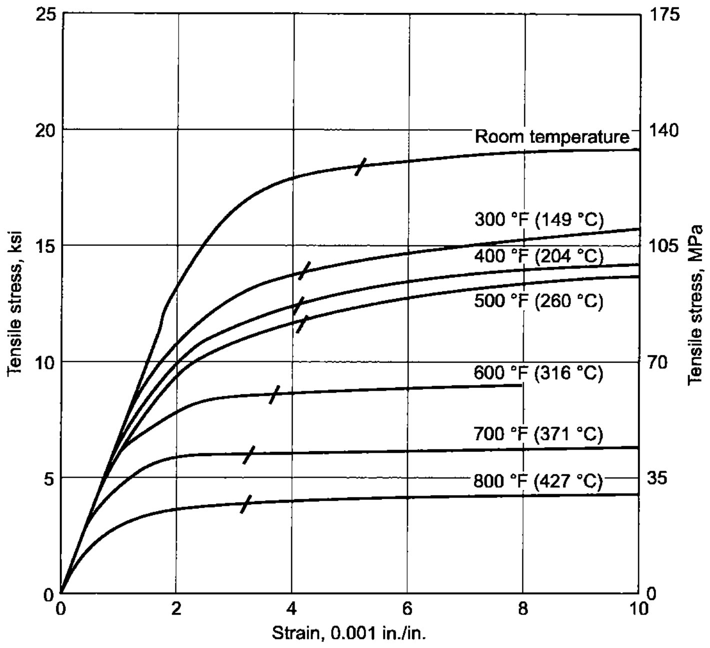
Source: "Mechanical Properties at Various Temperatures of AZ 92 A-T6 Sand Castings," Data Sheet, Alcoa Research Laboratories, 29 Aug 1957. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3403, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 5



Mg.033 EK31XA-T6 magnesium alloy forging, isochronous stress-strain curves

Composition: Mg-3Di-0.5Zr. Didymium is a natural mixture of rare-earth elements neodymium and praseodymium given the quasi-chemical symbol Di. 1.99 mm (0.505 in.) bar cut from large forging

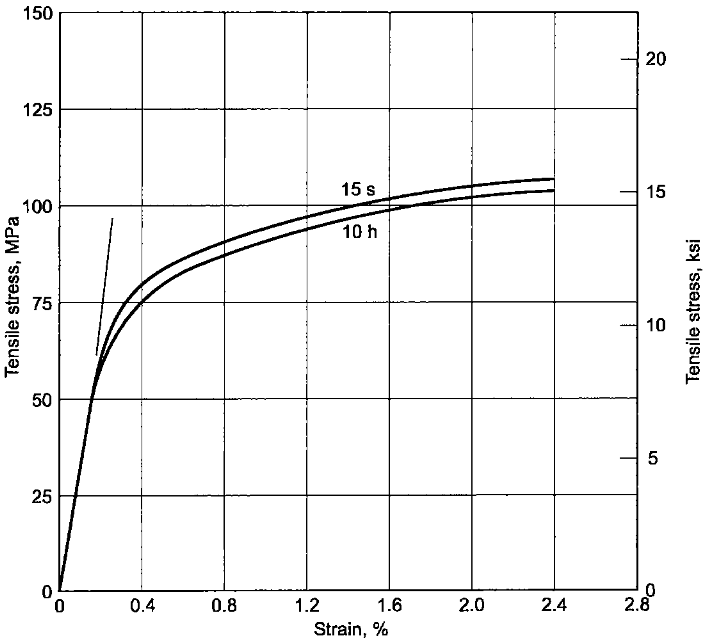
Source: "Magnesium Forging Alloys for Elevated Temperature Service," Dow Chemical Co., 1963. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3502, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 5



Mg.034 EZ33A-T5 magnesium alloy sand cast test bar, tensile stress-strain curve at room and elevated temperatures

Composition: Mg-3RE-3Zn-0.7Zr. UNS M12330

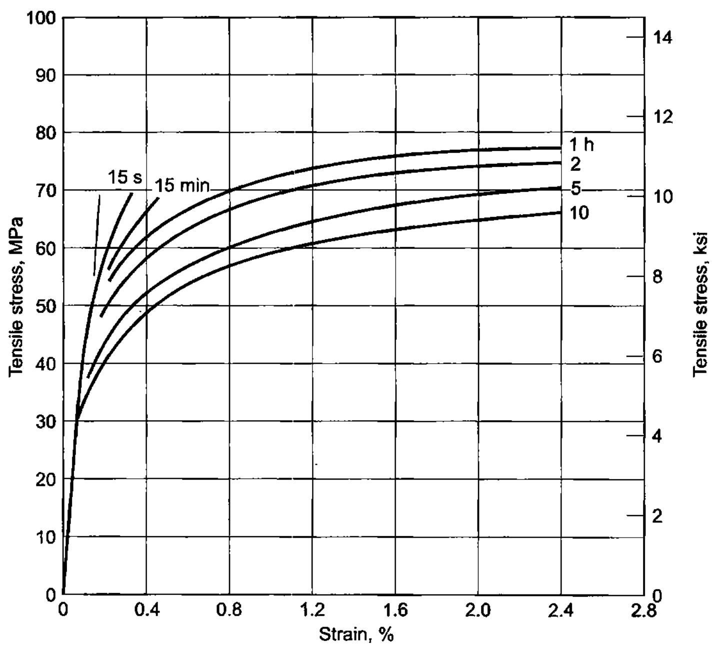
Source: "Room and Elevated Temperature Properties of Magnesium Cast Alloys," Bulletin No. 141-176, Dow Chemical Co., 1958. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3404, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 9



Mg.035 EZ33A-T5 magnesium alloy sand cast test bar, isochronous stress-strain curves at 204 °C (400 °F)

Specimens exposed to elevated temperature for 3 h before loading. Composition: Mg-3RE-3Zn-0.7Zr. UNS M12330

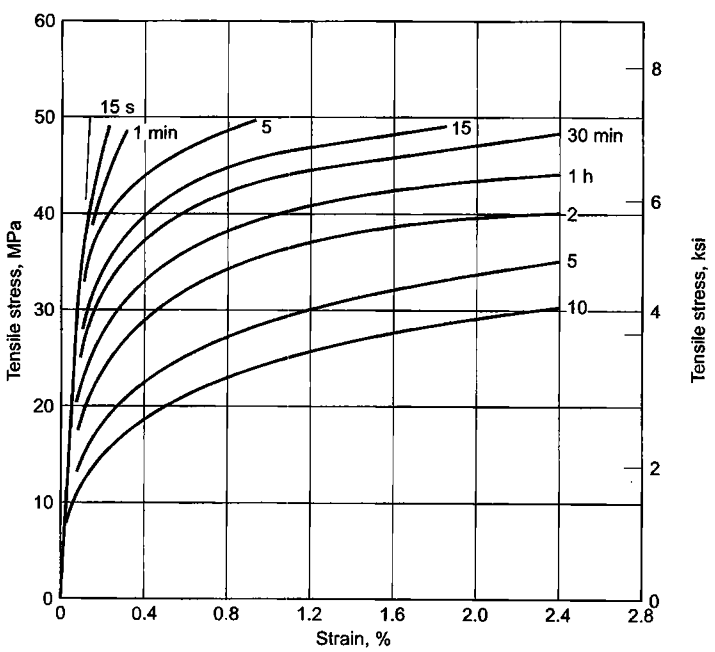
Source: *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials,* Vol 2, *ASM Handbook,* ASM International, 1990, p 504



Mg.036 EZ33A-T5 magnesium alloy sand cast test bar, isochronous stress-strain curves at 260 °C (500 °F)

Specimens exposed to elevated temperature for 3 h before loading. Composition: Mg-3RE-3Zn-0.7Zr. UNS M12330

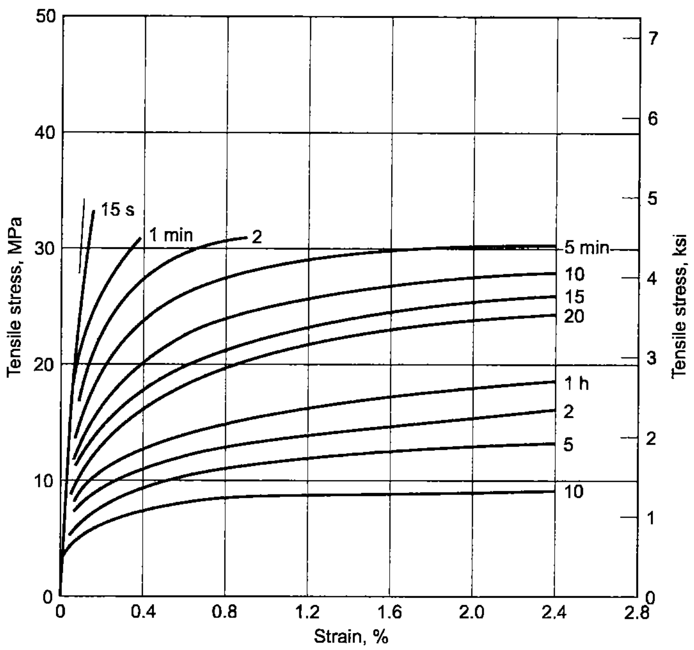
Source: *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials,* Vol 2, *ASM Handbook,* ASM International, 1990, p 504



Mg.037 EZ33A-T5 magnesium alloy sand cast test bar, isochronous stress-strain curves at 316 °C (600 °F)

Specimens exposed to elevated temperature for 3 h before loading. Composition: Mg-3RE-3Zn-0.7Zr. UNS M12330

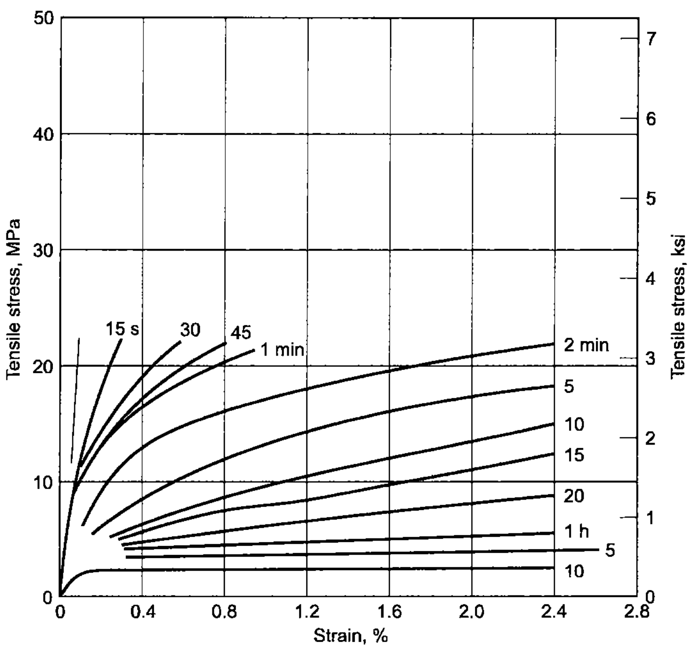
Source: *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials,* Vol 2, *ASM Handbook,* ASM International, 1990, p 504



Mg.038 EZ33A-T5 magnesium alloy sand cast test bar, isochronous stress-strain curves at 371 °C (700 °F)

Specimens exposed to elevated temperature for 3 h before loading. Composition: Mg-3RE-3Zn-0.7Zr. UNS M12330

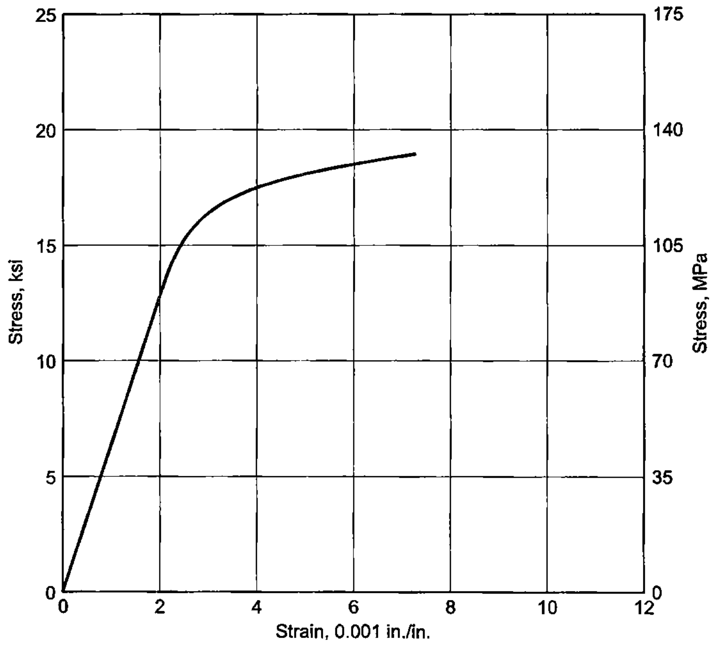
Source: *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials,* Vol 2, *ASM Handbook,* ASM International, 1990, p 505



Mg.039 EZ33A-T5 magnesium alloy sand cast test bar, isochronous stress-strain curves at 427 °C (800 °F)

Specimens exposed to elevated temperature for 3 h before loading. Composition: Mg-3RE-3Zn-0.7Zr. UNS M12330

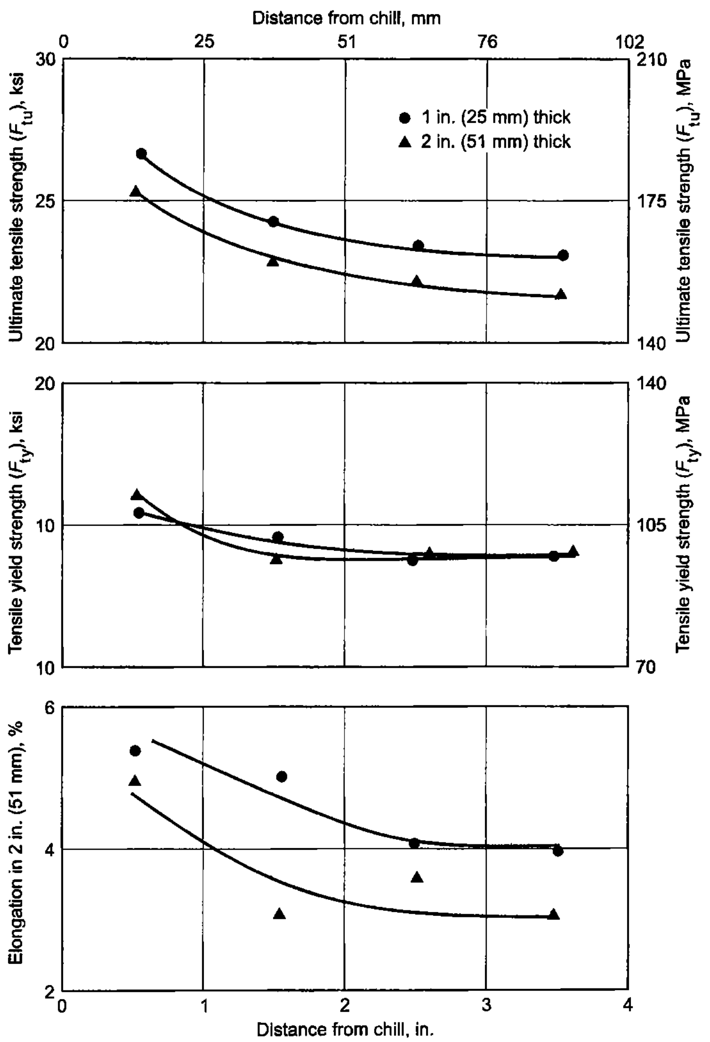
Source: *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials,* Vol 2, *ASM Handbook,* ASM International, 1990, p 505



Mg.040 EZ33A-T5 magnesium alloy cast, tensile stress-strain curve at room temperature

Ramberg-Osgood parameter: n(room temperature) = 15. Composition: Mg-3RE-3Zn-0.7Zr. UNS M12330

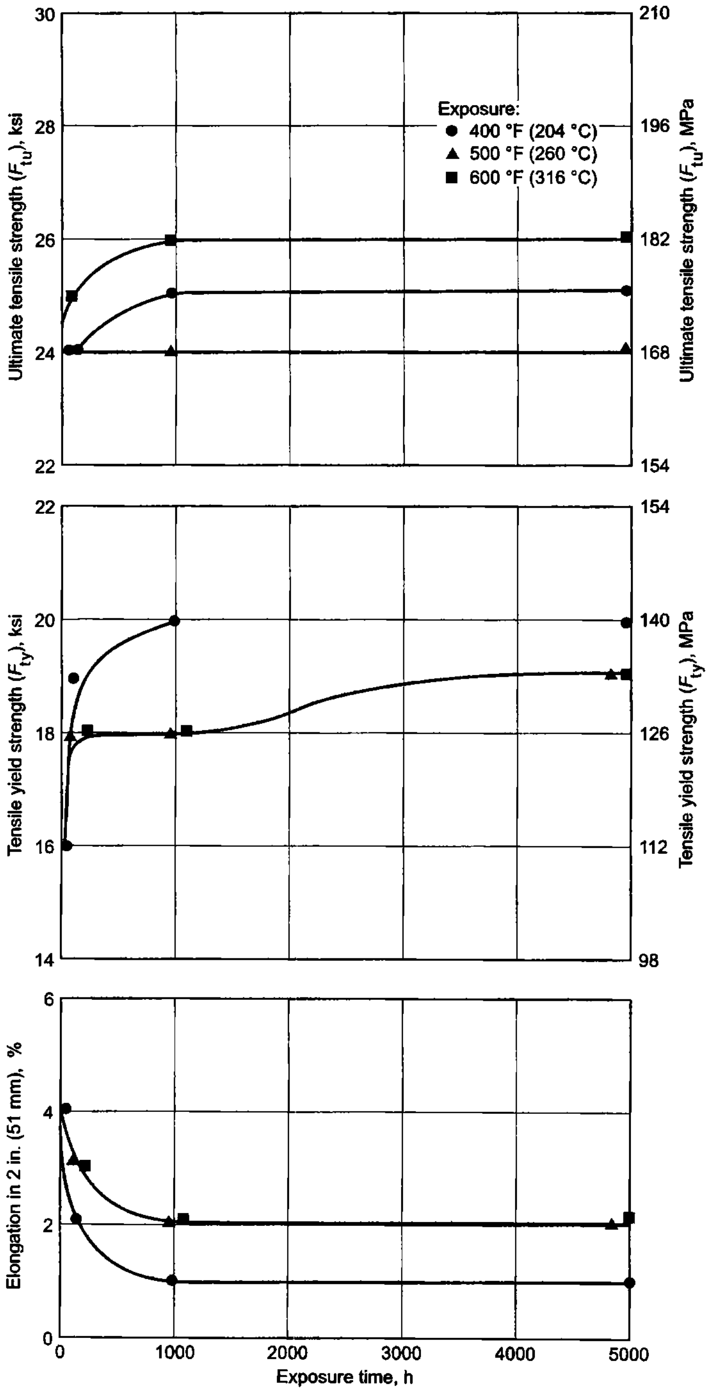
Source: *MIL-HDBK-5H*, Dec 1998, p 4–43



Mg.041 EZ33A-T5 magnesium alloy sand cast plate, effect of end chill on tensile properties

Thickness: 1 in. (25 mm) and 2 in. (51 mm).
Composition: Mg-3RE-3Zn-0.7Zr. UNS M12330

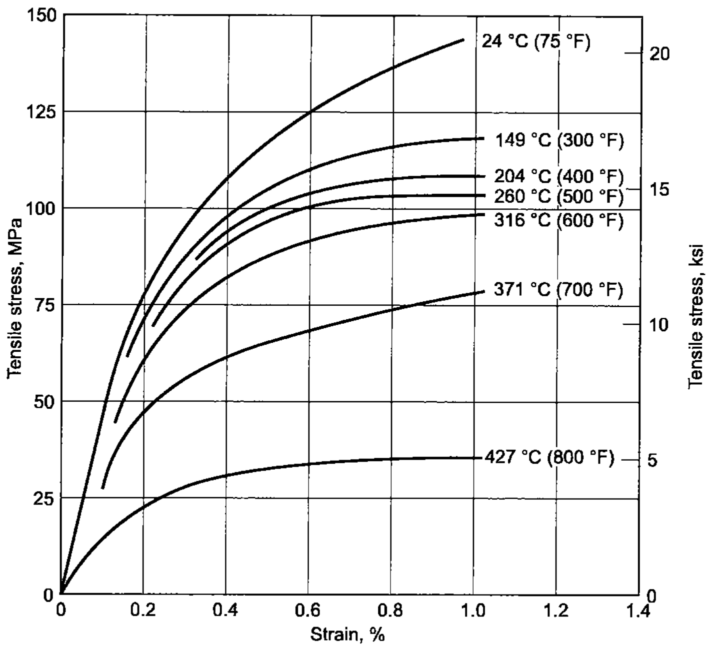
Source: B. Lagowski and J.W. Meier, Premium Strength in Sand-Cast Magnesium Alloys, *AFS Trans.*, Vol 72, 1964, p 673–685. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3404, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 9



Mg.042 EZ33A-T5 magnesium alloy sand cast bar, effect of exposure at elevated temperatures on room-temperature tensile properties

Composition: Mg-3RE-3Zn-0.7Zr. UNS M12330

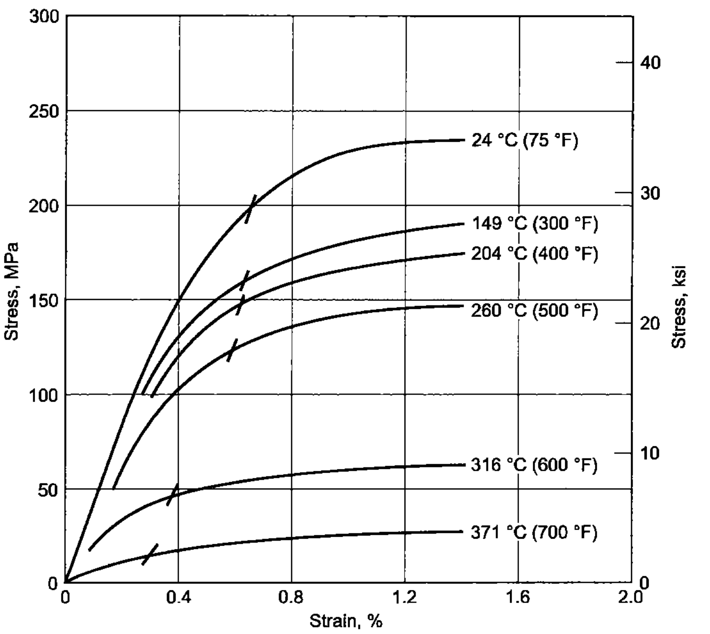
Source: "Magnesium Design," Form No. 141-91-457, Dow Chemical Co., 1957. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3404, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 9



Mg.043 HK31A magnesium alloy separately cast bar, tensile stress-strain curves

Composition: Mg-3Th-0.7Zr. UNS M13310

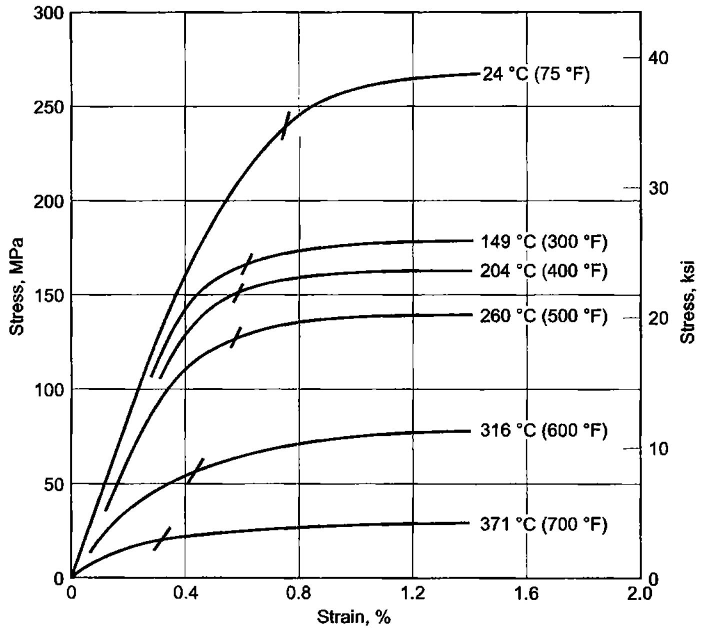
Source: *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials,* Vol 2, *ASM Handbook,* ASM International, 1990, p 505



Mg.044 HK31A-H24 magnesium alloy sheet, tensile stress-strain curves at various temperatures

Sheet thickness: 1.63 mm (0.064 in.). Test direction: longitudinal. Typical yield strength: 21 °C (70 °F), 205 MPa (30 ksi); 149 °C (300°F), 165 MPa (24 ksi); 204 °C (400 °F), 145 MPa (21 ksi); 260 °C (500 °F), 115 MPa (17 ksi); 316 °C (600 °F) 48 MPa (7 ksi); 343 °C (650 °F), 28 MPa (4 ksi). Composition: Mg-3Th-0.7Zr. UNS M13310

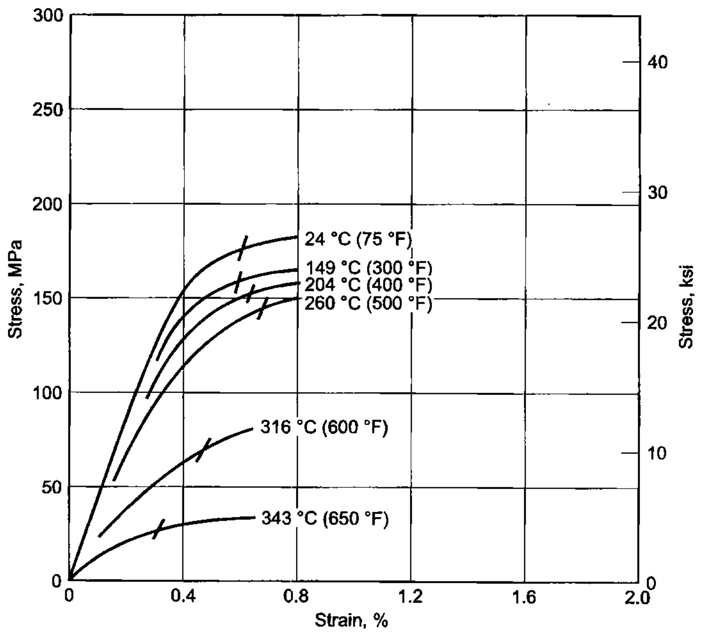
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, 9th ed., *Metals Handbook,* American Society for Metals, 1979, p 558



Mg.045 HK31A-H24 magnesium alloy sheet, tensile stress-strain curves at various temperatures

Sheet thickness: 1.63 mm (0.064 in.). Test direction: transverse. Typical yield strength: 21 °C (70 °F), 205 MPa (30 ksi); 149 °C (300°F), 165 MPa (24 ksi); 204 °C (400 °F), 145 MPa (21 ksi); 260 °C (500 °F), 115 MPa (17 ksi); 316 °C (600 °F) 48 MPa (7 ksi); 343 °C (650 °F), 28 MPa (4 ksi). Composition: Mg-3Th-0.7Zr. UNS M13310

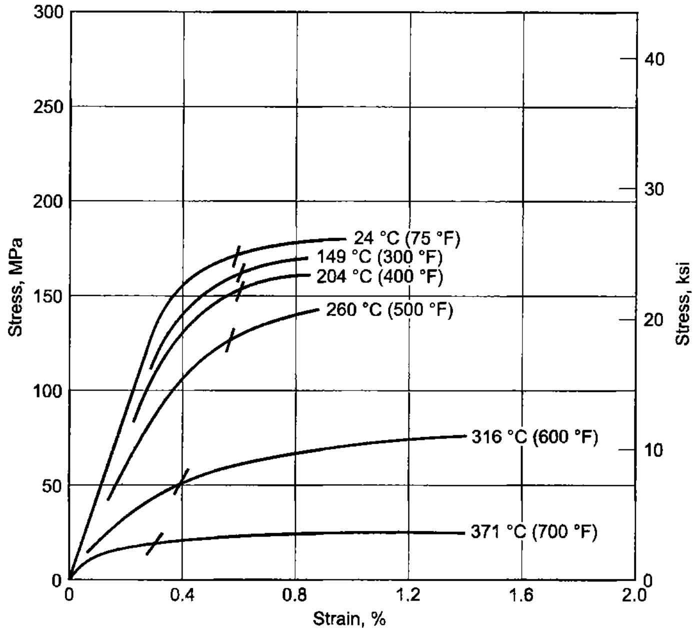
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 558



Mg.046 HK31A-H24 magnesium alloy sheet, compressive stress-strain curves at various temperatures

Sheet thickness: 1.63 mm (0.064 in.). Test direction: longitudinal. Composition: Mg-3Th-0.7Zr. UNS M13310

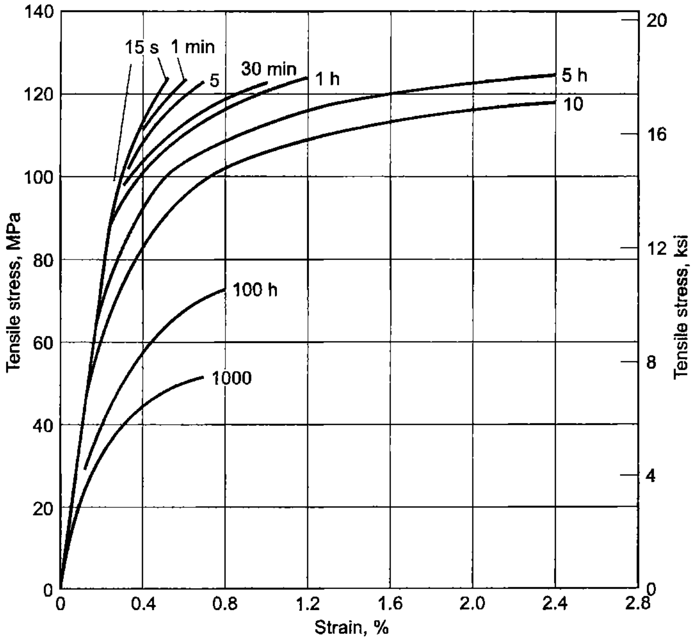
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 558



Mg.047 HK31A-H24 magnesium alloy sheet, compressive stress-strain curves at various temperatures

Sheet thickness: 1.63 mm (0.064 in.). Test direction: transverse. Composition: Mg-3Th-0.7Zr. UNS M13310

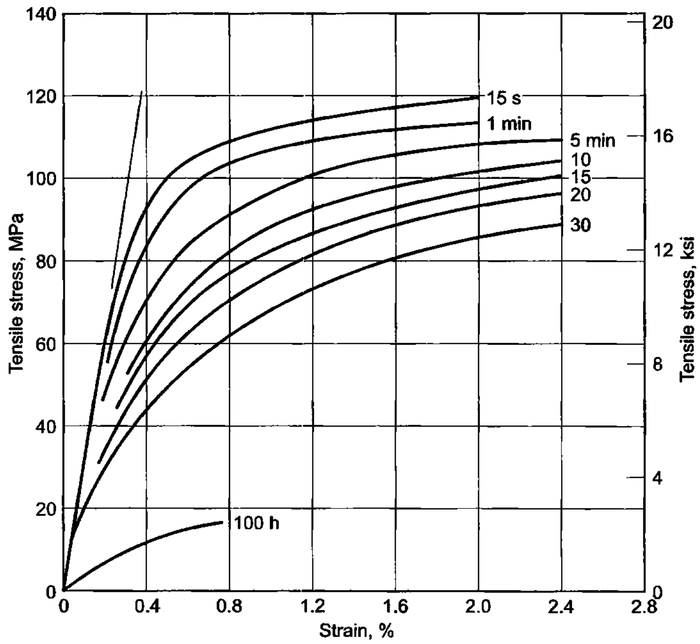
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 558



Mg.048 HK31A-H24 magnesium alloy sheet, isochronous stress-strain curves at 204 °C (400 °F)

Sheet thickness: 1.63 mm (0.064 in.). Specimens exposed to elevated temperatures for 3 h before loading. Composition: Mg-3Th-0.7Zr. UNS M13310

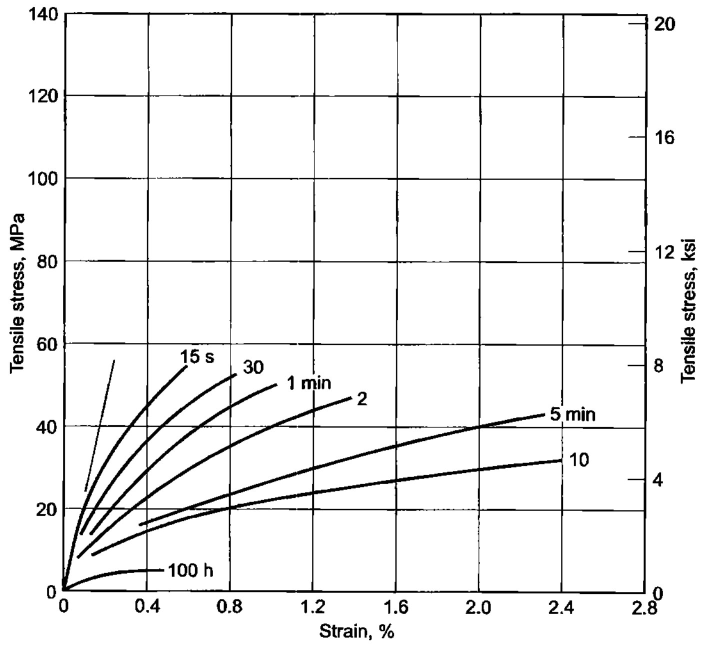
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 560



Mg.049 HK31A-H24 magnesium alloy sheet, isochronous stress-strain curves at 260 °C (500 °F)

Sheet thickness: 1.63 mm (0.064 in.). Specimens exposed to elevated temperatures for 3 h before loading. Composition: Mg-3Th-0.7Zr. UNS M13310

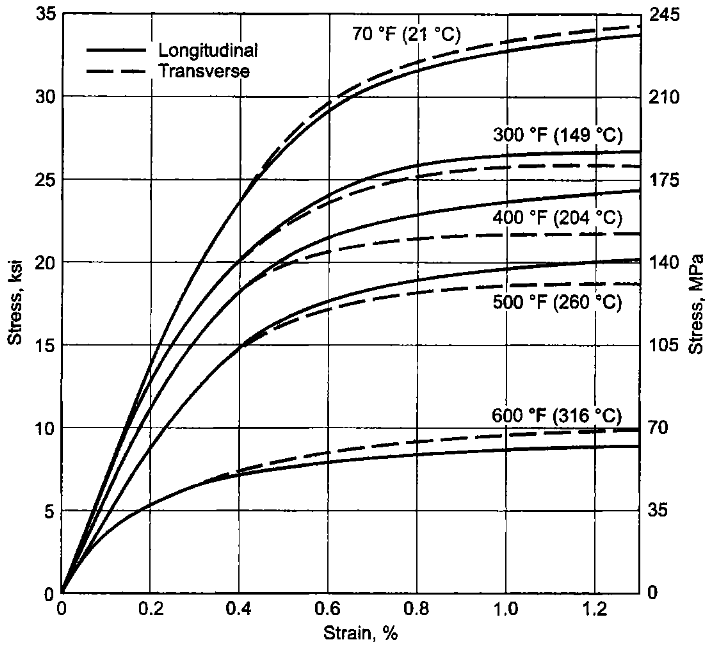
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 560



Mg.050 HK31A-H24 magnesium alloy sheet, isochronous stress-strain curves at 316 °C (600 °F)

Sheet thickness: 1.63 mm (0.064 in.). Specimens exposed to elevated temperatures for 3 h before loading. Composition: Mg-3Th-0.7Zr. UNS M13310

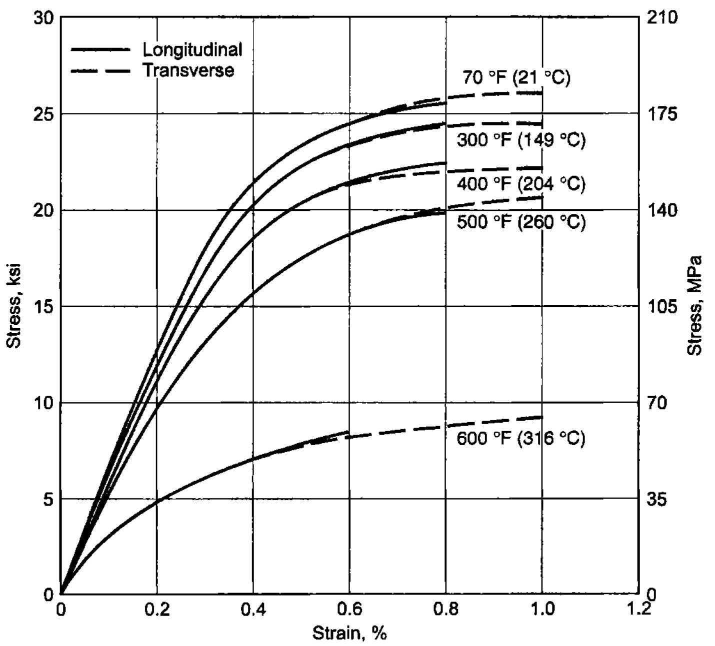
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 560



Mg.051 HK31A-H24 magnesium alloy sheet, tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal and transverse. Typical shear ultimate strength in the lowest strength direction, 180 MPa (26.0 ksi) for sheet 0.406–6.350 mm (0.016–0.250 in.) thick and plate 25.42–76.20 mm (1.001–3.000 in.) thick. Composition: Mg-3Th-0.7Zr. UNS M13310

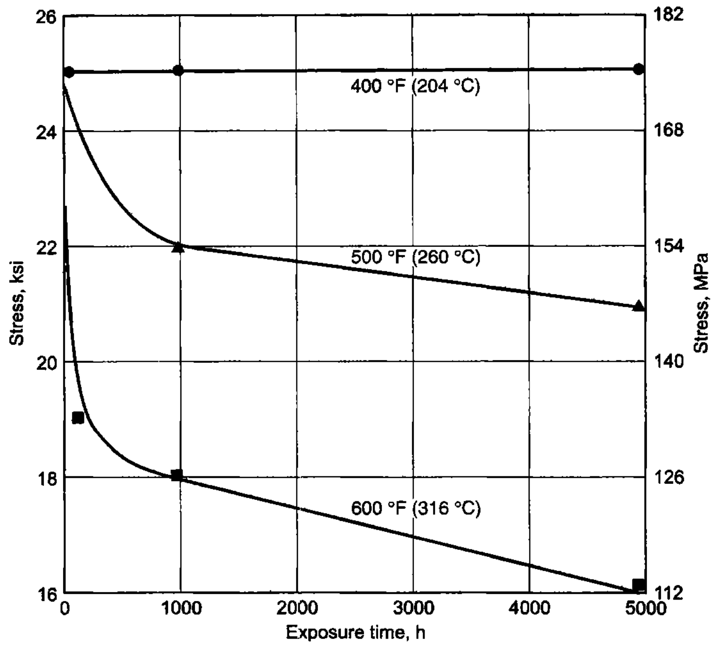
Source: "Magnesium in Design," Form No. 141-213-67, Dow Chemical Co., 1967. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3503, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 6



Mg.052 HK31A-H24 magnesium alloy sheet, compressive stress-strain curves at room and elevated temperatures

Test direction: longitudinal and transverse. Typical bearing ultimate strength in the lowest strength direction with edge-to-diameter ratio of 2.5, 450 MPa (65.0 ksi) for sheet 3.20–6.350 mm (0.126–0.250 in.) thick and plate 25.42–76.20 mm (1.001–3.000 in.) thick. Composition: Mg-3Th-0.7Zr. UNS M13310

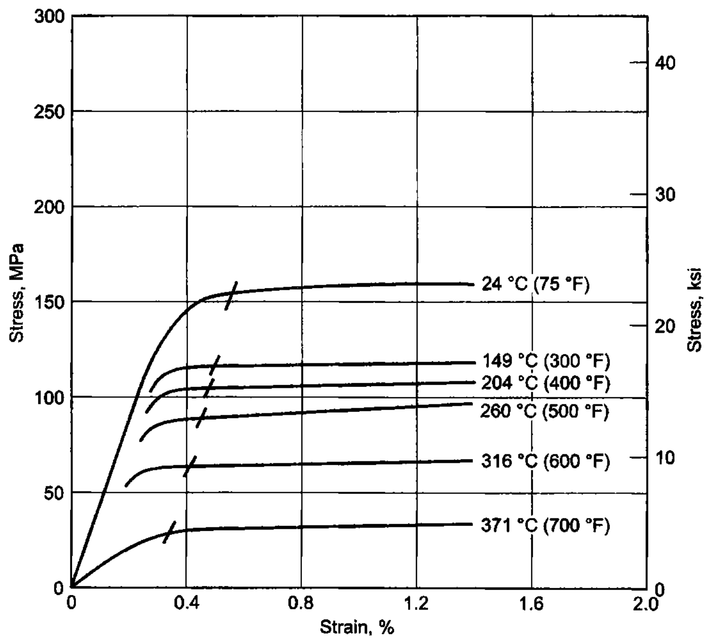
Source: "Magnesium in Design," Form No. 141-213-67, Dow Chemical Co., 1967. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3503, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 9



Mg.053 HK31A-H24 magnesium alloy sheet, effect of elevated temperatures on room-temperature compressive properties

Composition: Mg-3Th-0.7Zr. UNS M13310

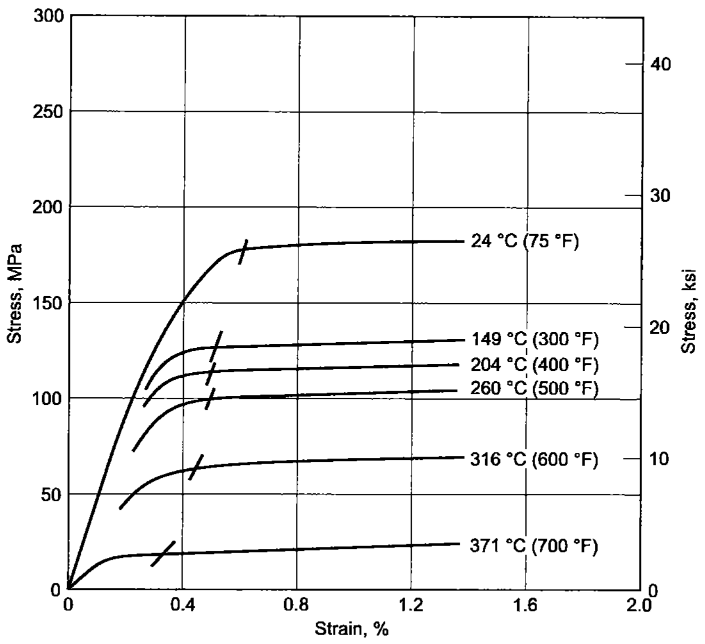
Source: "Magnesium in Design," Form No. 141-213-67, Dow Chemical Co., 1967. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3503, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 7



Mg.054 HK31A-O magnesium alloy sheet, tensile stress-strain curves at various temperatures

Sheet thickness: 1.63 mm (0.064 in.). Test direction: longitudinal. Composition: Mg-3Th-0.7Zr. UNS M13310

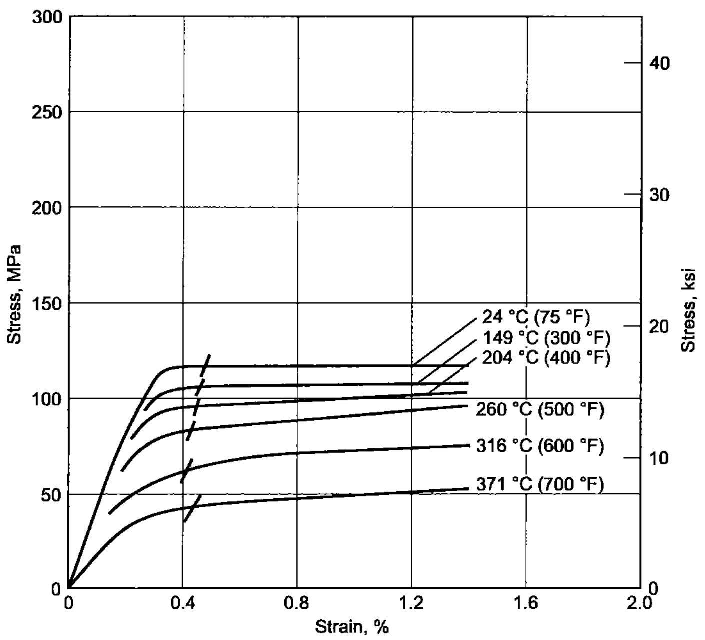
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals*, Vol 2, *Metals Handbook*, American Society for Metals, 1979, p 559



Mg.055 HK31A-O magnesium alloy sheet, tensile stress-strain curves at various temperatures

Sheet thickness: 1.63 mm (0.064 in.). Test direction: transverse. Composition: Mg-3Th-0.7Zr. UNS M13310

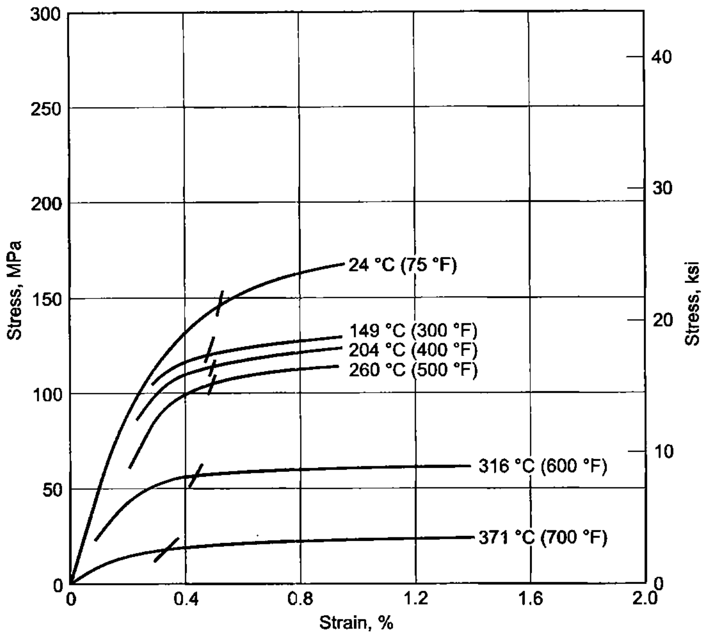
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 559



Mg.056 HK31A-O magnesium alloy sheet, compressive stress-strain curves at various temperatures

Sheet thickness: 1.63 mm (0.064 in.). Test direction: longitudinal. Composition: Mg-3Th-0.7Zr. UNS M13310

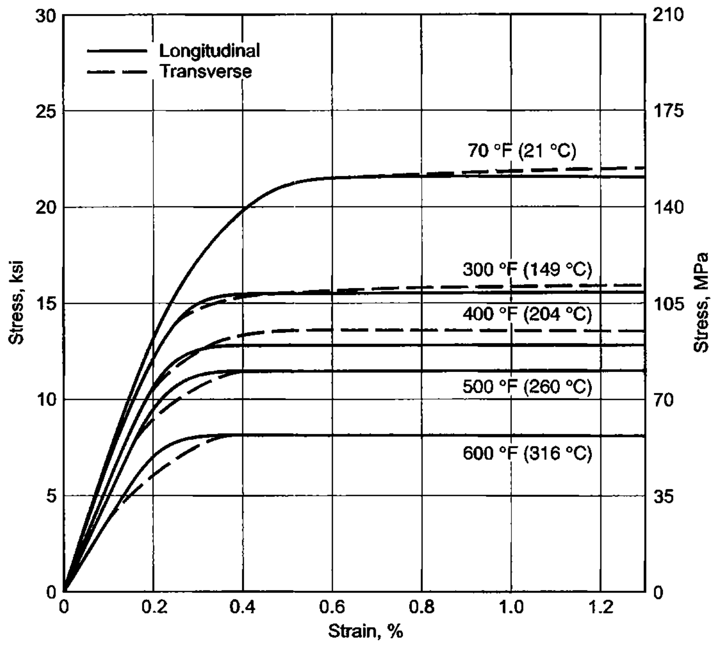
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 559



Mg.057 HK31A-O magnesium alloy sheet, compressive stress-strain curves at various temperatures

Sheet thickness: 1.63 mm (0.064 in.). Test direction: transverse. Composition: Mg-3Th-0.7Zr. UNS M13310

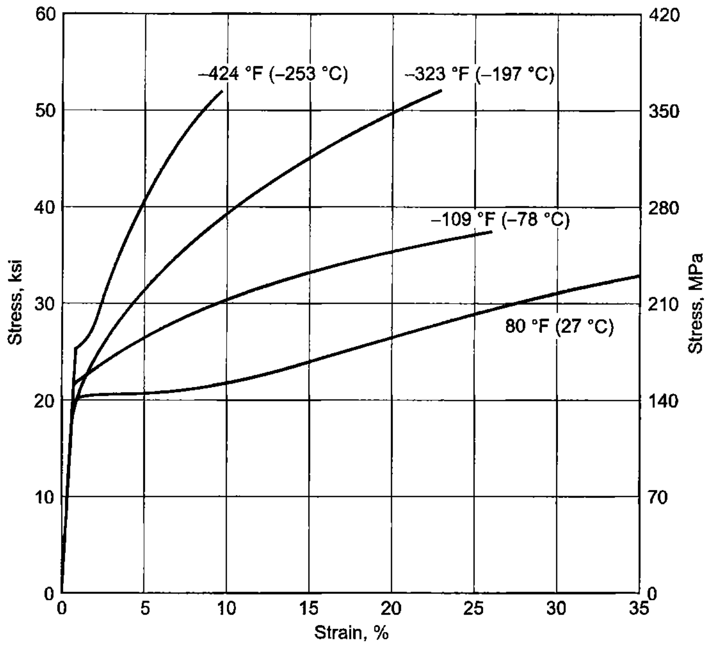
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 559



Mg.058 HK31A-O magnesium alloy sheet, tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal and transverse. Composition: Mg-3Th-0.7Zr. UNS M13310

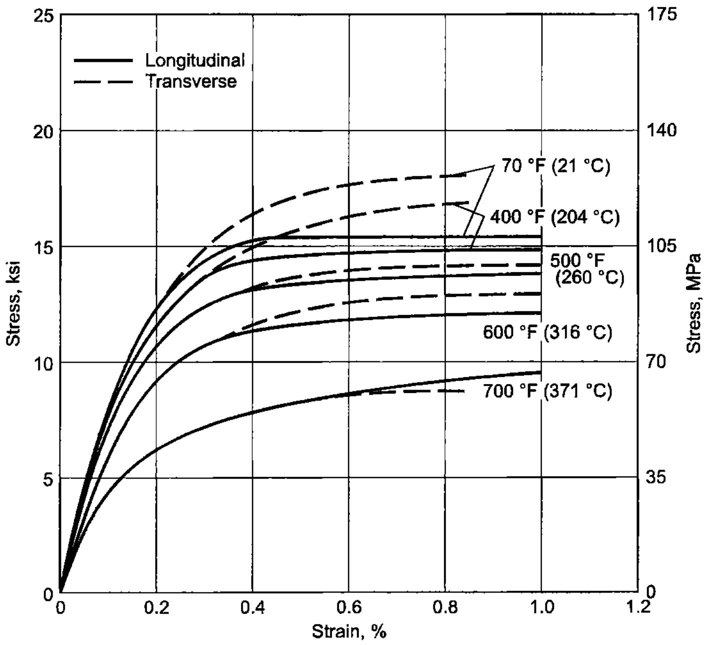
Source: "Magnesium in Design," Form No. 141-213-67, Dow Chemical Co., 1967. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3503, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 6



Mg.059 HK31A-O magnesium alloy sheet, complete tensile stress-strain curves at low temperatures

Composition: Mg-3Th-0.7Zr. UNS M13310

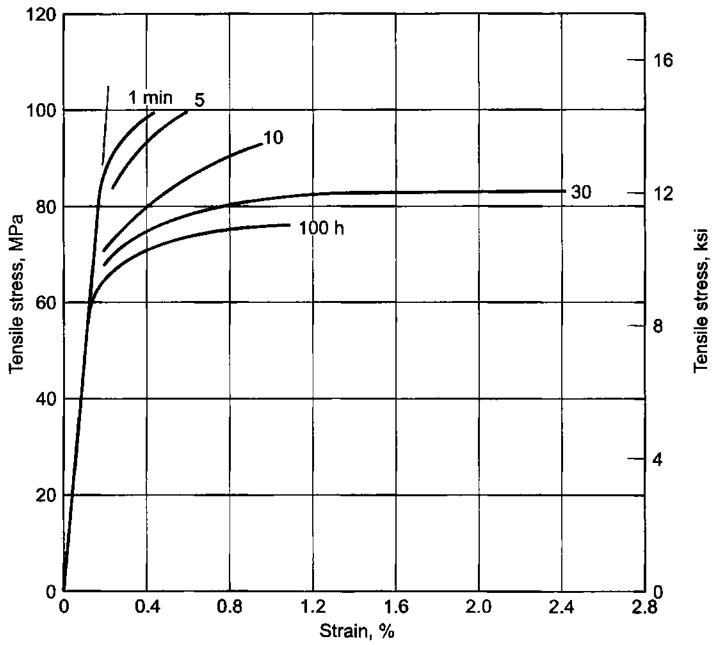
Source: R.P. Reed, R.P. Mikesell, and R.L. Greeson, "Some Mechanical Properties of Magnesium Alloys at Low Temperatures," ASTM STP 287, 1961, p 61–73. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3503, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 7



Mg.060 HK31A-O magnesium alloy sheet, compressive stress-strain curves at room and elevated temperatures

Composition: Mg-3Th-0.7Zr. UNS M13310

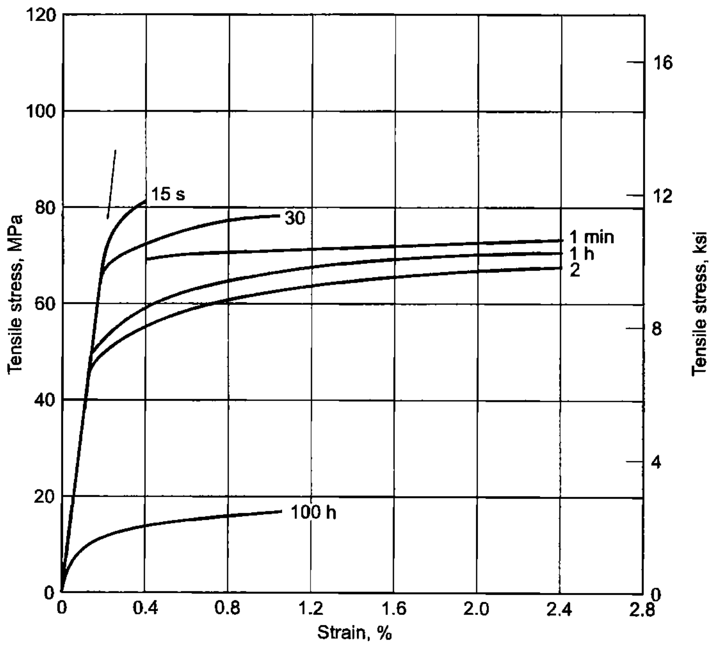
Source: "Magnesium in Design," Form No. 141-213-67, Dow Chemical Co., 1967. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3503, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 9



Mg.061 HK31A-O magnesium alloy sheet, isochronous stress-strain curves at 204 °C (400 °F)

Sheet thickness: 1.63 mm (0.064 in.). Specimens exposed at testing temperature for 3 h before loading. Composition: Mg-3Th-0.7Zr. UNS M13310

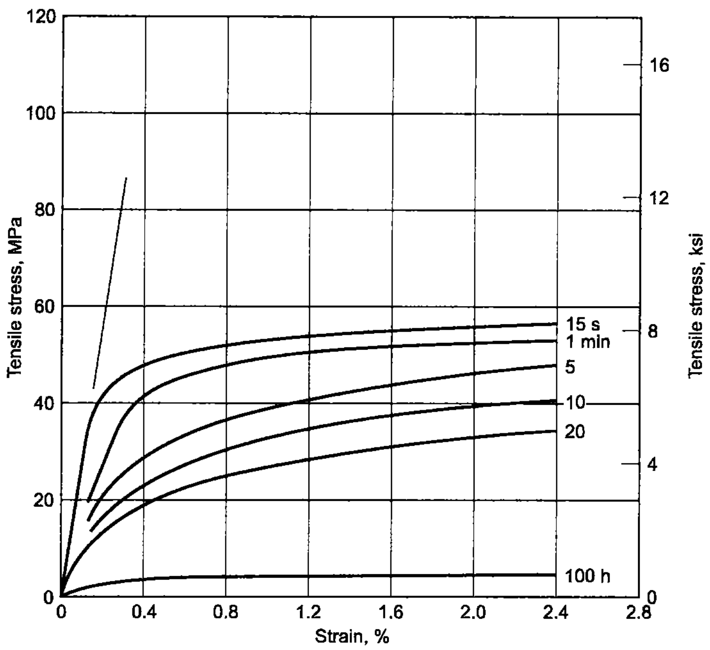
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 561



Mg.062 HK31A-O magnesium alloy sheet, isochronous stress-strain curves at 260 °C (500 °F)

Sheet thickness: 1.63 mm (0.064 in.). Specimens exposed at testing temperature for 3 h before loading. Composition: Mg-3Th-0.7Zr. UNS M13310

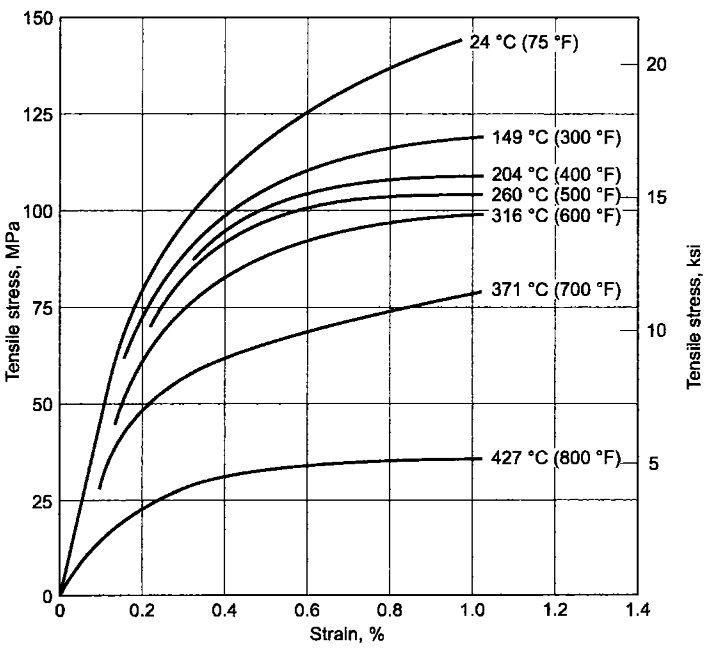
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 561



Mg.063 HK31A-O magnesium alloy sheet, isochronous stress-strain curves at 316 °C (600 °F)

Sheet thickness: 1.63 mm (0.064 in.). Specimens exposed at testing temperature for 3 h before loading. Composition: Mg-3Th-0.7Zr. UNS M13310

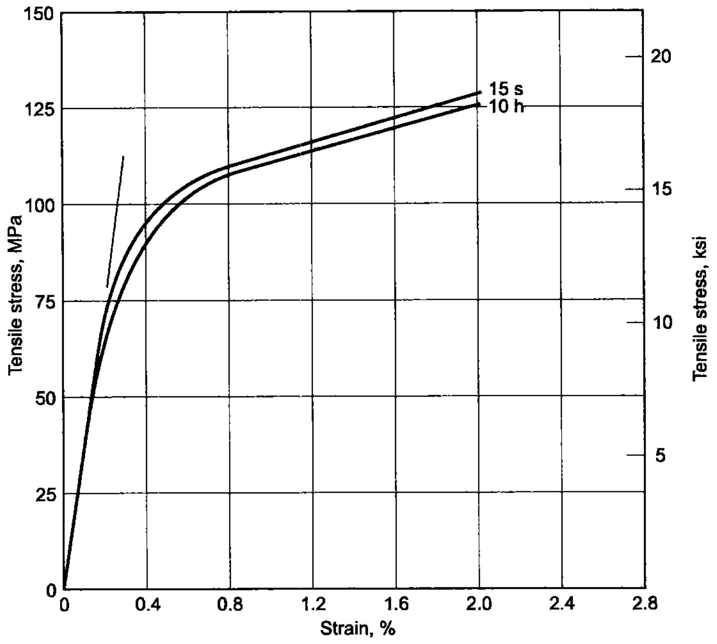
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 561



Mg.064 HK31A-T6 magnesium alloy sand cast test bar, tensile stress-strain curves at room and elevated temperatures

Specimens exposed at testing temperature for 3 h before loading. Composition: Mg-3Th-0.7Zr. UNS M13310

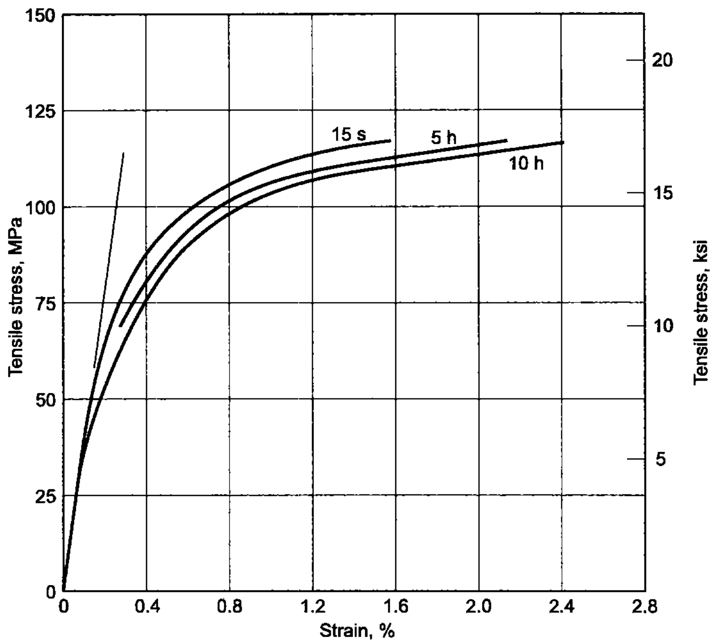
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 583



Mg.065 HK31A-T6 magnesium alloy separately cast test bars, isochronous stress-strain curves at 204 °C (400 °F)

Specimens exposed at testing temperature for 3 h before loading. Composition: Mg-3Th-0.7Zr. UNS M13310

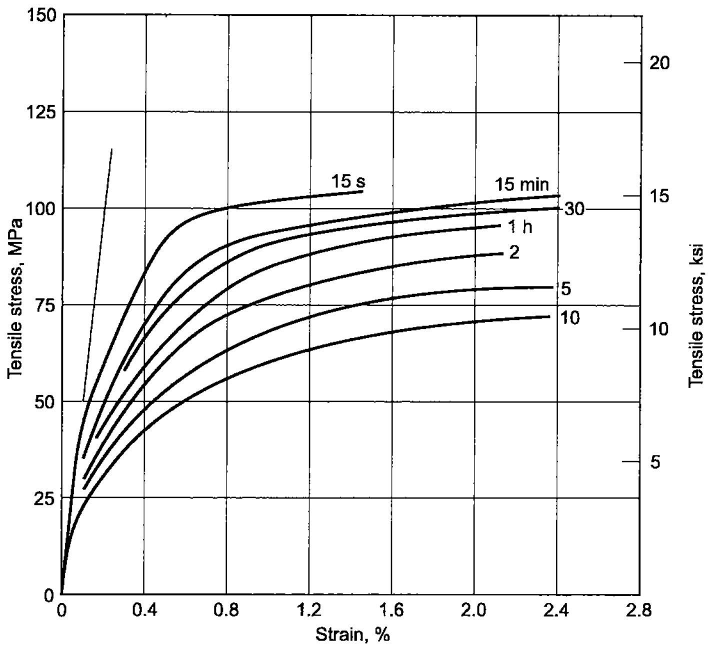
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 583



Mg.066 HK31A-T6 magnesium alloy separately cast test bars, isochronous stress-strain curves at 260 °C (500 °F)

Specimens exposed at testing temperature for 3 h before loading. Composition: Mg-3Th-0.7Zr. UNS M13310

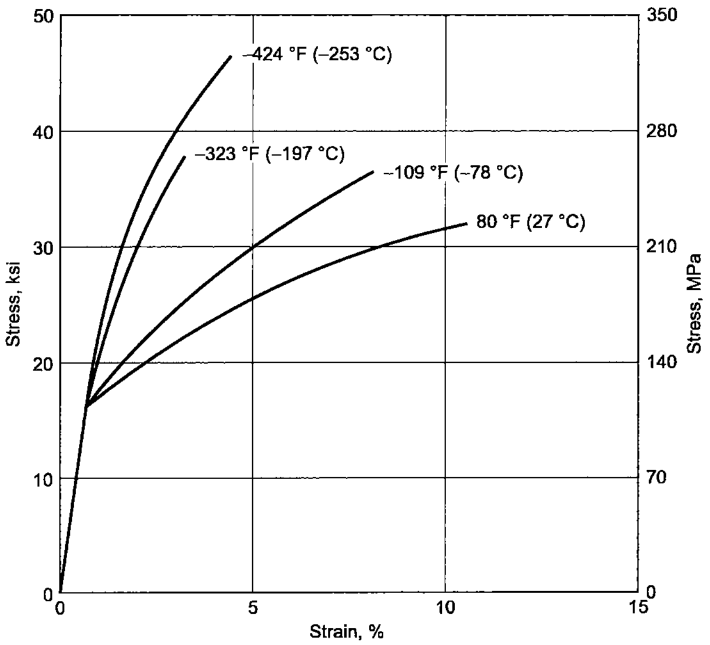
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 583



Mg.067 HK31A-T6 magnesium alloy separately cast test bars, isochronous stress-strain curves at 316 °C (600 °F)

Composition: Mg-3Th-0.7Zr. UNS M13310

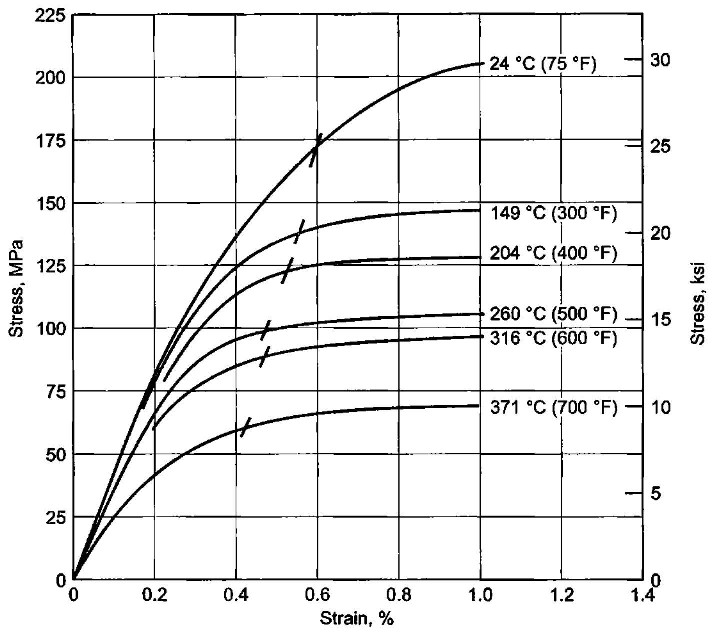
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 583



Mg.068 HK31A-T6 magnesium alloy sand cast test bar, complete tensile stress-strain curves at low temperatures

Composition: Mg-3Th-0.7Zr. UNS M13310

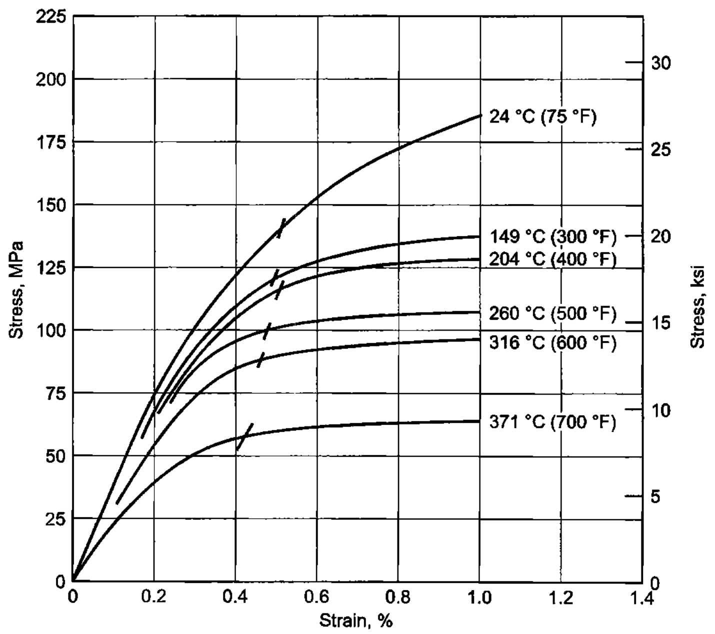
Source: R.P. Reed, R.P. Mikesell, and R.L. Greeson, "Some Mechanical Properties of Magnesium Alloys at Low Temperatures," ASTM STP 287, 1961, p 61–73. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3503, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 7



Mg.069 HM21A-T8 magnesium alloy sheet, tensile stress-strain curves at various temperatures

Test direction: longitudinal. Specimens held at test temperature 3 h before testing. Composition: Mg-2Th-0.8Mn. UNS M13210

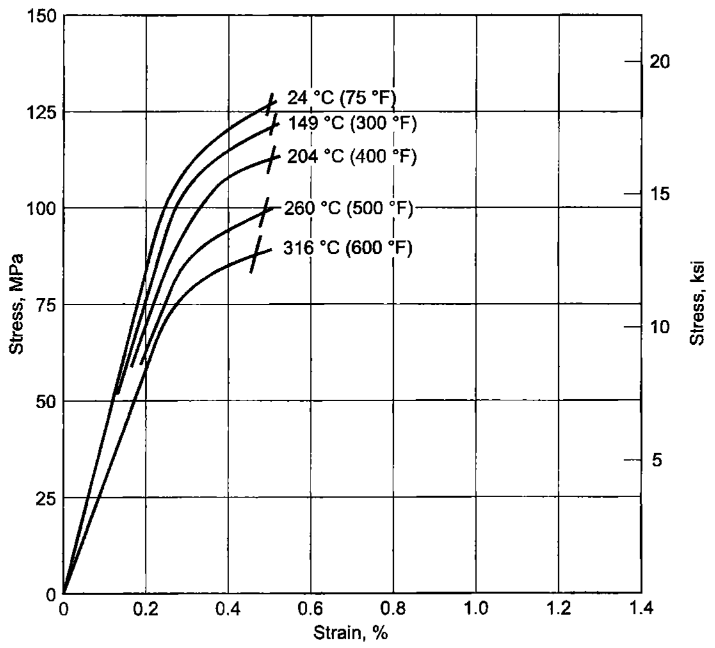
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 562



Mg.070 HM21A-T8 magnesium alloy sheet, tensile stress-strain curves at various temperatures

Test direction: transverse. Specimens held at test temperature 3 h before testing. Composition: Mg-2Th-0.8Mn. UNS M13210

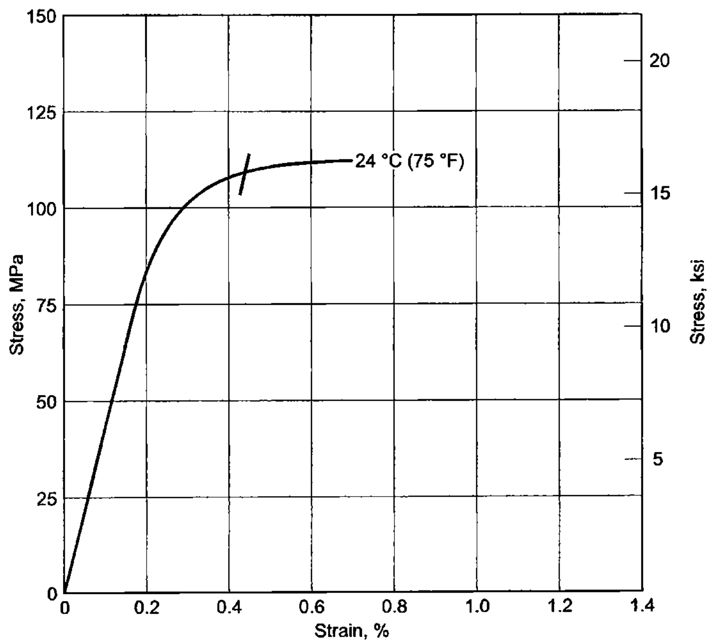
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 562



Mg.071 HM21A-T8 magnesium alloy sheet, compressive stress-strain curves at various temperatures

Test direction: longitudinal. Specimens held at test temperature 3 h before testing. Composition: Mg-2Th-0.8Mn. UNS M13210

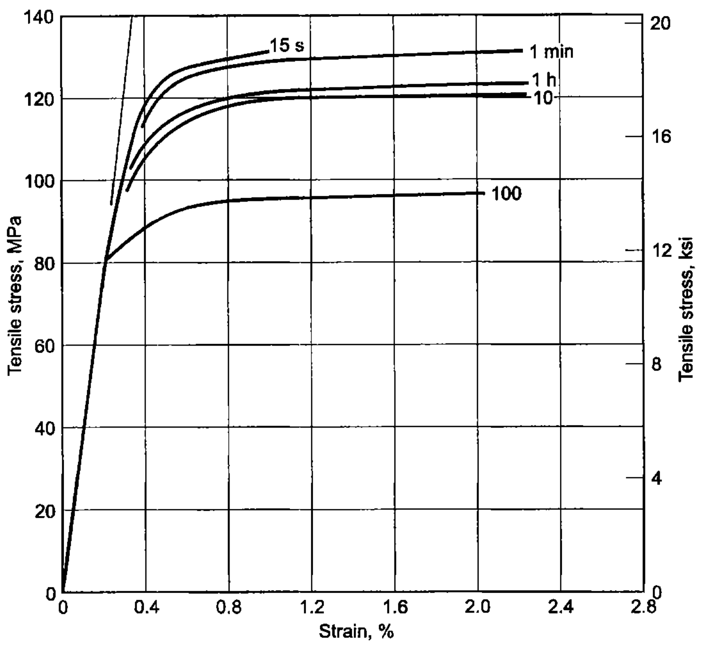
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 562



Mg.072 HM21A-T8 magnesium alloy sheet, compressive stress-strain curves at various temperatures

Test direction: transverse. Specimens held at test temperature 3 h before testing. Composition: Mg-2Th-0.8Mn. UNS M13210

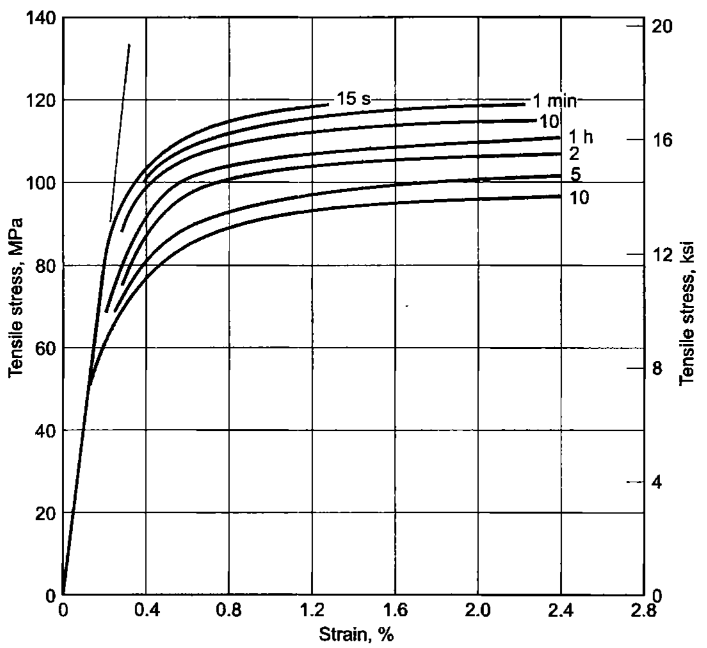
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 562



Mg.073 HM21A-T8 magnesium alloy sheet, isochronous stress-strain curves at 204 °C (400 °F)

Sheet thickness: 1.63 mm (0.064 in.). Specimens held at test temperature 3 h before testing. Composition: Mg-2Th-0.8Mn. UNS M13210

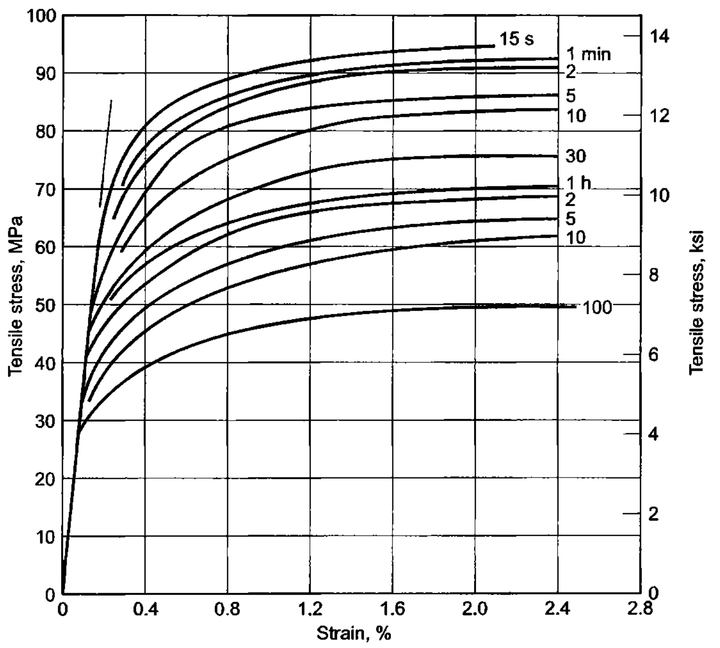
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 563



Mg.074 HM21A-T8 magnesium alloy sheet, isochronous stress-strain curves at 260 °C (500 °F)

Sheet thickness: 1.63 mm (0.064 in.). Specimens held at test temperature 3 h before testing. Composition: Mg-2Th-0.8Mn. UNS M13210

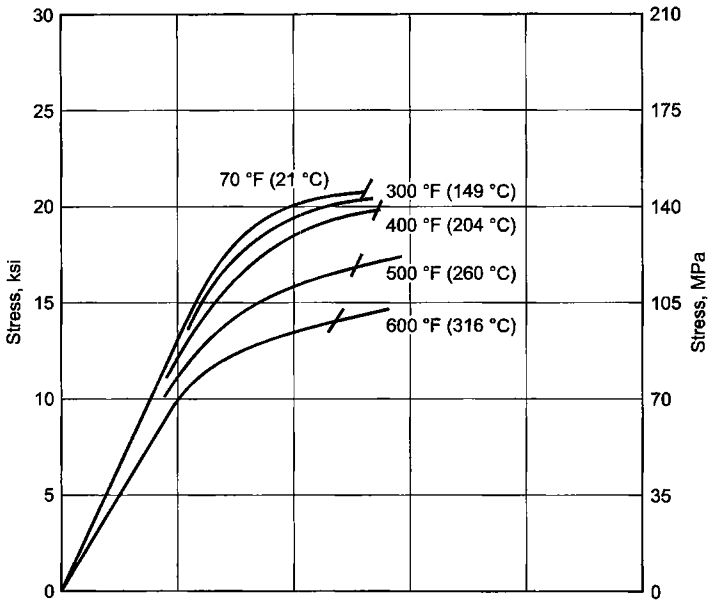
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 563

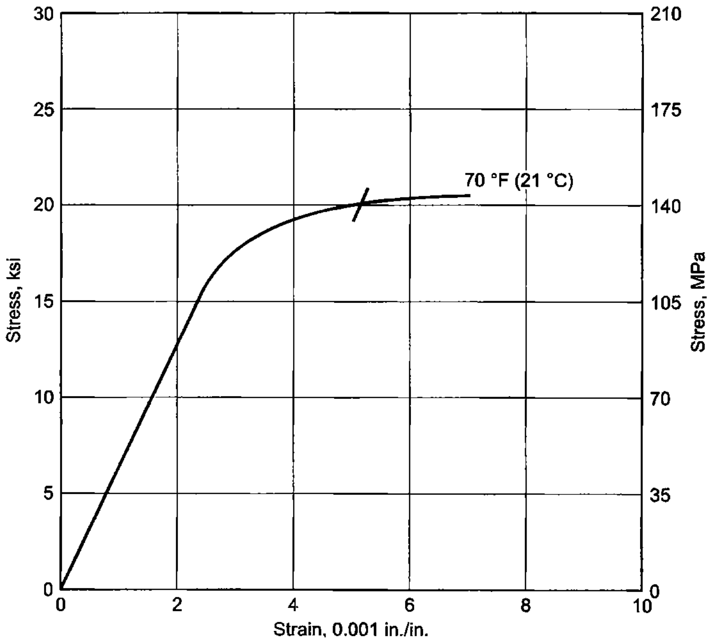


Mg.075 HM21A-T8 magnesium alloy sheet, isochronous stress-strain curves at 316 °C (600 °F)

Sheet thickness: 1.63 mm (0.064 in.). Specimens held at test temperature 3 h before testing. Composition: Mg-2Th-0.8Mn. UNS M13210

Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 563

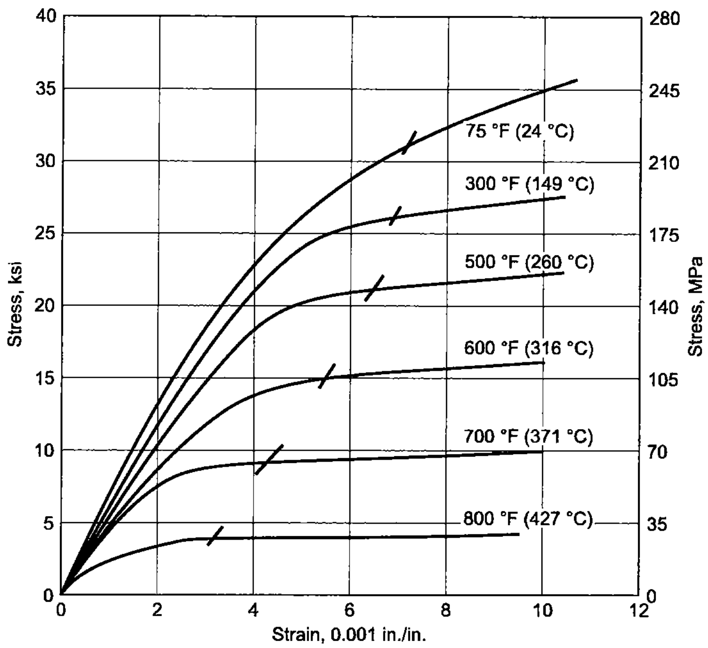




Mg.076 HM21A-T8 magnesium alloy sheet, compressive stress-strain curves at room and elevated temperatures

Top curves are for the longitudinal direction. Bottom curve is transverse. Composition: Mg-2Th-0.8Mn. UNS M13210

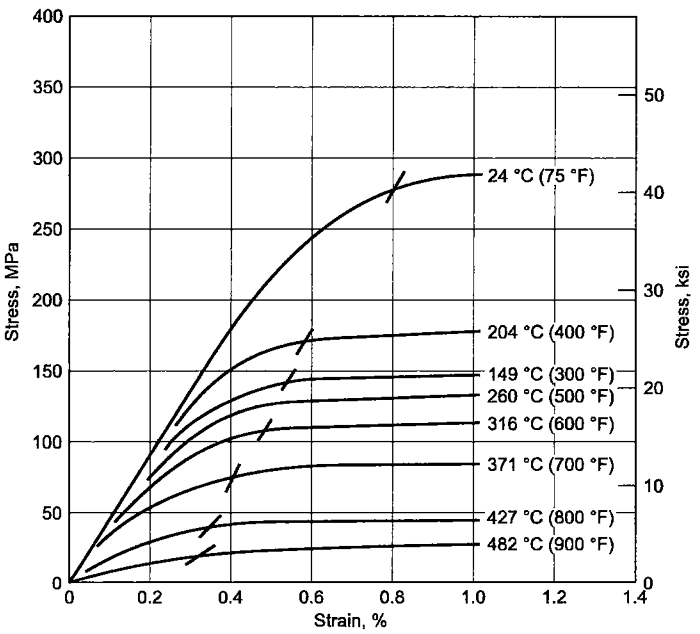
Source: "Magnesium in Aerospace Design," Bulletin 141-213, Dow Chemical Co., 1963. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3504, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 8



Mg.077 HM21A-T81 magnesium alloy sheet, tensile stress-strain curves at various temperatures

Sheet thickness: 4.826 mm (0.190 in.). Composition: Mg-2Th-0.8Mn. UNS M13210

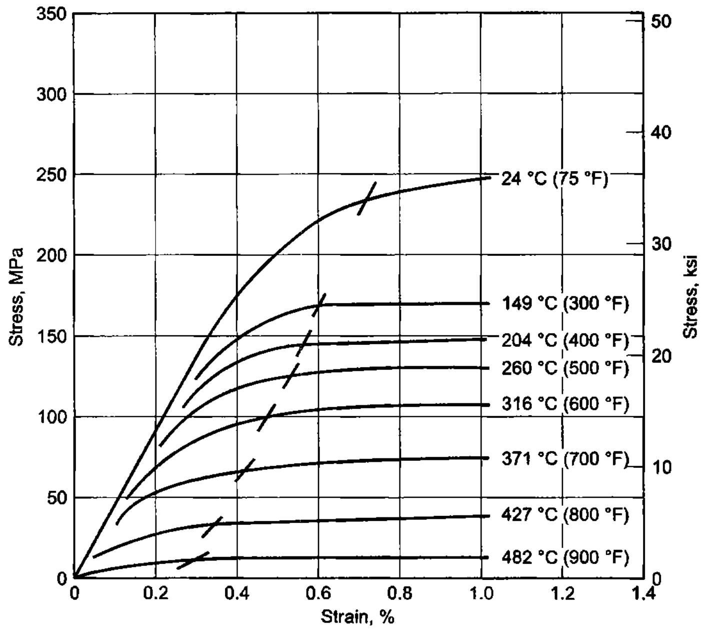
Source: "Magnesium in Aerospace Design," Bulletin 141-213, Dow Chemical Co., 1963. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3504, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 6



Mg.078 HM31A magnesium alloy extrusion, tensile stress-strain curves at various temperatures

Extrusion ratio of 25:1 approximate. 50.8 × 25.4 mm (2 × 1 in.) rectangles tested in the longitudinal direction. Composition: Mg-3Th-1.5Mn. UNS M13312

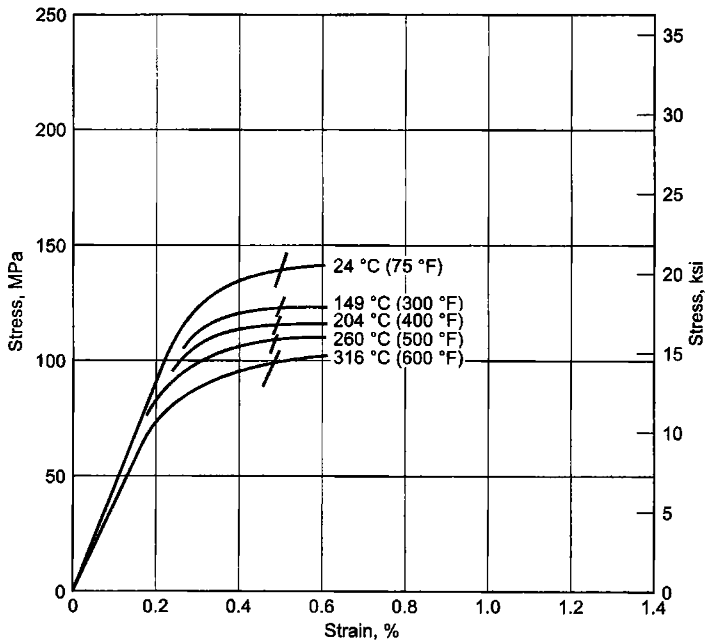
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 566



Mg.079 HM31A magnesium alloy extrusion, tensile stress-strain curves at various temperatures

Extrusion ratio of 67:1 approximate. 9.525 × 50.8 mm (0.375 × 2 in.) rectangles tested in the longitudinal direction. Composition: Mg-3Th-1.5Mn. UNS M13312

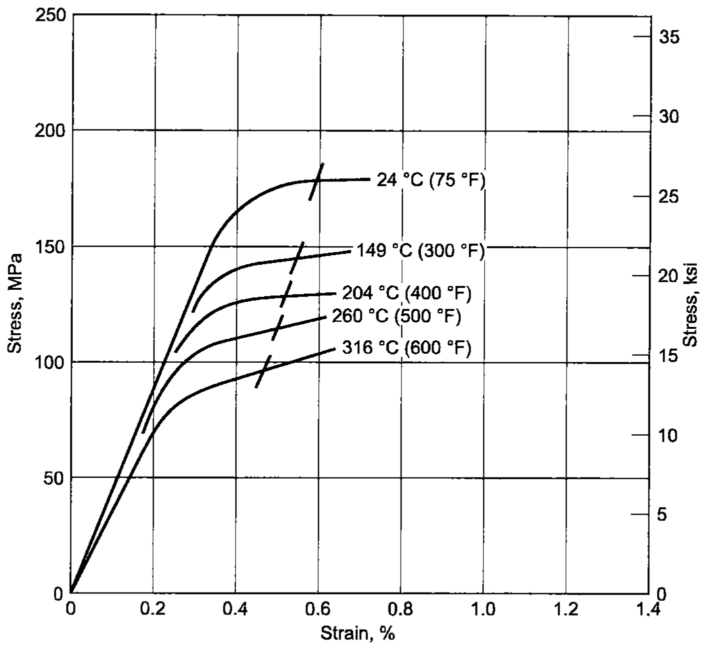
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 566



Mg.080 HM31A magnesium alloy extrusion, compressive stress-strain curves at various temperatures

Extrusion ratio of 25:1 approximate. 50.8 × 25.4 mm (2 × 1 in.) rectangles tested in the longitudinal direction. Composition: Mg-3Th-1.5Mn. UNS M13312

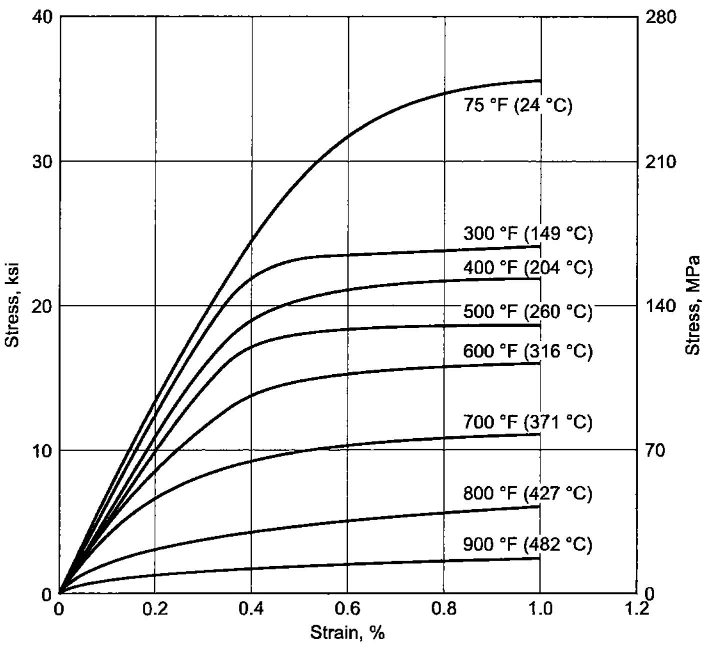
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 566



Mg.081 HM31A magnesium alloy extrusion, compressive stress-strain curves at various temperatures

Extrusion ratio of 67:1 approximate. 9.525 × 50.8 mm (0.375 × 2 in.) rectangles tested in the longitudinal direction. Composition: Mg-3Th-1.5Mn. UNS M13312

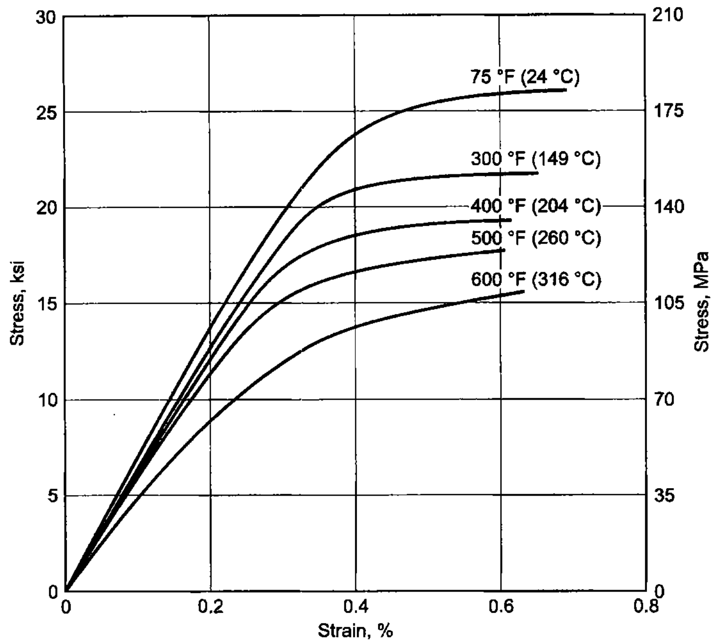
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 566



Mg.082 HM31A-F magnesium alloy extrusion, stress-strain curves at room and elevated temperatures

Extrusions up to 25.8 cm^2 (4.0 in.^{2}) cross section tested in longitudinal direction. Composition: Mg-3Th-1.5Mn. UNS M13312

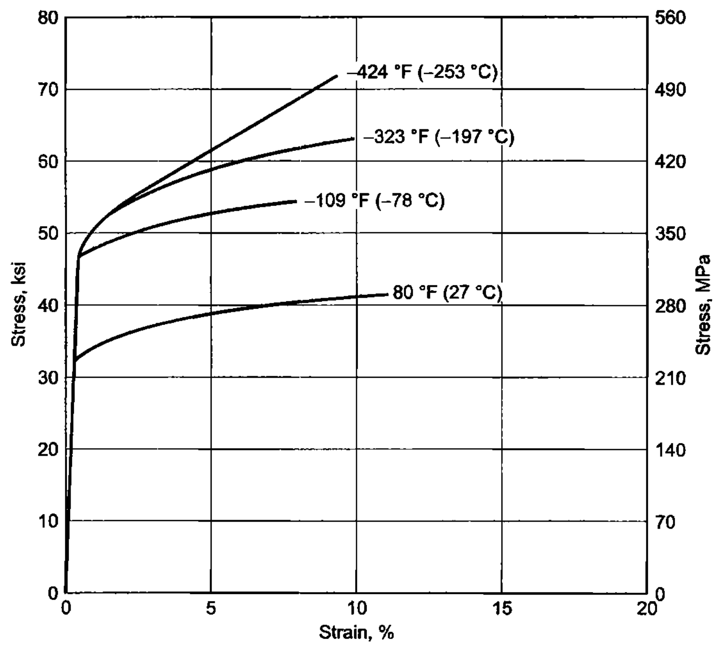
Source: "HM31XA Magnesium Alloy Extrusions," Bulletin No. 141-199, Dow Chemical Co. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3505, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 4



Mg.083 HM31A-F magnesium alloy extrusion, compressive stress-strain curves at room and elevated temperatures

Extrusions up to 25.8 cm^2 (4.0 $in.^2$) cross section tested in longitudinal direction. Composition: Mg-3Th-1.5Mn. UNS M13312

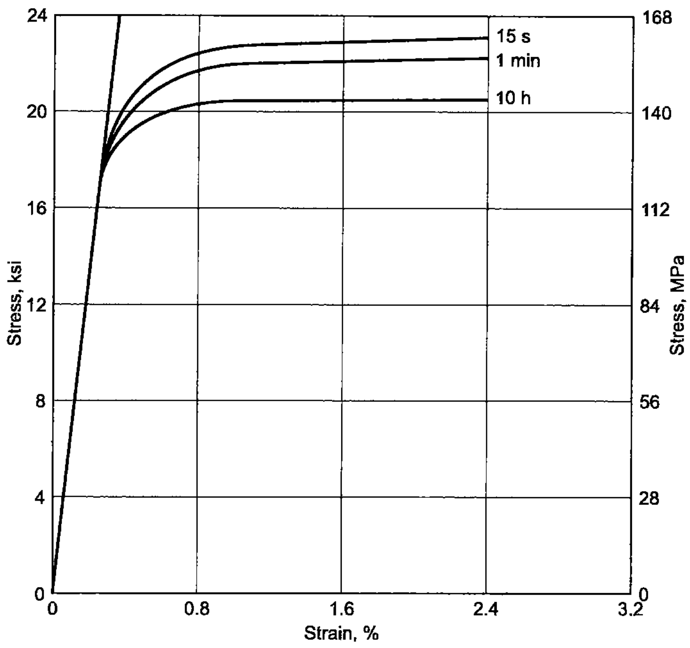
Source: "Magnesium in Design," Form No. 141-213-67, Dow Chemical Co., 1967. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3505, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 6



Mg.084 HM31A-F magnesium alloy extrusion, complete stress-strain curves at low temperatures

Tested in longitudinal direction. Composition: Mg-3Th-1.5Mn. UNS M13312

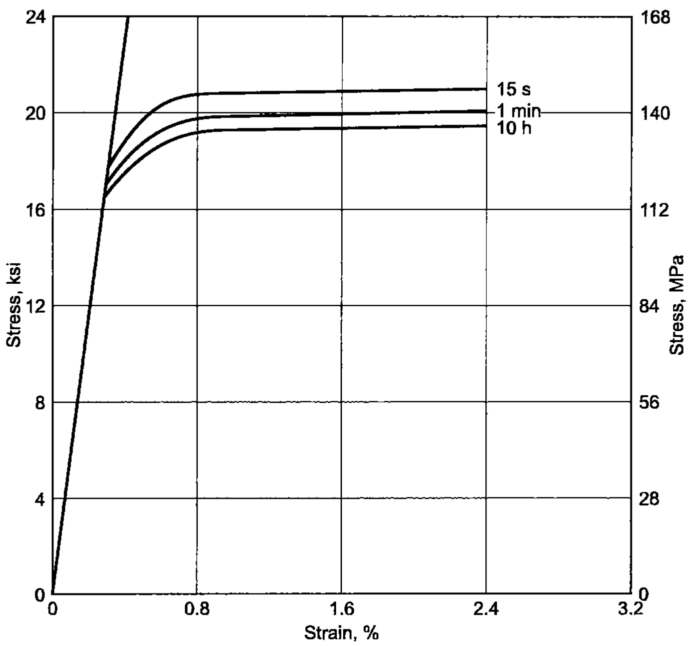
Source: R.P. Reed, R.P. Mikesell, and R.L. Greeson, "Some Mechanical Properties of Magnesium Alloys at Low Temperatures," ASTM STP 287, 1961, p 61-73. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3505, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 5



Mg.085 HM31A-F magnesium alloy extrusion, isochronous stress-strain curves at 149 °C (300 °F)

Solid extrusions up to 25.8 cm^2 (4.0 $in.^2$) cross section, exposed to elevated temperature for 3 h prior to loading. Composition: Mg-3Th-1.5Mn. UNS M13312

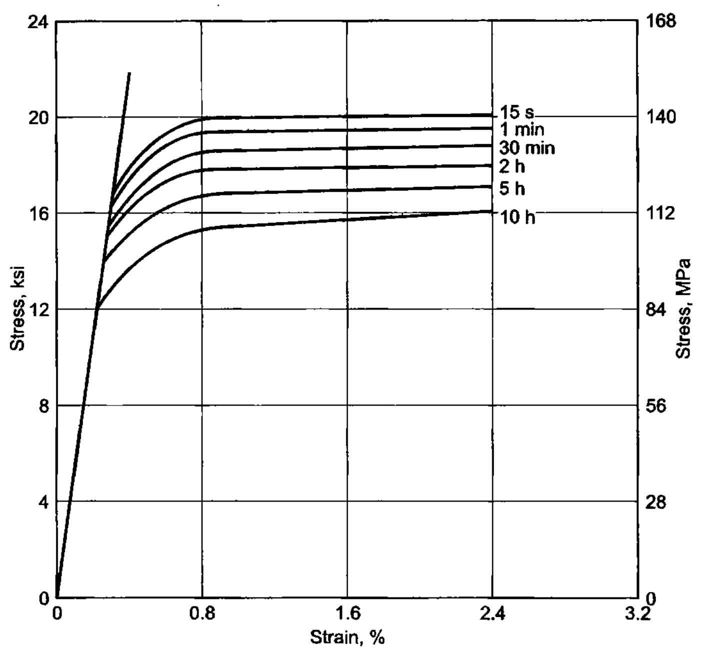
Source: "HM31XA Magnesium Alloy Extrusions," Bulletin No. 141-199, Dow Chemical Co. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3505, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 8



Mg.086 HM31A-F magnesium alloy extrusion, isochronous stress-strain curves at 204 °C (400 °F)

Solid extrusions up to 25.8 cm^2 (4.0 $in.^2$) cross section, exposed to elevated temperature for 3 h prior to loading. Composition: Mg-3Th-1.5Mn. UNS M13312

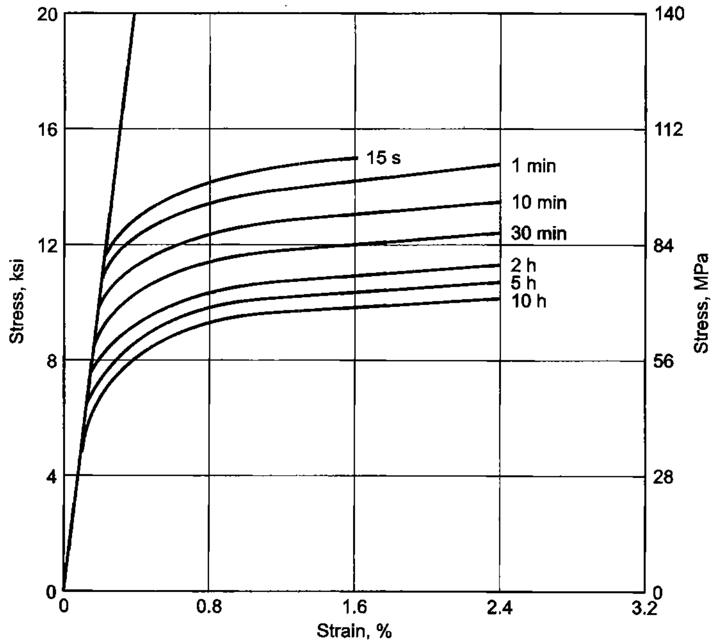
Source: "HM31XA Magnesium Alloy Extrusions," Bulletin No. 141-199, Dow Chemical Co. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3505, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 8



Mg.087 HM31A-F magnesium alloy extrusion, isochronous stress-strain curves at 260 °C (500 °F)

Solid extrusions up to 25.8 cm^2 (4.0 $in.^2$) cross section, exposed to elevated temperature for 3 h prior to loading. Composition: Mg-3Th-1.5Mn. UNS M13312

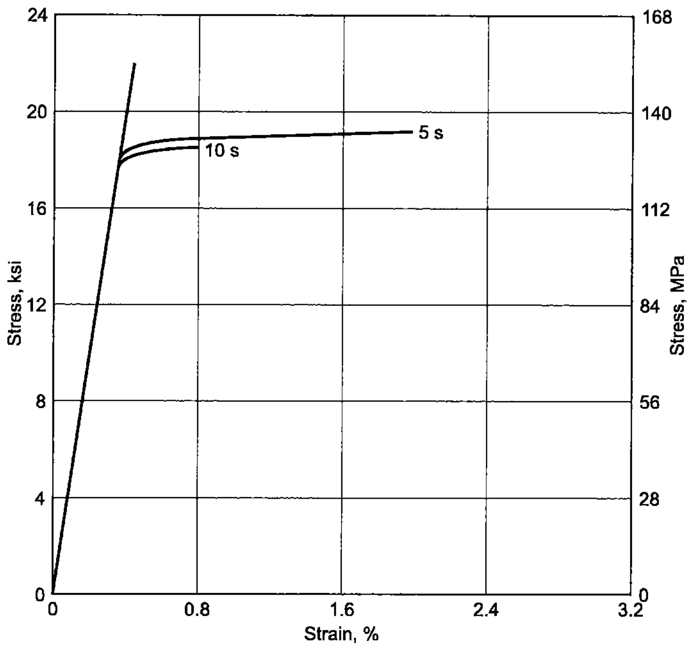
Source: "HM31XA Magnesium Alloy Extrusions," Bulletin No. 141-199, Dow Chemical Co. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3505, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 8



Mg.088 HM31A-F magnesium alloy extrusion, isochronous stress-strain curves at 316 °C (600 °F)

Solid extrusions up to 25.8 cm^2 (4.0 $in.^2$) cross section, exposed to elevated temperature for 3 h prior to loading. Composition: Mg-3Th-1.5Mn. UNS M13312

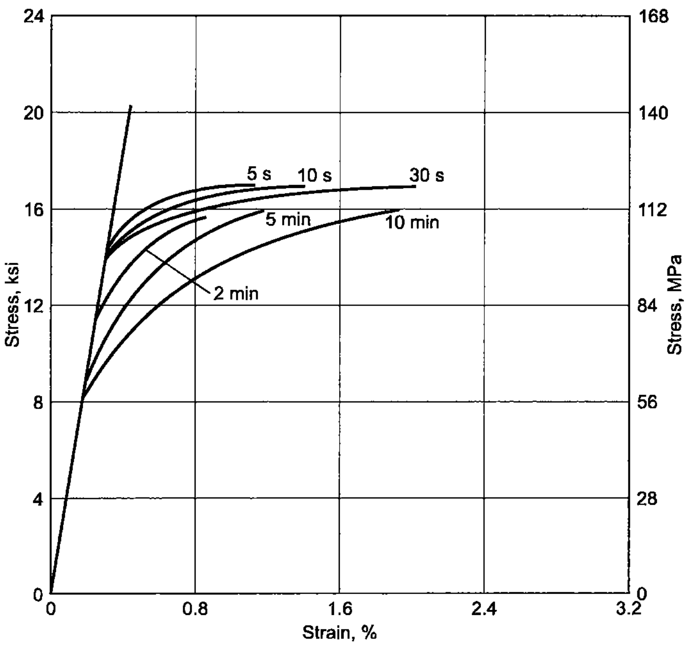
Source: "HM31XA Magnesium Alloy Extrusions," Bulletin No. 141-199, Dow Chemical Co. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3505, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 8



Mg.089 HM31A-F magnesium alloy extruded tubing, isochronous stress-strain curves at 260 °C (500 °F)

25.4 cm (10 in.) OD × 8 mm (0.315 in.) wall. Short-time tests after 5 s exposure to test temperature prior to loading. Composition: Mg-3Th-1.5Mn. UNS M13312

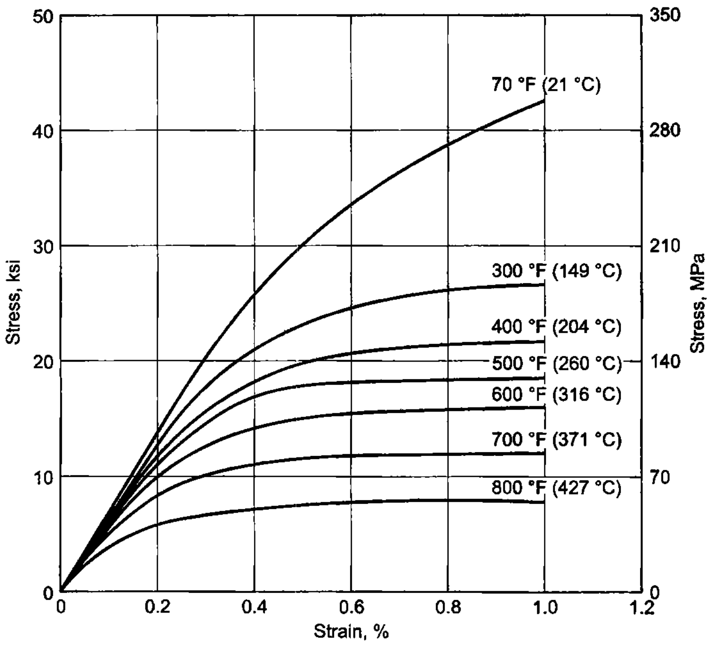
Source: "HM31XA Magnesium Alloy Extrusions," Bulletin No. 141-199, Dow Chemical Co. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3505, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 9



Mg.090 HM31A-F magnesium alloy extruded tubing, isochronous stress-strain curves at 316 °C (600 °F)

25.4 cm (10 in.) OD × 8 mm (0.315 in.) wall. Short-time tests after 5 s exposure to test temperature prior to loading. Composition: Mg-3Th-1.5Mn. UNS M13312

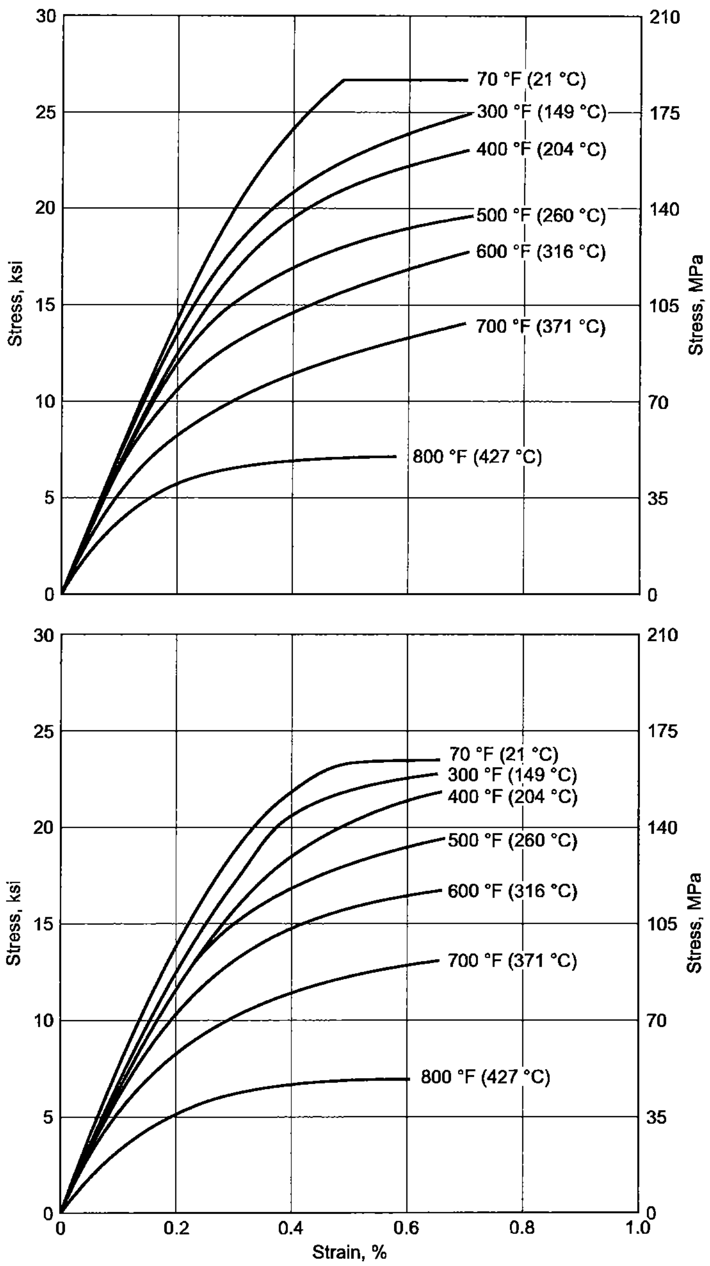
Source: "HM31XA Magnesium Alloy Extrusions," Bulletin No. 141-199, Dow Chemical Co. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3505, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 9



Mg.091 HM31A-T5 magnesium alloy extrusion, stress-strain curves at room and elevated temperatures

Extrusions up to 25.8 cm^2 (4.0 in.^{2}) cross section tested in longitudinal direction. Composition: Mg-3Th-1.5Mn. UNS M13312

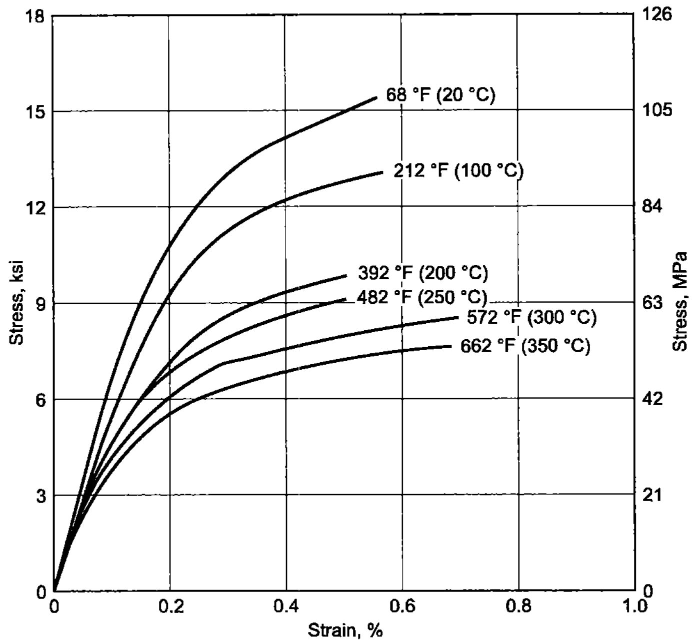
Source: "Magnesium in Design," Form No. 141-213-67, Dow Chemical Co., 1967. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3505, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 4



Mg.092 HM31A-T5 magnesium alloy extrusion, compressive stress-strain curves at room and elevated temperatures

Top curves for extrusions with cross section less than 6.45 cm^2 (1 $in.^2$). Bottom for extrusions with cross section 6.45–25.8 cm^2 (1–4 $in.^2$). Tested in longitudinal direction. Composition: Mg-3Th-1.5Mn. UNS M13312

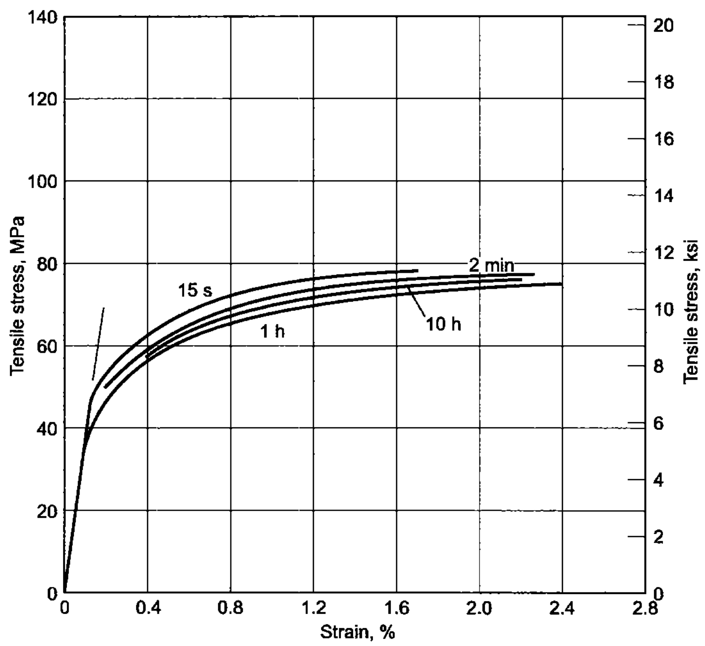
Source: "Magnesium in Design," Form No. 141-213-67, Dow Chemical Co., 1967. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3505, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 6



Mg.093 HZ32A-T5 magnesium alloy sand cast bar, tensile stress-strain curves at various temperatures

Composition: Mg-3.2Th-2.1Zn-0.7Zr. UNS M13320

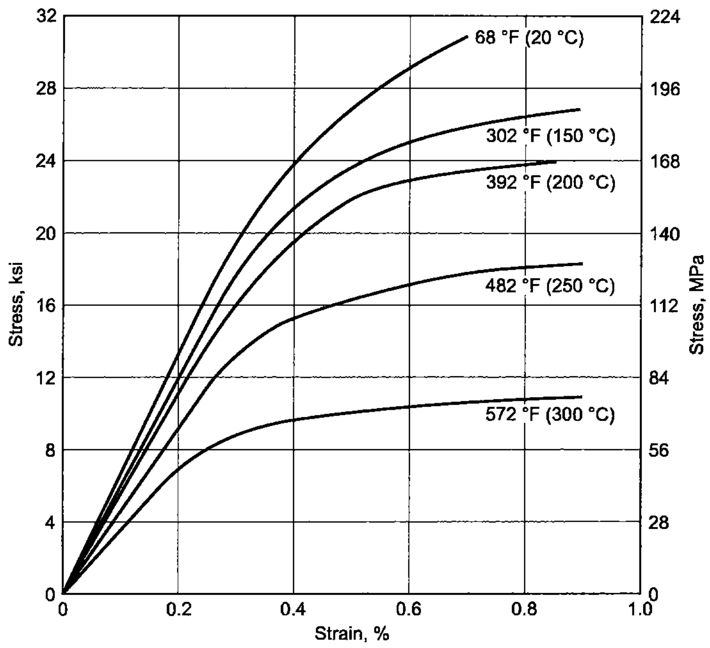
Source: "Design," Booklet by Magnesium Elektron Ltd. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3408, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 3



Mg.094 HZ32A-T5 magnesium alloy separately sand cast test bar, isochronous tensile stress-strain curves at 204 °C (400 °F)

Specimens exposed to elevated temperature for 3 h before loading. Composition: Mg-3.2Th-2.1Zn-0.7Zr. UNS M13320

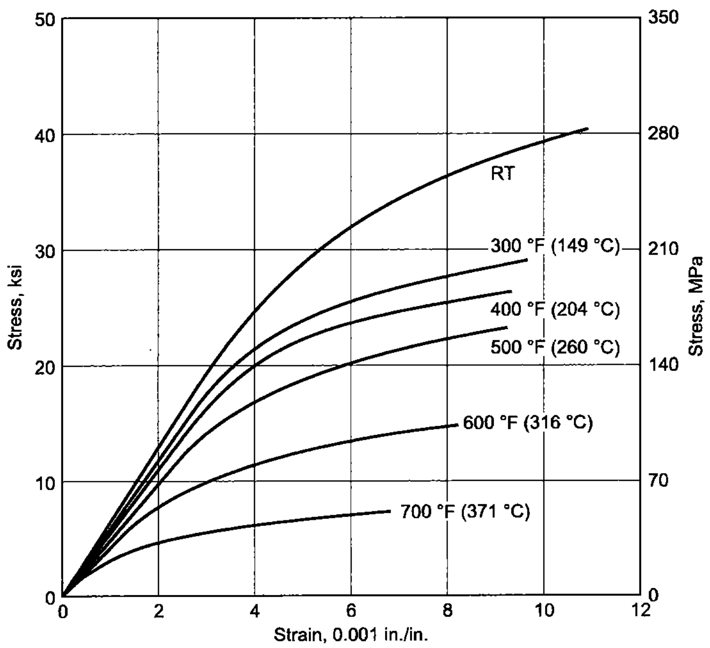
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals*, Vol 2, *Metals Handbook*, American Society for Metals, 1979, p 585



Mg.095 QE22A-T6 magnesium alloy sand casting, stress-strain curves at room and elevated temperatures

Composition: Mg-2.5Ag-2.0Di-0.4Zr. Didymium is a natural mixture of rare-earth elements neodymium and praseodymium given the quasi-chemical symbol Di. UNS M18220

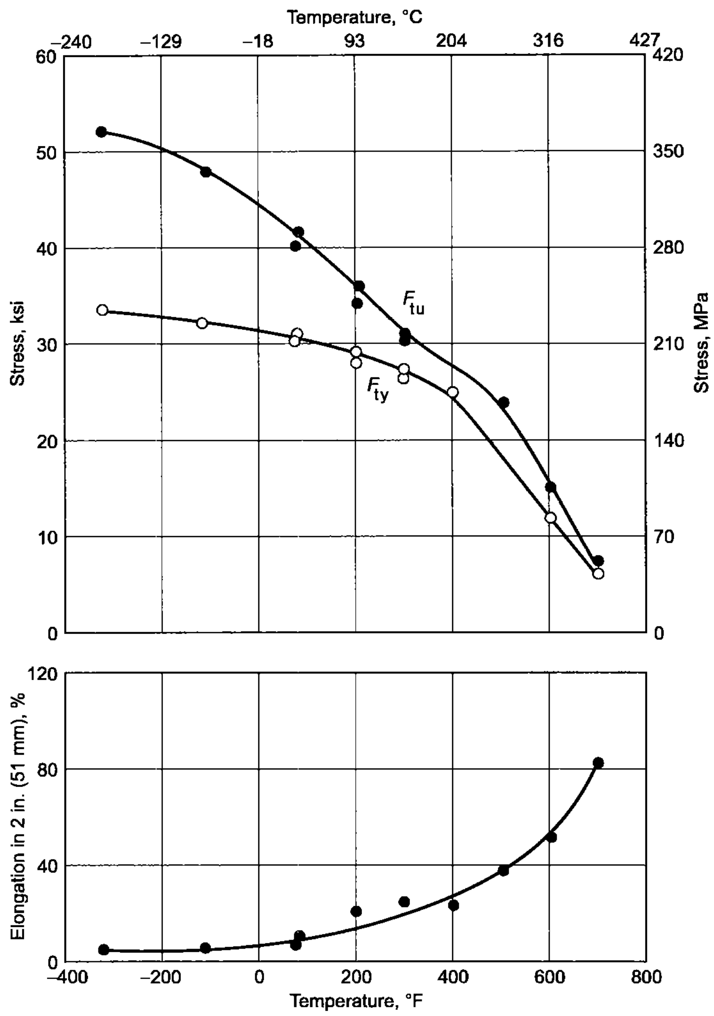
Source: "Design," Booklet by Magnesium Elektron Ltd. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3406, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 4



Mg.096 QE22A-T6 magnesium alloy casting, typical stress-strain curves at room and elevated temperatures

RT, room temperature. Specimens exposed to elevated temperatures for 0.5 h. Ramberg-Osgood parameters: n(RT) = 6.5, n(300 °F [or 149 °C]) = 7.9, n(400 °F [or 204 °C]) = 9.0, n(600 °F [or 314 °C]) = 4.8, n(700 °F [or 371 °C]) = 3.9. Composition: Mg-2.5Ag-2.0Di-0.4Zr. Didymium is a natural mixture of rare-earth elements neodymium and praseodymium given the quasi-chemical symbol Di. UNS M18220

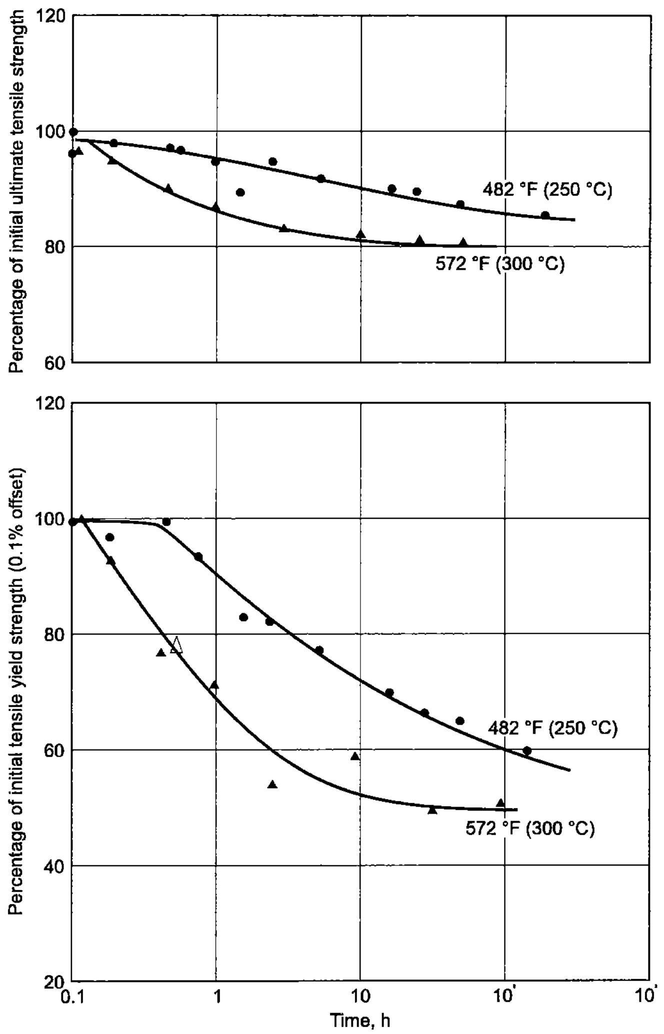
Source: *MIL-HDBK-5H*, Dec 1998, p 4–47



Mg.097 QE22A-T6 magnesium alloy sand cast test bar, effect of temperature on tensile properties

F_{tu}, ultimate tensile strength; F_{ty}, tensile yield strength. Composition: Mg-2.5Ag-2.0Di-0.4Zr. Didymium is a natural mixture of rare-earth elements neodymium and praseodymium given the quasi-chemical symbol Di. UNS M18220

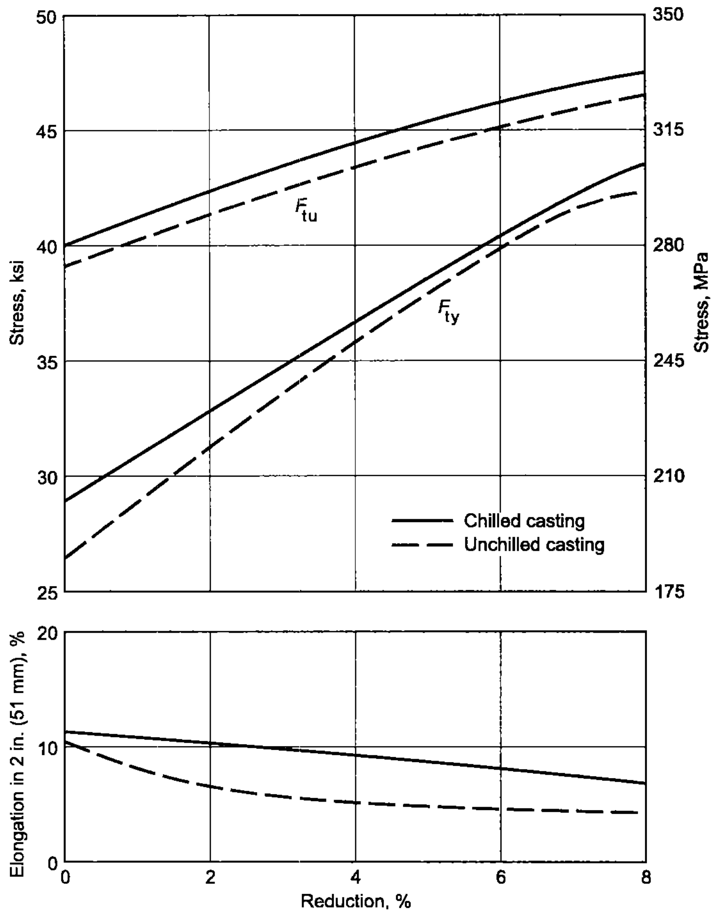
Source: J.B. Hallowell and H.R. Ogden, "An Introduction to Magnesium Alloys," DMIC Report 206, Battelle Memorial Institute, 1964. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3406, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 4



Mg.098 QE22A-T6 magnesium alloy sand cast bar, effect of overaging on tensile properties

Composition: Mg-2.5Ag-2.0Di-0.4Zr. Didymium is a natural mixture of rare-earth elements neodymium and praseodymium given the quasi-chemical symbol Di. UNS M18220

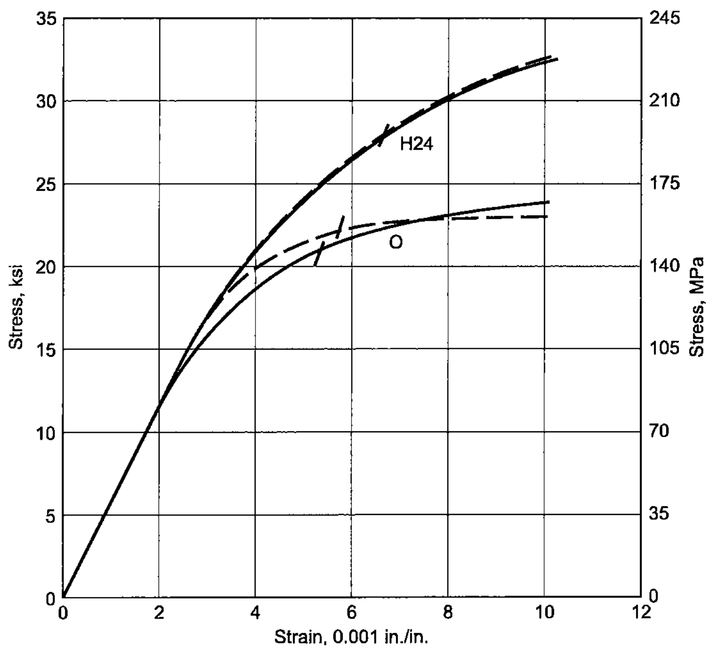
Source: "Crucible Melting of Magnesium Alloys," Bulletin No. 181-27, Dow Chemical Co. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3406, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 4



Mg.099 QE22A-T8 magnesium alloy sand cast, effect of cold work on tensile properties

F_{tu}, ultimate tensile strength; F_{ty}, tensile yield strength. Effect of casting process is shown. Composition: Mg-2.5Ag-2.0Di-0.4Zr. Didymium is a natural mixture of rare-earth elements neodymium and praseodymium given the quasi-chemical symbol Di. UNS M18220

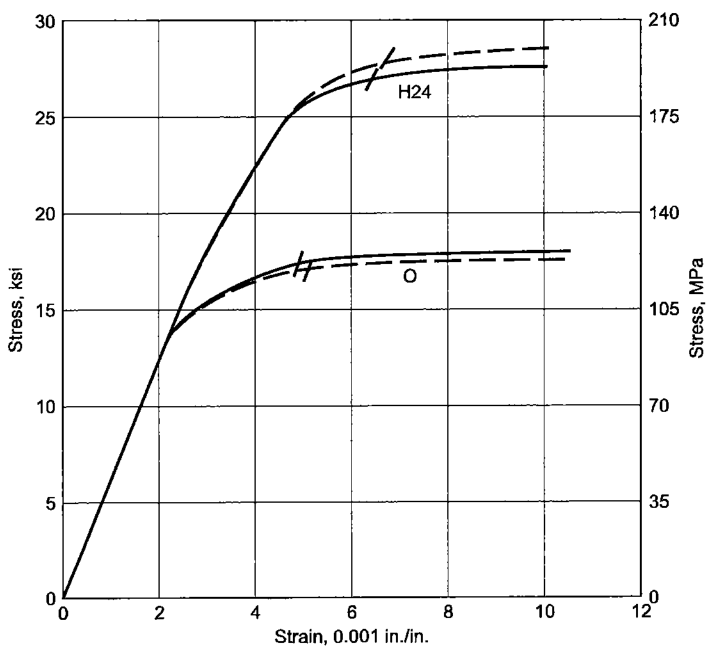
Source: B. Lagowski and J.W. Meier, Effect of Cold Work on Tensile Properties of Magnesium Alloys, *AFS Trans.*, Vol 76, 1968, p 174–182. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3406, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 4



Mg.100 ZE10A-H24, ZE10A-O magnesium alloy sheet, tensile stress-strain curves

Curves generated with a strain rate of 0.005/min. Solid line curves for 1.0 mm (0.040 in.) thick sheet and dashed line curves for 3.18 mm (0.125 in.) thick sheet. Composition: Mg-1Zn-0.2RE. UNS M16100

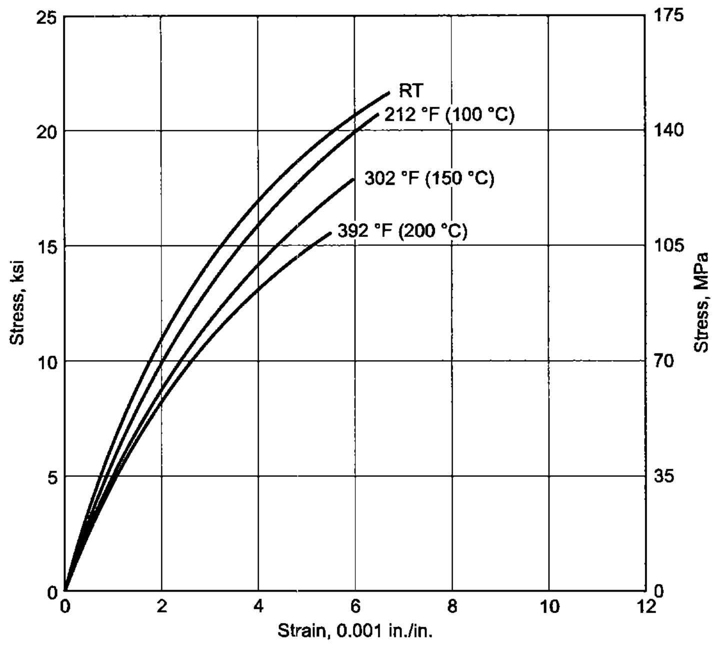
Source: "Stress-Strain Curve for ZE 10A (Sheet)," Dow Chemical Co., 1959. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3602, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 2



Mg.101 ZE10A-H24, ZE10A-O magnesium alloy sheet, compressive stress-strain curves

Curves generated with a strain rate of 0.005/min. Solid line curves for 1.0 mm (0.040 in.) thick sheet and dashed line curves for 3.18 mm (0.125 in.) thick sheet. Composition: Mg-1Zn-0.2RE. UNS M16100

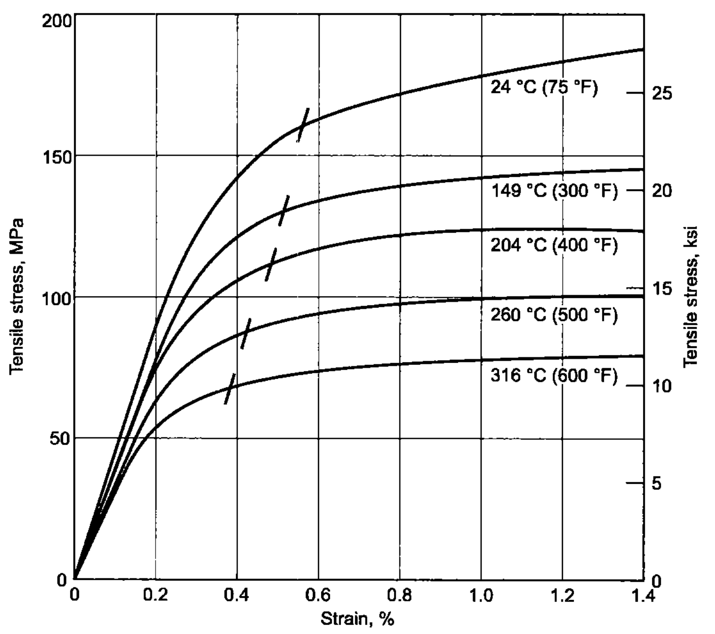
Source: "Stress-Strain Curve for ZE 10A (Sheet)," Dow Chemical Co., 1959. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3602, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 2



Mg.102 ZE41A-T5 magnesium alloy sand casting, typical tensile stress-strain curves at room and elevated temperatures

RT, room temperature. Specimens exposed to elevated temperatures for 0.5 h. Ramberg-Osgood parameters: *n*(RT) = 3.6, *n*(212 °F [or 100 °C]) = 3.4, *n*(302 °F [or 150 °C]) = 3.1, *n*(392 °F [or 200 °C]) = 2.9. Composition: Mg-4Zn-1RE-0.7Zr. UNS M16410

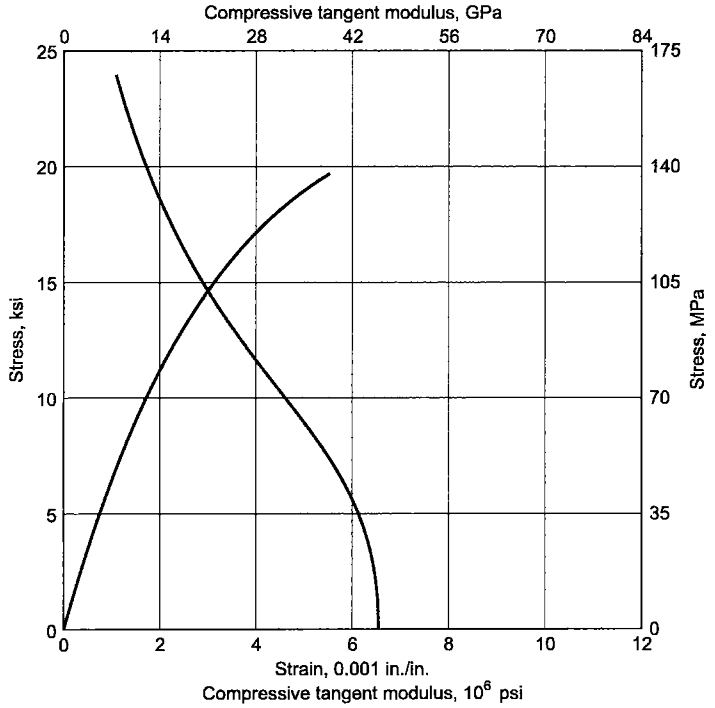
Source: *MIL-HDBK-5H,* Dec 1998, p 4–52



Mg.103 ZE41A-T5 magnesium alloy separately sand cast test bar, tensile stress-strain curves at room and elevated temperatures

Composition: Mg-4Zn-1RE-0.7Zr. UNS M16410

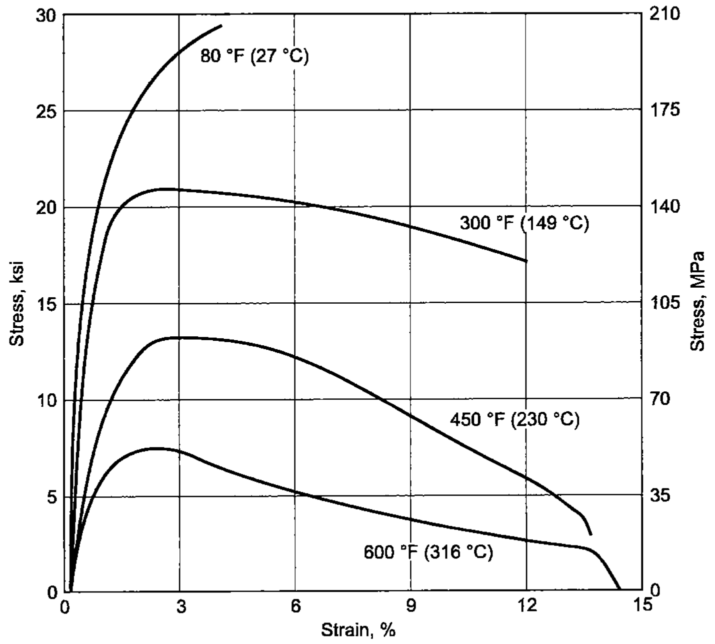
Source: *Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol 2, *Metals Handbook,* American Society for Metals, 1979, p 591



Mg.104 ZE41A-T5 magnesium alloy sand casting, typical compressive stress-strain and tangent modulus curves at room temperature

Ramberg-Osgood parameter: n(compression) = 3.7. Composition: Mg-4Zn-1RE-0.7Zr. UNS M16410

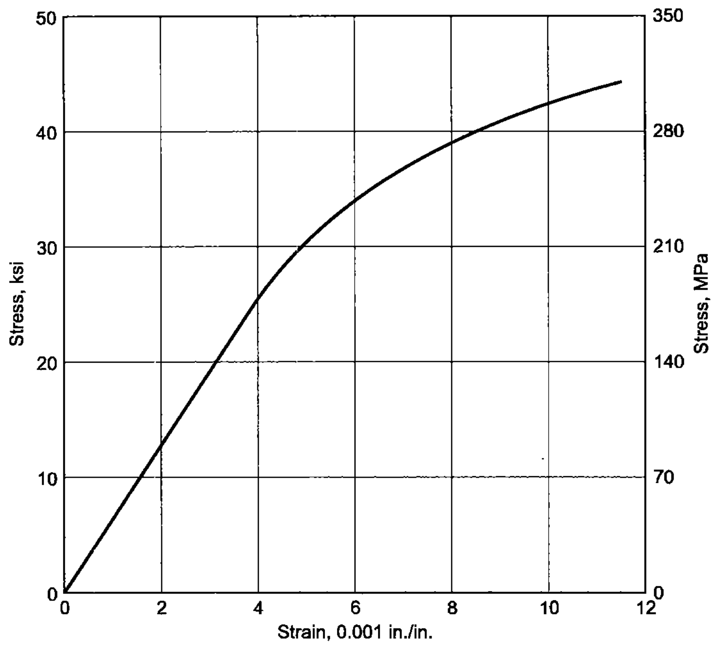
Source: *MIL-HDBK-5H*, Dec 1998, p 4–52



Mg.105 ZH62A-T5 magnesium alloy sand casting, complete tensile stress-strain curves at various temperatures

Strain rate: 0.03/min. Composition: Mg-5.7Zn-1.5Th-0.7Zr. UNS M16620

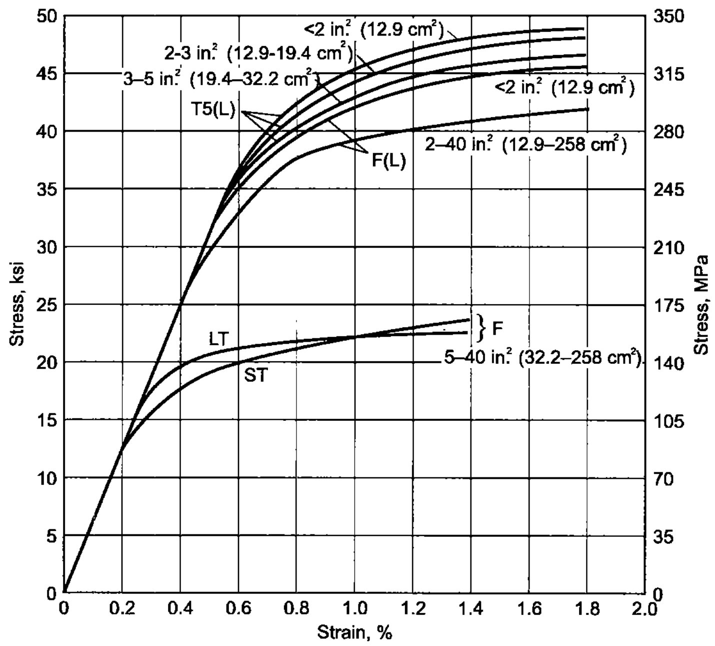
Source: H.E. Dedman, E.J. Wheelahan, and J.R. Kattus, "Tensile Properties of Aircraft Structural Metals at Various Rates of Loading after Rapid Heating," WADC Technical Report 58-440, Part 1, ASTIA Doc. No. 206074, 1958. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3407, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 3



Mg.106 ZK60A-T5 magnesium alloy extrusion, typical tensile stress-strain curves at room temperature

Ramberg-Osgood parameter: n(room temperature) = 7.0. Composition: Mg-5.5Zn-0.5Zr. UNS M16600

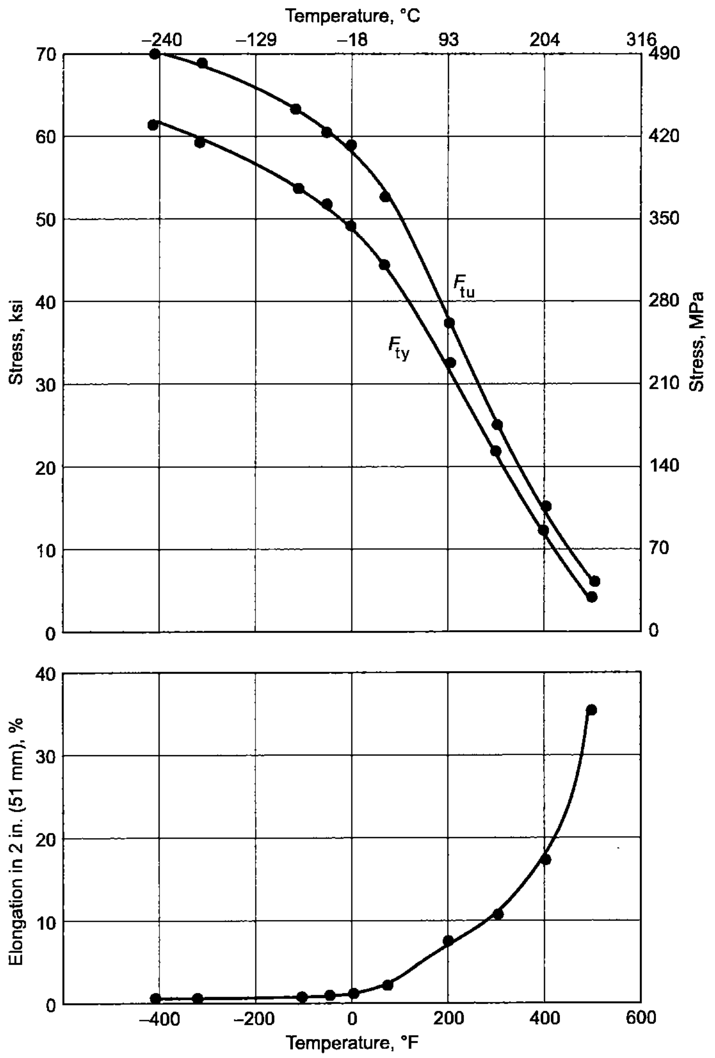
Source: *MIL-HDBK-5H,* Dec 1998, p 4–23



Mg.107 ZK60A-F, -T5 magnesium alloy extrusion, compressive stress-strain curves at room temperature

Test direction: L, longitudinal; LT, long transverse; ST, short transverse. Curves for extrusions in different conditions, orientations, and section sizes. Composition: Mg-5.5Zn-0.5Zr. UNS M16600

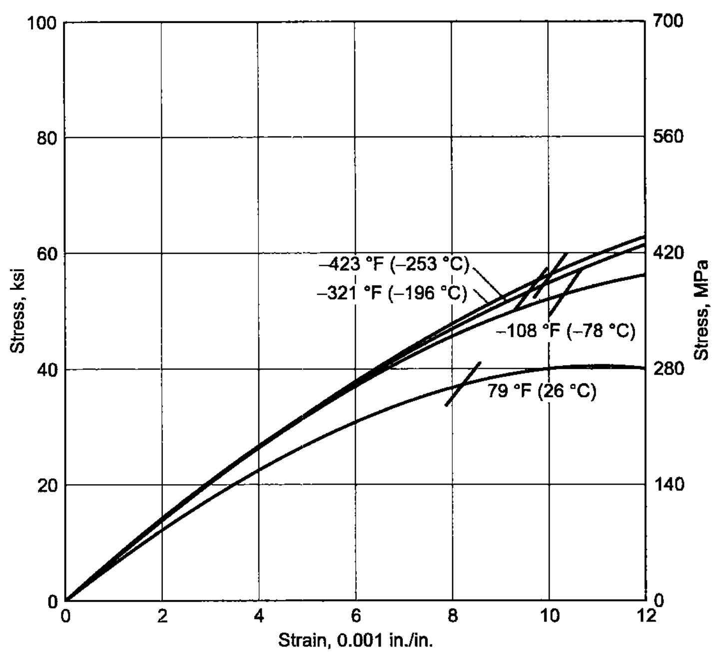
Source: "Magnesium in Design," Form No. 141-213-67, Dow Chemical Co., 1967. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3506, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 4



Mg.108 ZK60A-T5 magnesium alloy extrusion, effect of temperature on tensile properties

Test direction: longitudinal. F_{tu}, ultimate tensile strength; F_{ty}, tensile yield strength. Composition: Mg-5.5Zn-0.5Zr. UNS M16600

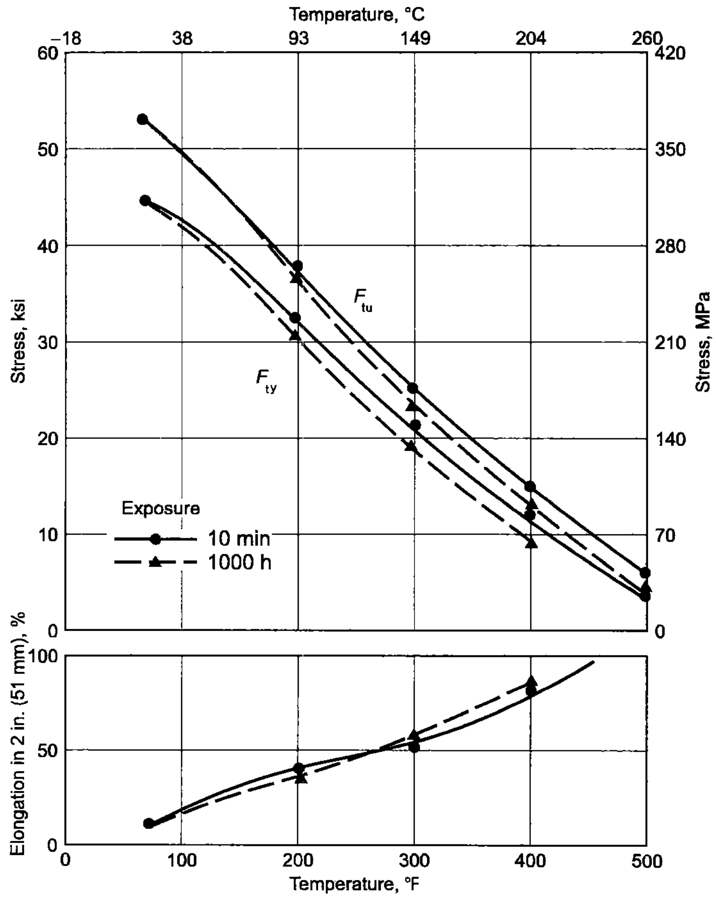
Source: "Magnesium in Design," Form No. 141-213-67, Dow Chemical Co., 1967. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3506, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 8



Mg.109 ZK60A-T5 magnesium alloy extrusion, stress-strain curves at room and low temperatures

Composition: Mg-5.5Zn-0.5Zr. UNS M16600

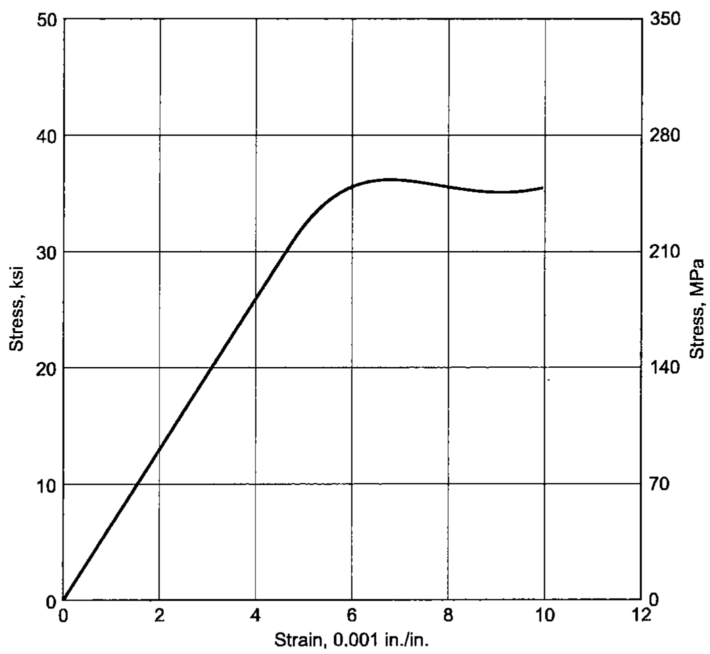
Source: R.L. McGee, J.E. Campbell, R.L. Carlson, and G.K. Manning, "The Mechanical Properties of Certain Aircraft Structural Metals at Very Low Temperatures," Battelle Memorial Institute, WADC TR58-386, 1958. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3506, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 8



Mg.110 ZK60A-T5 magnesium alloy extrusion, effect of elevated temperature on tensile properties

Test direction: longitudinal. F_{tu}, ultimate tensile strength; F_{ty}, tensile yield strength. Composition: Mg-5.5Zn-0.5Zr. UNS M16600

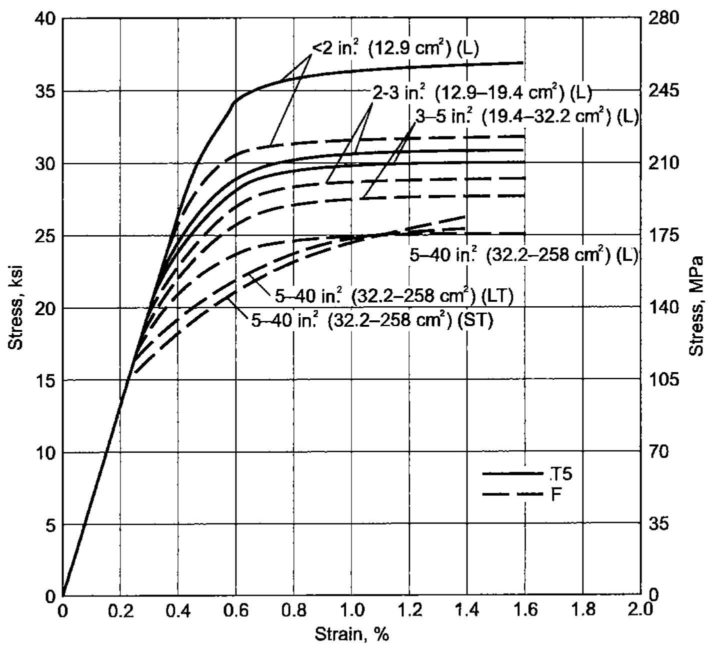
Source: "Magnesium in Design," Form No. 141-213-67, Dow Chemical Co., 1967. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3506, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 8



Mg.111 ZK60A-T5 magnesium alloy extrusion, compressive stress-strain curve at room temperature

Tested in longitudinal direction. Extrusions with cross-sectional area less than 12.90 cm^2 (2.000 in.^{2}). Composition: Mg-5.5Zn-0.5Zr. UNS M16600

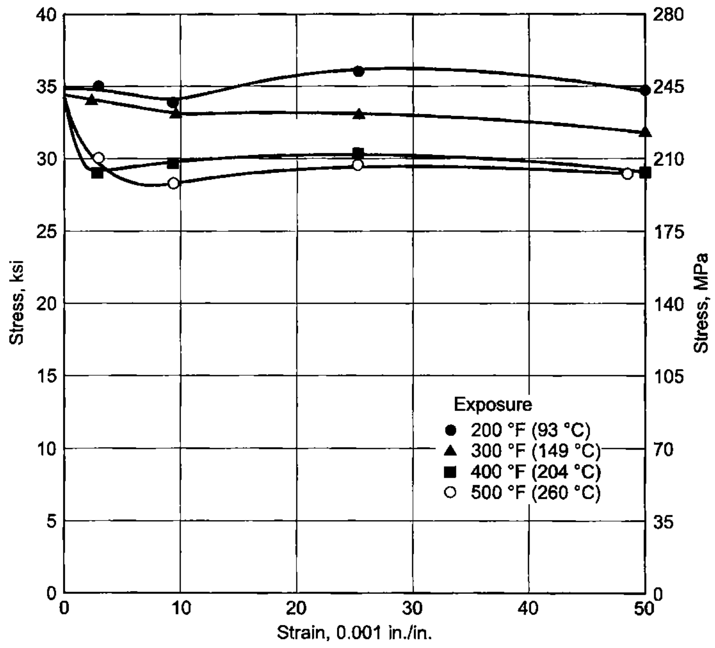
Source: *MIL-HDBK-5H,* Dec 1998, p 4–23



Mg.112 ZK60A-F, ZK60A-T5 magnesium alloy extrusion, compressive stress-strain curves at room temperature

Test direction: L, longitudinal; LT, long transverse; ST, short transverse. Curves for extrusions in different conditions, orientations, and section sizes. Composition: Mg-5.5Zn-0.5Zr. UNS M16600

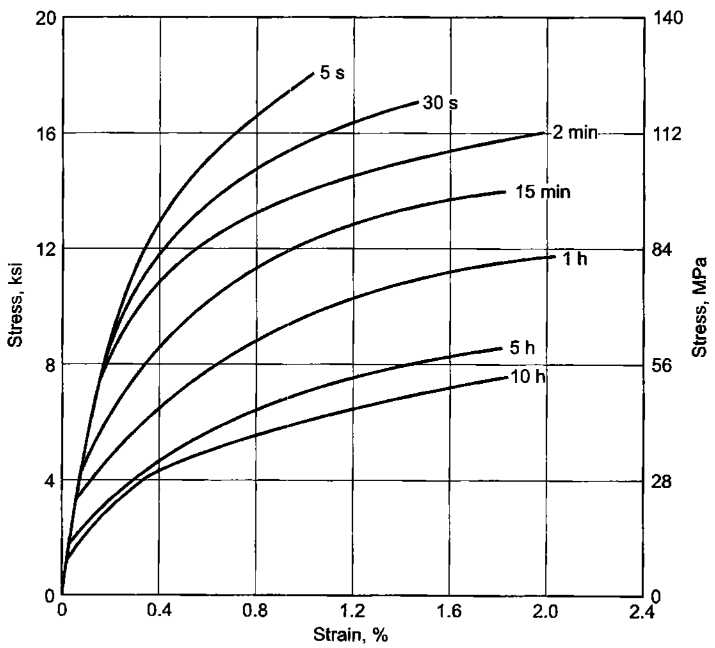
Source: "Magnesium in Design," Form No. 141-213-67, Dow Chemical Co., 1967. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3506, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 6



Mg.113 ZK60A-T5 magnesium alloy extrusion, effect of elevated temperature on compressive yield strength at room temperature

Test direction: longitudinal. Composition: Mg-5.5Zn-0.5Zr. UNS M16600

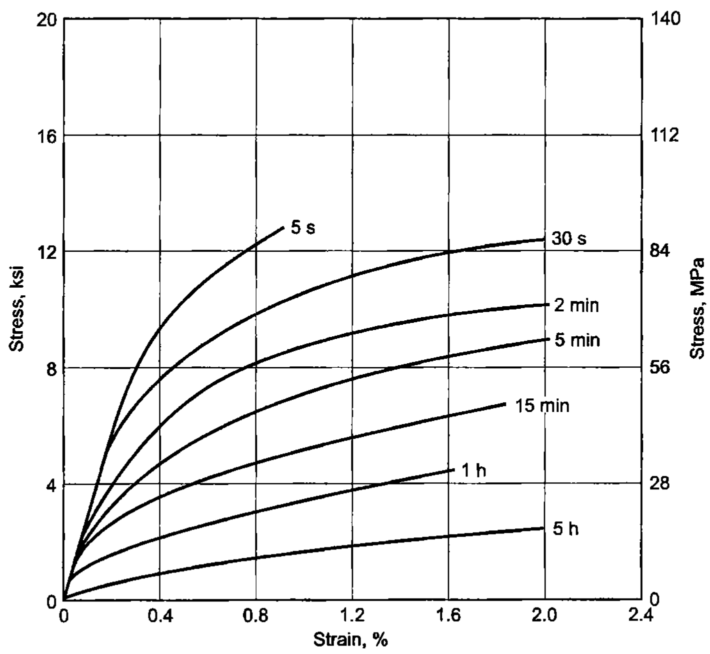
Source: "Magnesium in Design," Form No. 141-213-67, Dow Chemical Co., 1967. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3506, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 6



Mg.114 ZK60A-T5 magnesium alloy forging, isochronous stress-strain curves at 149 °C (300 °F)

Axial specimens from aircraft wheel rim. Composition: Mg-5.5Zn-0.5Zr. UNS M16600

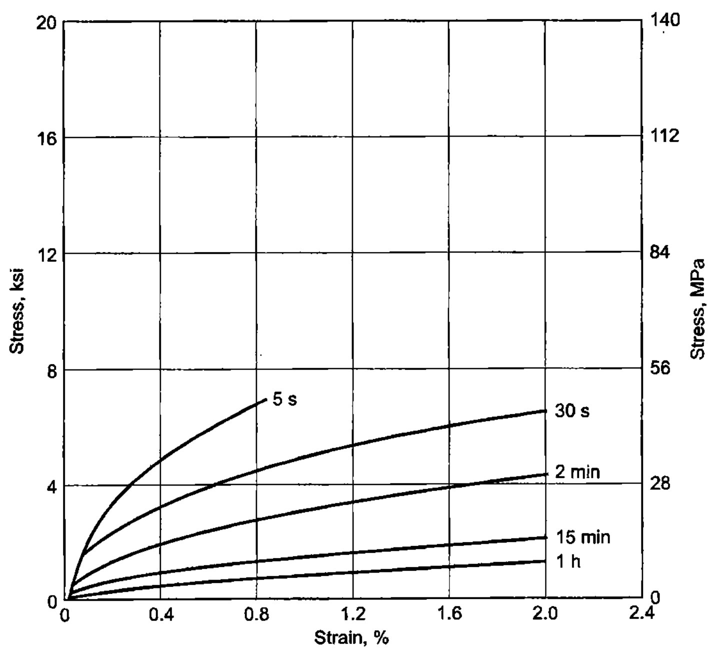
Source: "Magnesium in Design," Form No. 141-213-67, Dow Chemical Co., 1967. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3506, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 10



Mg.115 ZK60A-T5 magnesium alloy forging, isochronous stress-strain curves at 204 °C (400 °F)

Axial specimens from aircraft wheel rim. Composition: Mg-5.5Zn-0.5Zr. UNS M16600

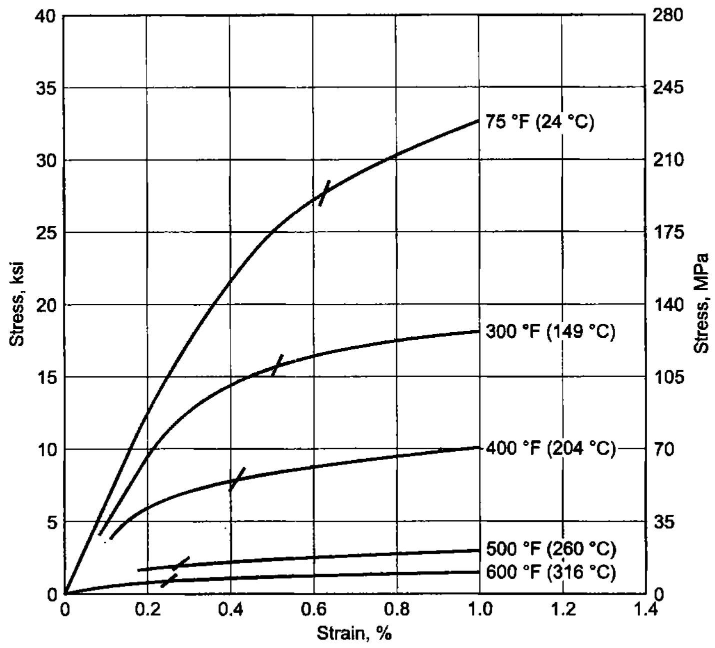
Source: "Magnesium in Design," Form No. 141-213-67, Dow Chemical Co., 1967. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3506, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 10



Mg.116 ZK60A-T5 magnesium alloy forging, isochronous stress-strain curves at 260 °C (500 °F)

Axial specimens from aircraft wheel rim. Composition: Mg-5.5Zn-0.5Zr. UNS M16600

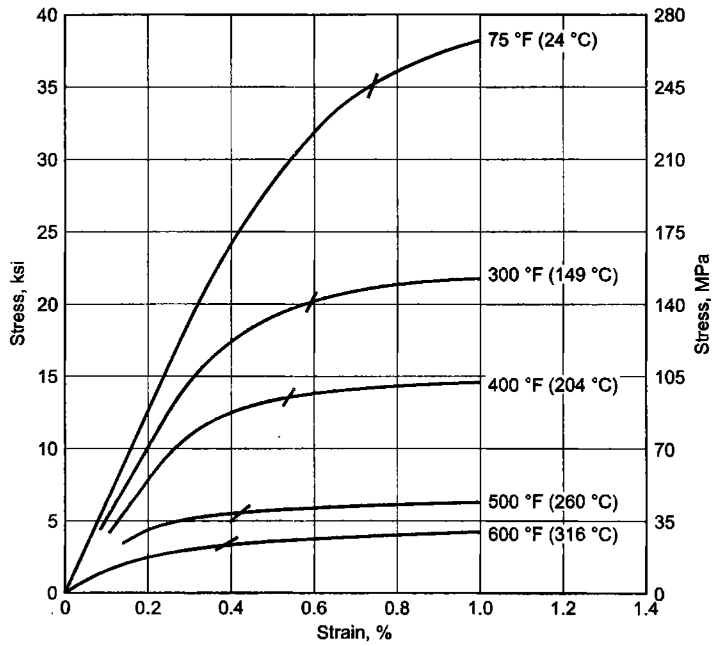
Source: "Magnesium in Design," Form No. 141-213-67, Dow Chemical Co., 1967. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3506, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 10



Mg.117 ZK60A-T5 magnesium alloy forging, stress-strain curves at room and elevated temperatures

Forged at 316 °C (600 °F) from extruded material. Composition: Mg-5.5Zn-0.5Zr. UNS M16600

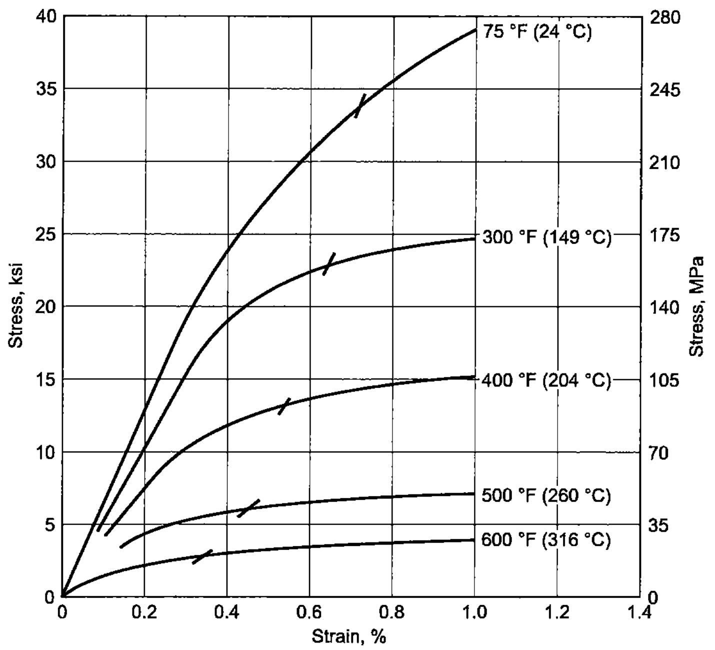
Source: Properties of Magnesium and Magnesium Alloys, *Properties and Selection of Metals,* Vol 1, 8th ed., *Metals Handbook,* American Society for Metals, 1961, p 1095–1112. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3506, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 7



Mg.118 ZK60A-T6 magnesium alloy forging, stress-strain curves at room and elevated temperatures

Forged at 316 °C (600 °F) from extruded material. Composition: Mg-5.5Zn-0.5Zr. UNS M16600

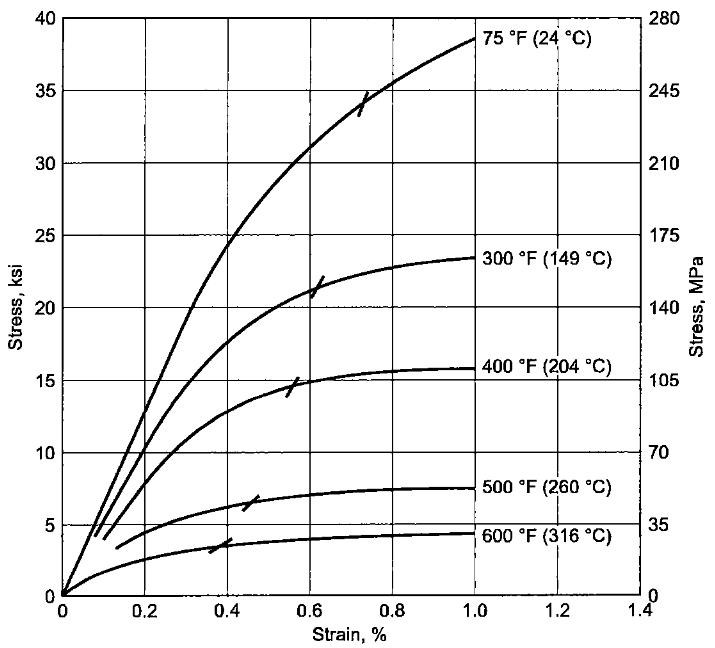
Source: Properties of Magnesium and Magnesium Alloys, *Properties and Selection of Metals,* Vol 1, 8th ed., *Metals Handbook,* American Society for Metals, 1961, p 1095–1112. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3506, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 7



Mg.119 ZK60A-T5 magnesium alloy forging, stress-strain curves at room and elevated temperatures

Forged at 427 °C (800 °F) from cast material. Composition: Mg-5.5Zn-0.5Zr. UNS M16600

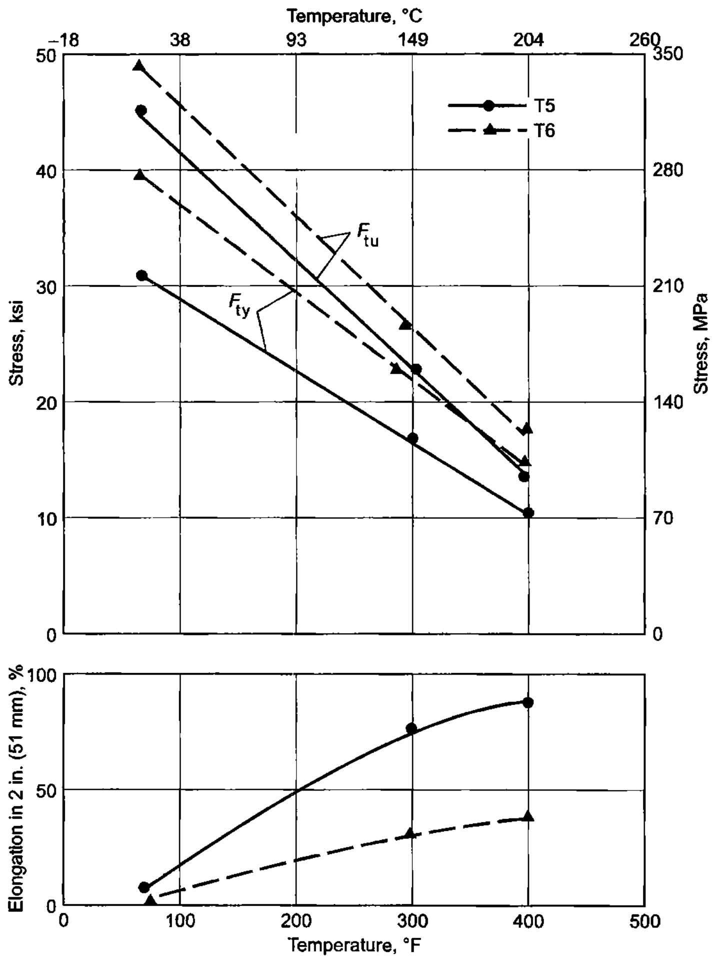
Source: Properties of Magnesium and Magnesium Alloys, *Properties and Selection of Metals,* Vol 1, 8th ed., *Metals Handbook,* American Society for Metals, 1961, p 1095–1112. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3506, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 7



Mg.120 ZK60A-T6 magnesium alloy forging, stress-strain curves at room and elevated temperatures

Forged at 427 °C (800 °F) from cast material. Composition: Mg-5.5Zn-0.5Zr. UNS M16600

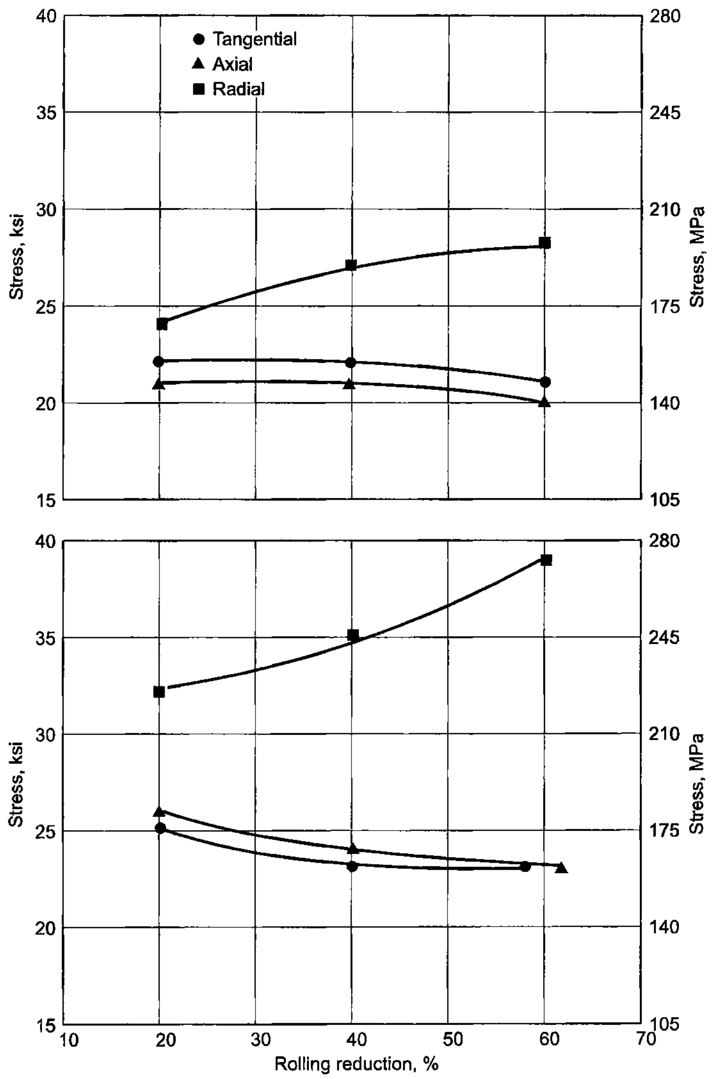
Source: Properties of Magnesium and Magnesium Alloys, *Properties and Selection of Metals,* Vol 1, 8th ed., *Metals Handbook,* American Society for Metals, 1961, p 1095–1112. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3506, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 7



Mg.121 ZK60A-T5, ZK60A-T6 magnesium alloy forging, effect of temperature on tensile properties

Longitudinal specimens. Composition: Mg-5.5Zn-0.5Zr. UNS M16600

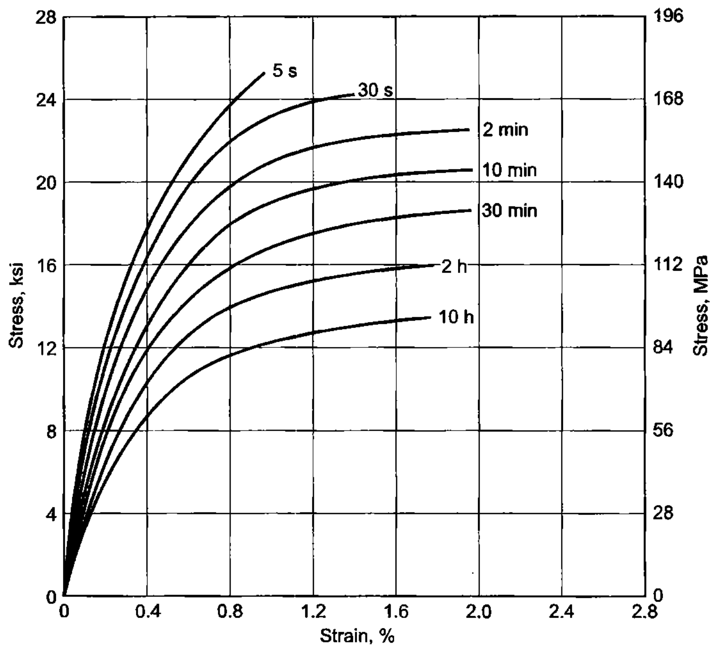
Source: "Magnesium in Design," Form No. 141-213-67, Dow Chemical Co., 1967. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3506, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 8



Mg.122 ZK60A-T5, ZK60A-T6 magnesium alloy roll-forged rings, effect of rolling reduction and orientation on compressive yield strength

Top: T5; bottom: T6. Roll forged rings produced directly from cast blanks. Composition: Mg-5.5Zn-0.5Zr. UNS M16600

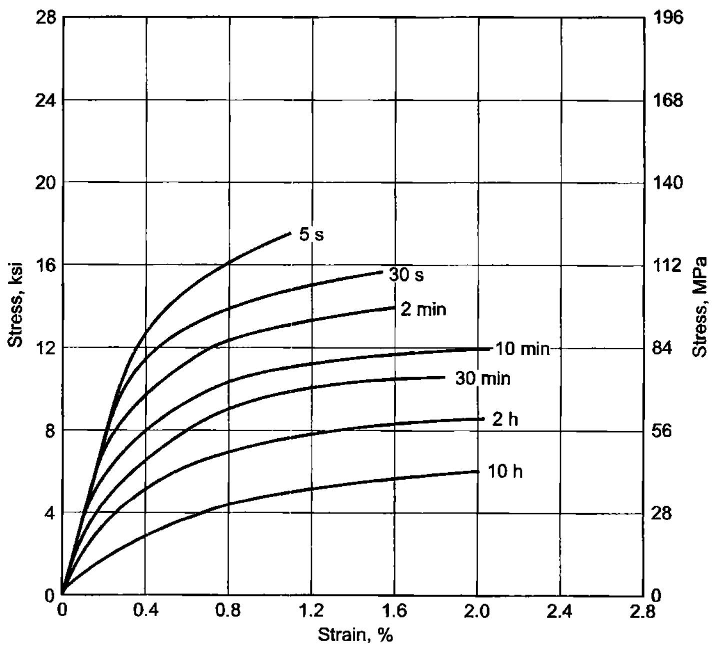
Source: "Magnesium Rolled Rings," Code 0.4 JFP/HB, Dow Chemical Co., 1964. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3506, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 6



Mg.123 ZK60A-T6 magnesium alloy forging, isochronous stress-strain curves at 149 °C (300 °F)

Axial specimens from aircraft wheel rims. Composition: Mg-5.5Zn-0.5Zr. UNS M16600

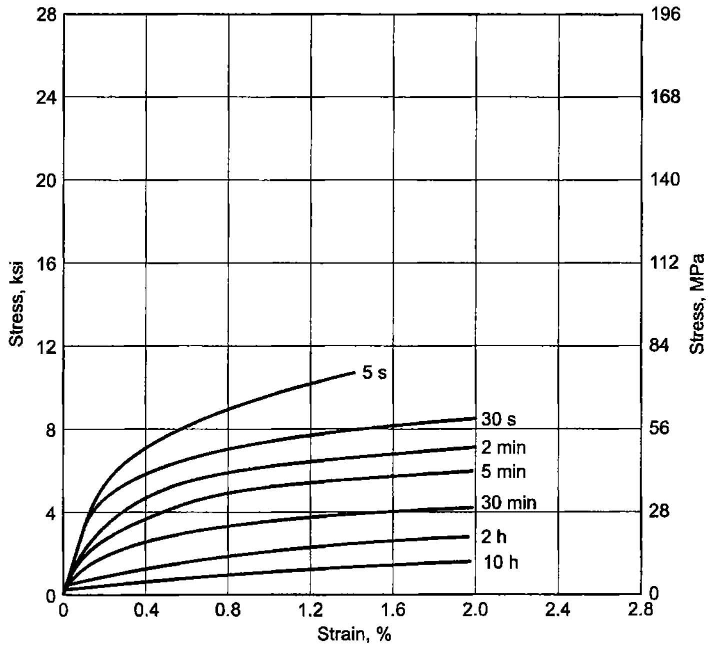
Source: "Magnesium in Design," Form No. 141-213-67, Dow Chemical Co., 1967. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3506, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 10



Mg.124 ZK60A-T6 magnesium alloy forging, isochronous stress-strain curves at 204 °C (400 °F)

Axial specimens from aircraft wheel rims. Composition: Mg-5.5Zn-0.5Zr. UNS M16600

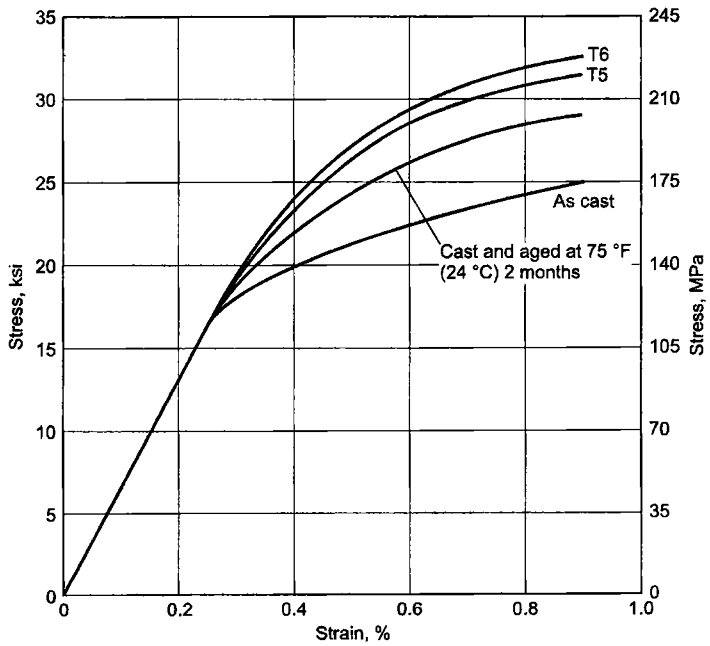
Source: "Magnesium in Design," Form No. 141-213-67, Dow Chemical Co., 1967. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3506, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 10



Mg.125 ZK60A-T6 magnesium alloy forging, isochronous stress-strain curves at 260 °C (500 °F)

Axial specimens from aircraft wheel rims. Composition: Mg-5.5Zn-0.5Zr. UNS M16600

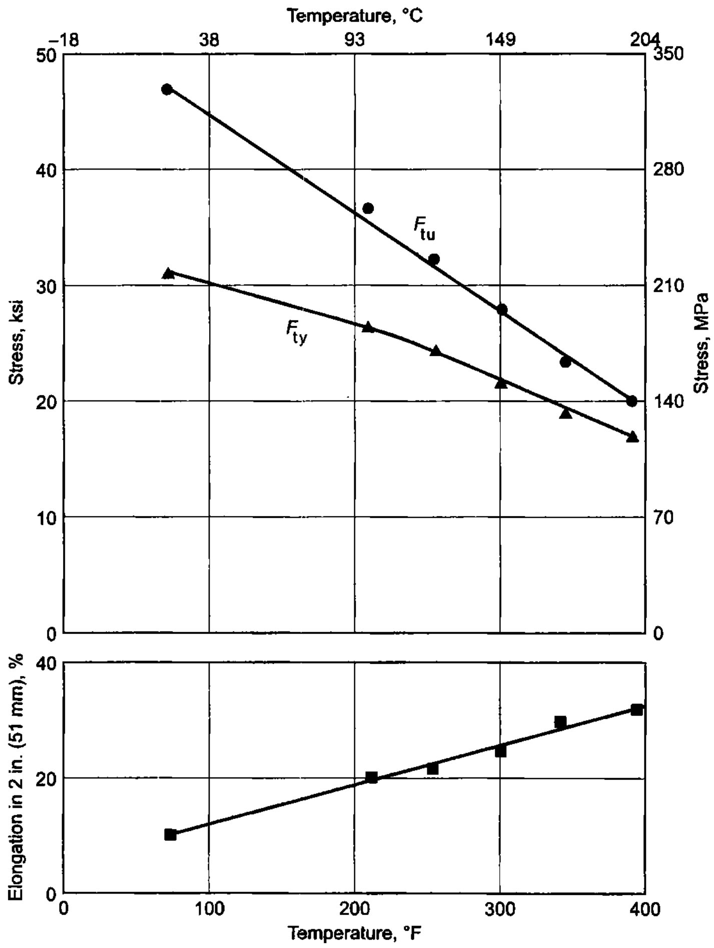
Source: "Magnesium in Design," Form No. 141-213-67, Dow Chemical Co., 1967. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3506, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 10



Mg.126 ZK61A-T5, ZK61A-T6 magnesium alloy sand cast test bar, stress-strain curves for various conditions

Composition: Mg-6Zn-0.8Zr. UNS M16600

Source: J.W. Meier and M.W. Martinson, Development of High-Strength Magnesium Casting Alloy ZK61, *Trans. AFS*, Vol 58, 1950, p 742–751. As published in *Aerospace Structural Metals Handbook*, Vol 3, Code 3409, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 4

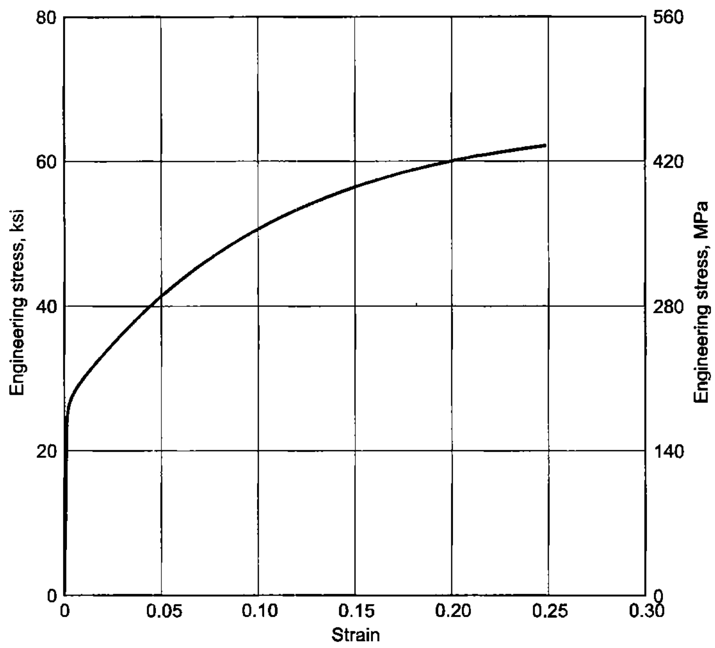


Mg.127 ZK61A-T6 magnesium alloy sand cast test bar, effect of temperature on tensile properties

F_{tu}, ultimate tensile strength; F_{ty}, tensile yield strength. Composition: Mg-6Zn-08Zr. UNS M16600

Source: J.W. Meier, Characteristics of High-Strength Magnesium Casting Alloy ZK61, *Trans. AFS,* Vol 61, 1953, p 719–728. As published in *Aerospace Structural Metals Handbook,* Vol 3, Code 3409, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 4

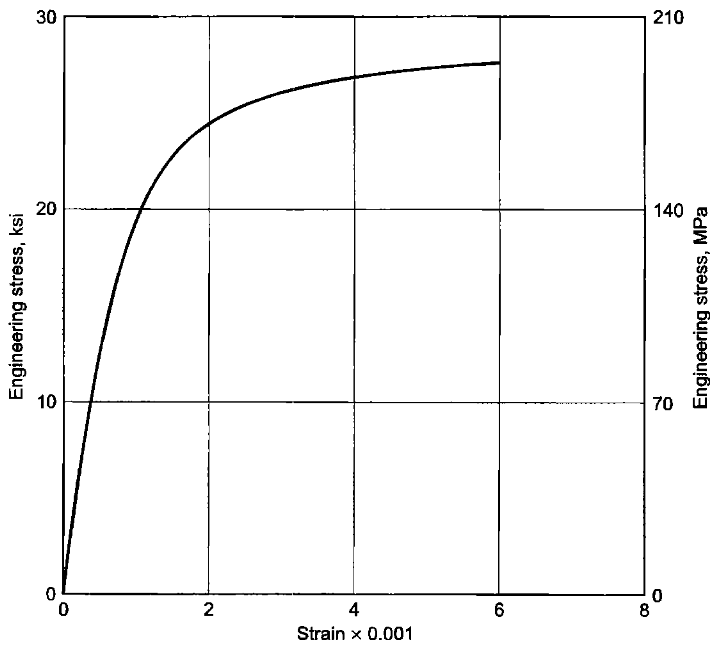
Nickel (Ni)



Ni.001 Ni 200 annealed nickel sheet, engineering stress-strain curve (full range)

Test direction: longitudinal. Sheet thickness = 0.787 mm (0.031 in.). Commercially pure nickel (UNS N02200). 0.2% yield strength = 185 MPa (26.9 ksi); ultimate tensile strength = 434 MPa (63.0 ksi); elongation = 39.5%; strength coefficient (K) = 138.2; strain-hardening exponent (n) = 0.387. Composition: Ni 99.0 min

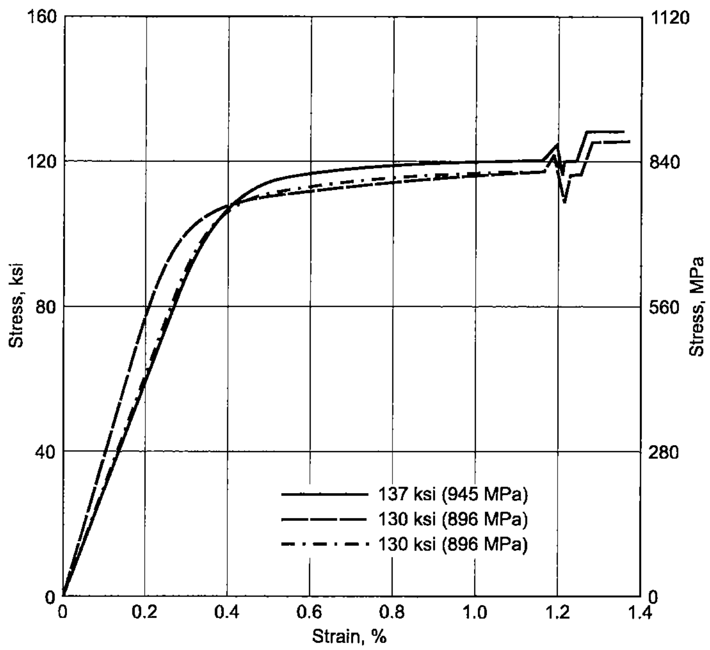
Courtesy of Special Metals Corporation



Ni.002 Ni 200 annealed nickel sheet, engineering stress-strain curve (expanded range)

Test direction: longitudinal. Sheet thickness = 0.787 mm (0.031 in.). Commercially pure nickel (UNS N02200). 0.2% yield strength = 180 MPa (26.1 ksi); ultimate tensile strength = 414 MPa (60.1 ksi); elongation = 39.0%. Composition: Ni 99.0 min

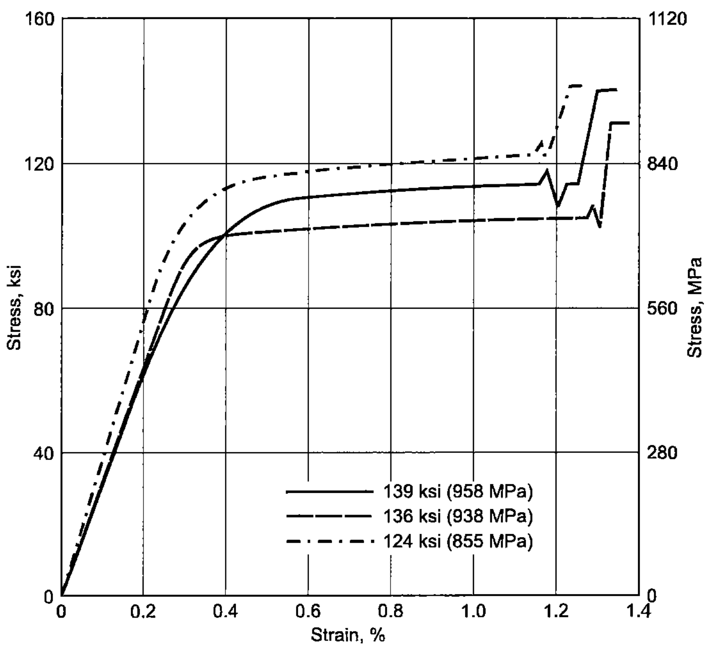
Courtesy of Special Metals Corporation



Ni.003 B-1900 as-cast and heat treated nickel alloy, stress-strain curves at room temperature

25.4 mm (1 in.) gage length. Heat treatment: 1065 °C (1950 °F), 4 h, rapid air cooled + 899 °C (1650 °F), 10 h, air cooled. Curves given for various ultimate strengths. Composition: Ni-10Co-8Cr-6Mo-6Al-4Ta-1(Ti + C + Zr + B)

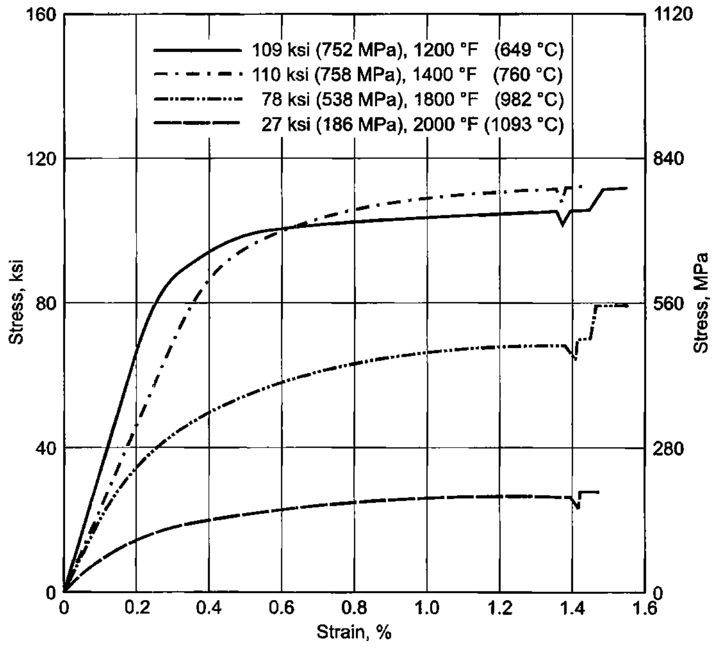
Source: Pratt and Whitney Aircraft Communication to MPDC. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4213, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 13



Ni.004 B-1900 as-cast nickel alloy, stress-strain curves at room temperature

25.4 mm (1 in.) gage length. Curves given for various ultimate strengths. Composition: Ni-10Co-8Cr-6Mo-6Al-4Ta-1(Ti + C + Zr + B)

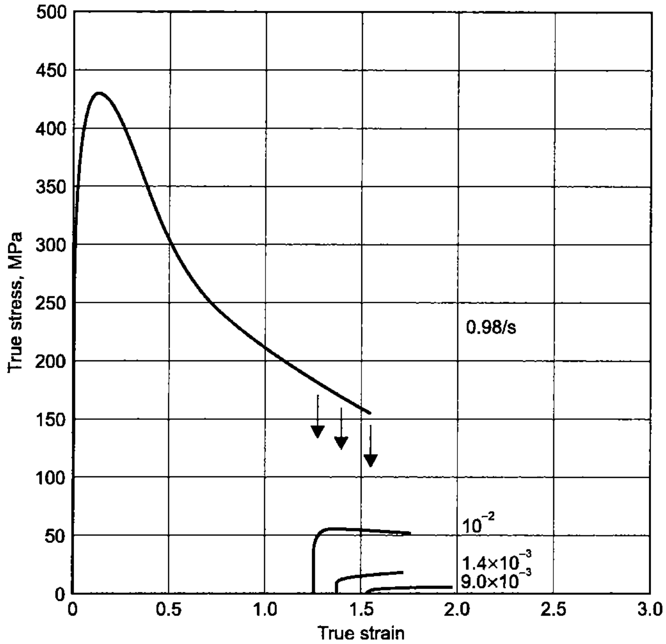
Source: Pratt and Whitney Aircraft Communication to MPDC. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4213, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 13

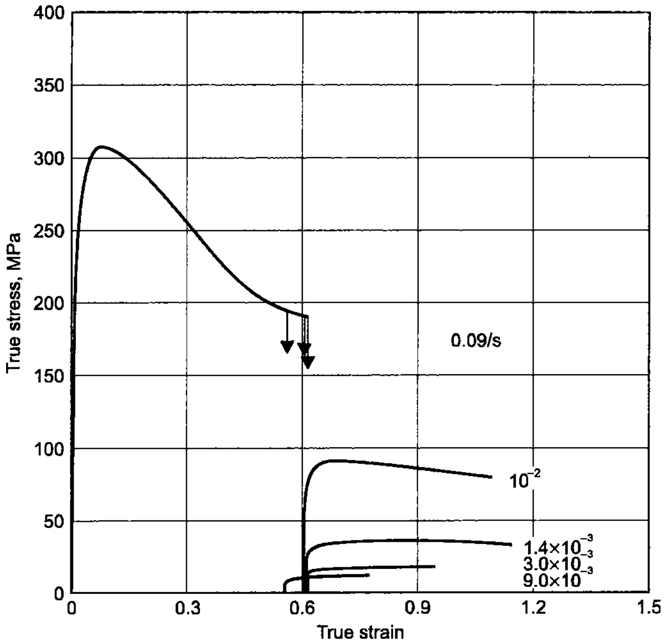


Ni.005 B-1900 as-cast nickel alloy, stress-strain curves at elevated temperature

25.4 mm (1 in.) gage length. Curves given for various ultimate strengths and test temperatures. Composition: Ni-10Co-8Cr-6Mo-6Al-4Ta-1(Ti + C + Zr + B)

Source: *Aerospace Structural Metals Handbook,* Vol 5, Code 4213, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 15

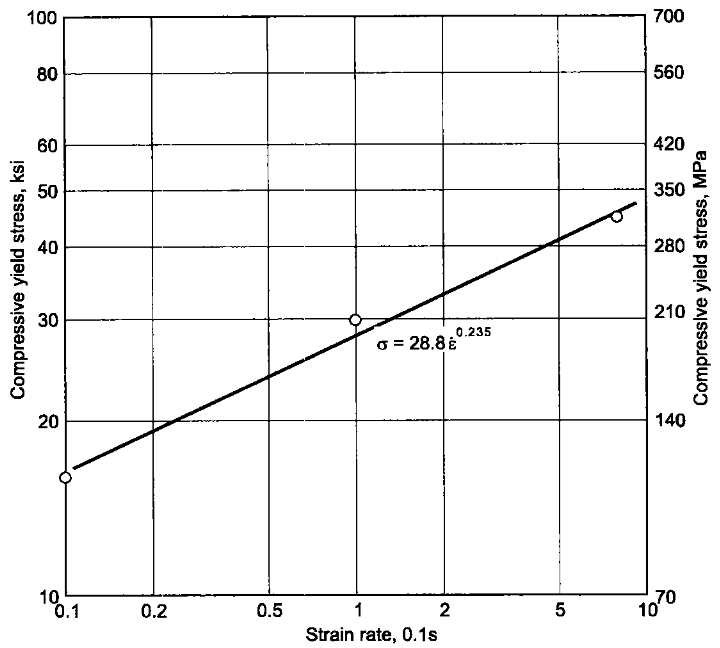




Ni.006 Inco 713LC nickel alloy, true stress-strain flow curves in interrupted tests

Effects of prestrain at 0.98/s (top) and 0.09/s (bottom) on flow curves at different strain rates (s^{-1}) and 1050 °C. Composition: 74Ni-12Cr-6Al-4.5Mo

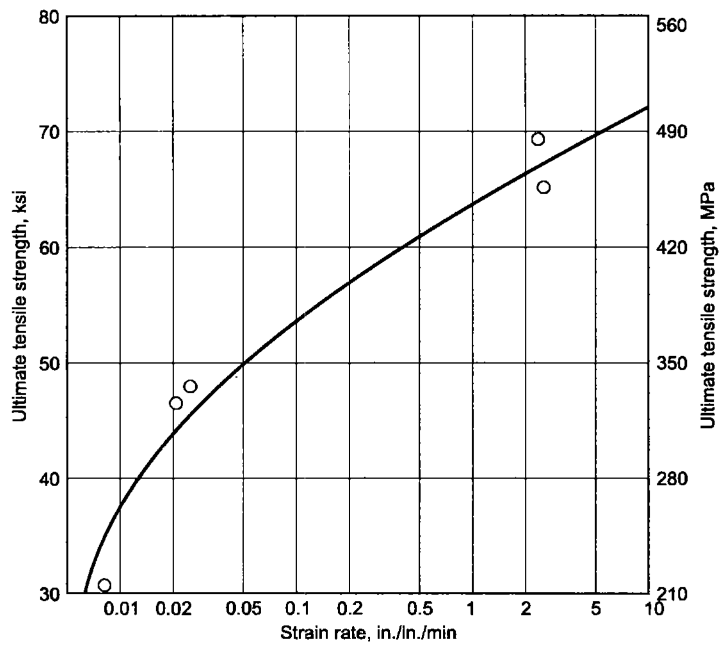
Source: J.P.A. Immarigeon and P.H. Floyd, Microstructural Instabilities During Superplastic Forging of a Nickel-Base Superalloy Compact, as published in *Production to Near Net Shape Source Book,* American Society for Metals, 1983, p 347



Ni.007 Inconel 713C cast nickel alloy, compressive yield stress-strain curve at 1177 °C (2150 °F)

Specimen diameter = 9.5 mm (0.375 in.). As cast in vacuum of (10^{-3} Hg). Held at temperature a minimum of 15 min before test. Composition: Ni-13Cr-6Al-4Mo-2Nb-0.7Ti. UNS N07713

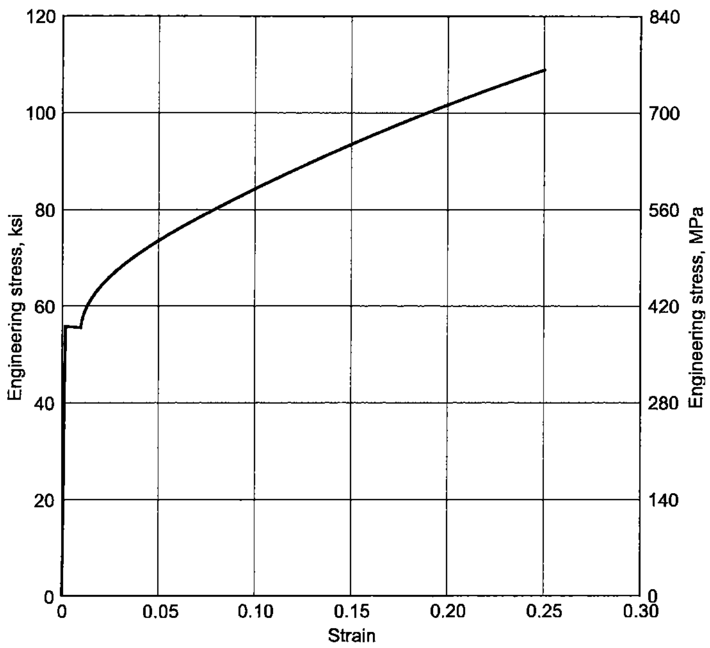
Source: D.R. Carnahan, D.S. Michlin, and V. DePierre, "Extrusion of Refractory Metals and Superalloys," AFML-TR-66-344, Dec 1966, p 137. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4119, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 16



Ni.008 Inconel 713C rolled and heat treated nickel alloy sheet, effect of strain rate on ultimate tensile strength at 1038 °C (1900 °F)

Rolled from 2.54–0.381 mm (0.10–0.015 in.). Heat treatment: 1177 °C (2150 °F), 40 h + 871 °C (1600 °F), 24 h. Composition: Ni-13Cr-6Al-4Mo-2Nb-0.7Ti. UNS N07713

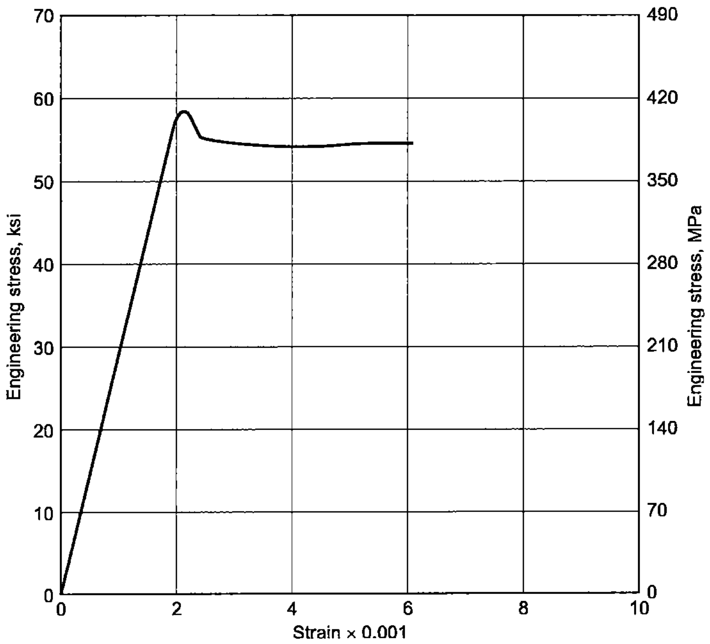
Source: H. Greenewald, Jr. and T.J. Riley, "Development of a Nickel-Base Alloy Sheet for High Temperature Applications," ASD-TDR-62-869, April 1963, p 86. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4119, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 13



Ni.009 Incoloy C276 annealed nickel alloy sheet, engineering stress-strain curve (full range)

Test direction: longitudinal. Sheet thickness = 1.067 mm (0.042 in.). 0.2% yield strength = 385 MPa (55.8 ksi); ultimate tensile strength = 839 MPa (121.7 ksi); elongation = 58.2%. Composition: 57.25Ni-15.5Cr-5.5 Fe-3.75W-2.5Co. UNS N10276

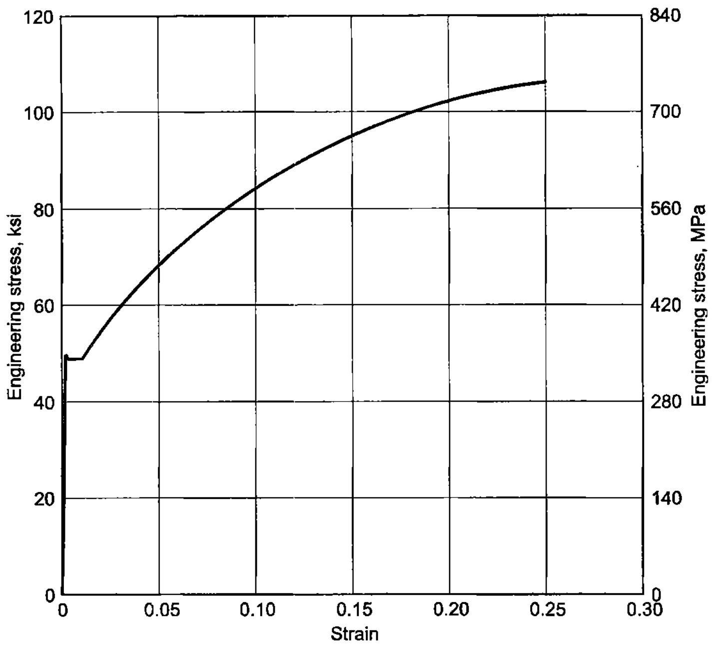
Courtesy of Special Metals Corporation



Ni.010 Incoloy C276 annealed nickel alloy sheet, engineering stress-strain curve (expanded range)

Test direction: longitudinal. Sheet thickness = 1.067 mm (0.042 in.). 0.2% yield strength = 372 MPa (53.9 ksi); ultimate tensile strength = 812 MPa (117.8 ksi); elongation = 55.8%. Composition: 57.25Ni-15.5Cr-5.5 Fe-3.75W-2.5Co. UNS N10276

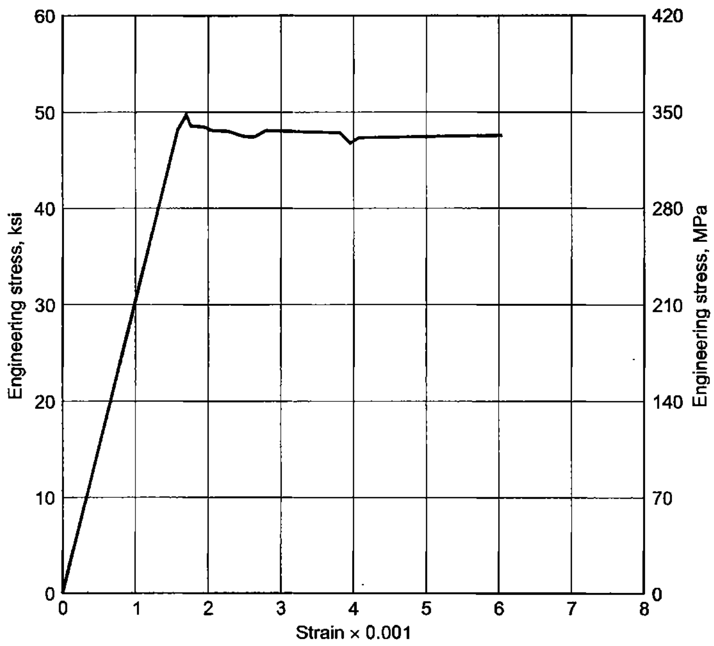
Courtesy of Special Metals Corporation



Ni.011 Inconel 600 annealed nickel alloy sheet, engineering stress-strain curve (full range)

Test direction: longitudinal. Sheet thickness = 0.864 mm (0.034 in.). 0.2% yield strength = 332 MPa (48.1 ksi); ultimate tensile strength = 747 MPa (108.4 ksi); elongation = 37.5%. Composition: 72Ni-15.5Cr-8Fe. UNS N06600

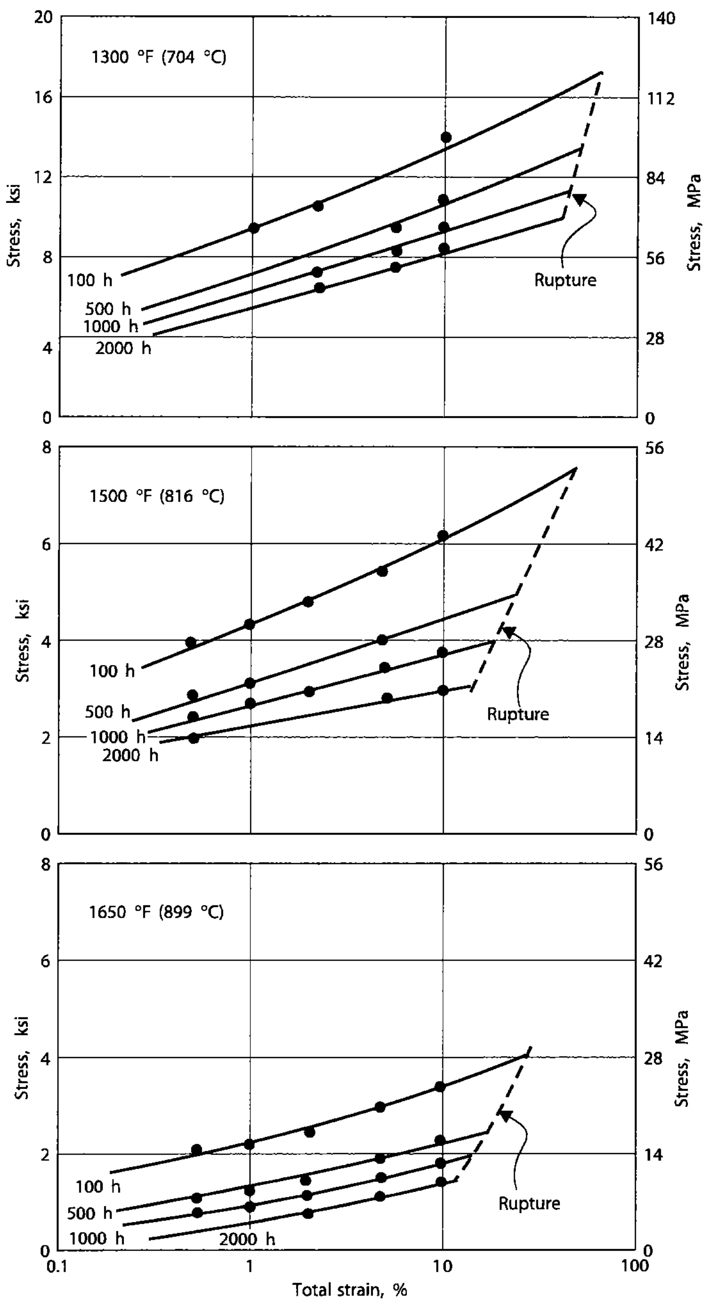
Courtesy of Special Metals Corporation



Ni.012 Inconel 600 annealed nickel alloy sheet, engineering stress-strain curve (expanded range)

Test direction: longitudinal. Sheet thickness = 0.864 mm (0.034 in.). 0.2% yield strength = 328 MPa (47.6 ksi); ultimate tensile strength = 721 MPa (104.5 ksi); elongation = 37.0%. Composition: 72Ni-15.5Cr-8Fe. UNS N06600

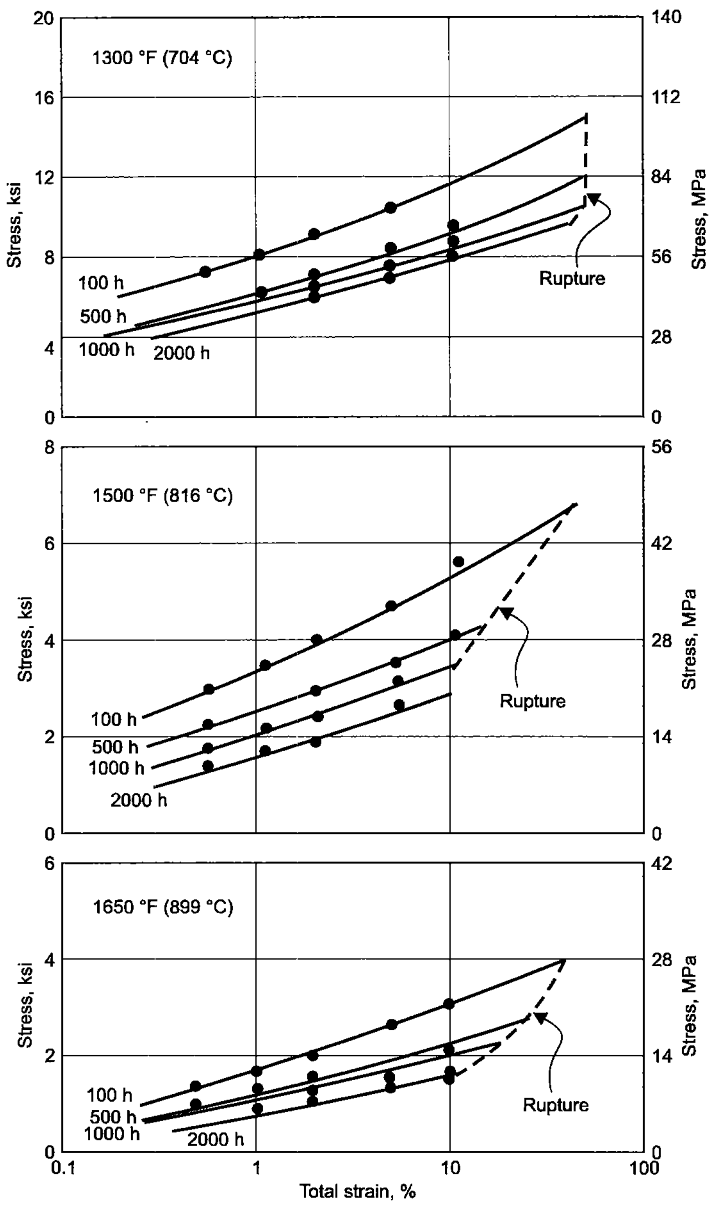
Courtesy of Special Metals Corporation



Ni.013 Inconel 600 annealed nickel alloy sheet, isochronous stress-strain curves at various temperatures

Sheet thickness = 1.524 mm (0.060 in.). Cold work 20%, + anneal at 1038 °C (1900 °F), 4.5 min. Tested in argon at temperature. Composition: 72Ni-15.5Cr-8Fe. UNS N06600

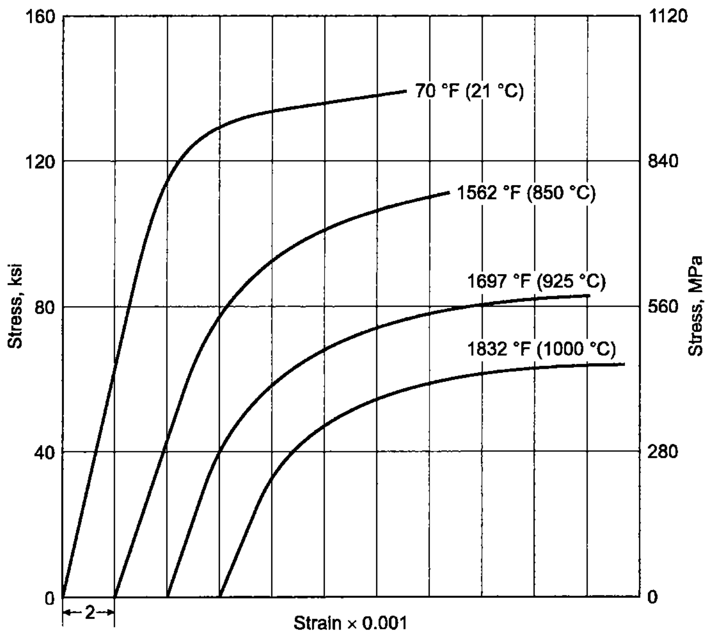
Source: J.R. Wier, Jr., D.A. Douglas, and W.D. Manly, "Inconel as a Structural Material for a High Temperature Fused Salt Reactor," ORNL-2264, June 1957. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 4101, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 14



Ni.014 Inconel 600 annealed nickel alloy sheet, isochronous stress-strain curves at various temperatures

Sheet thickness = 1.524 mm (0.060 in.). Annealed at 1121 °C (2050 °F), 2 h. Tested in argon at temperature. Composition: 72Ni-15.5Cr-8Fe. UNS N06600

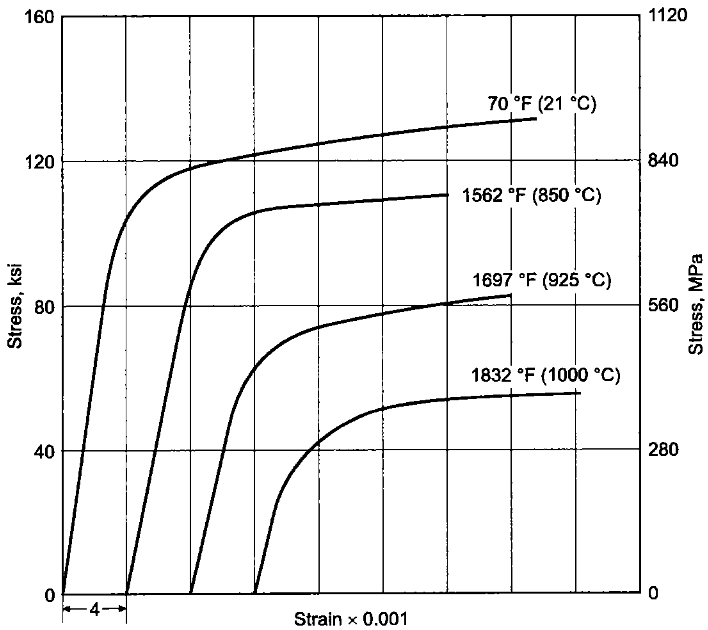
Source: J.R. Wier, D.A. Douglas, and W.D. Manly, "Inconel as a Structural Material for a High Temperature Fused Salt Reactor," ORNL-2264, June 1957. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4101, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 14



Ni.015 IN 100 as-cast nickel alloy, stress-strain curves at room and elevated temperatures

Composition: Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V. UNS N13100

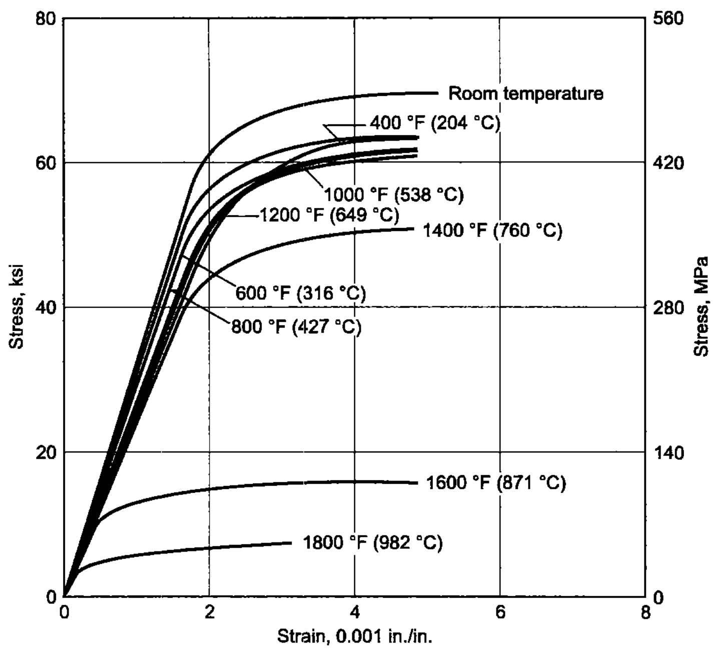
Source: W.F. Simmons and R.B. Gunia, "Compilation of Trade Names, Specifications, and Producers of Stainless Alloys and Superalloys," ASTM Data Series DS 45, 1969, p 7, 10, 115, revised by personal communication, Metcut to MPDC 13 June 1978. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4212, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 24



Ni.016 IN 100 nickel alloy, cast and JO coated, stress-strain curves at room and elevated temperatures

Cast to 6.35 mm (0.25 in.) diam bar; 50.8 mm (2 in.) gage length. JO coated by TRW with PWA A47 coating plus 1079 °C (1975 °F), 4 h in vacuum, + rapid argon quenched. Composition: Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V. UNS N13100

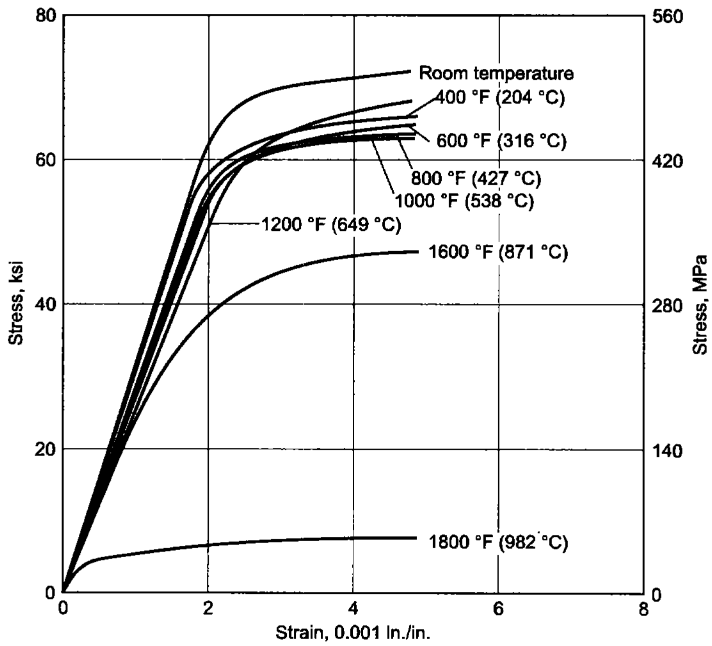
Source: W.F. Simmons and R.B. Gunia, "Compilation of Trade Names, Specifications, and Producers of Stainless Alloys and Superalloys," ASTM Data Series DS 45, 1969, p 7, 10, 123. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4121, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 25



Ni.017 Inconel 702 nickel alloy sheet, tensile stress-strain curves at various temperatures

Sheet thickness = 1.016 mm (0.040 in.). Heat treatment: 1079 °C (1975 °F), 0.5 h, air cooled + 760 °C (1400 °F), 5 h, air cooled. Composition: Ni-15Cr-3Al-0.5Ti. UNS N07702

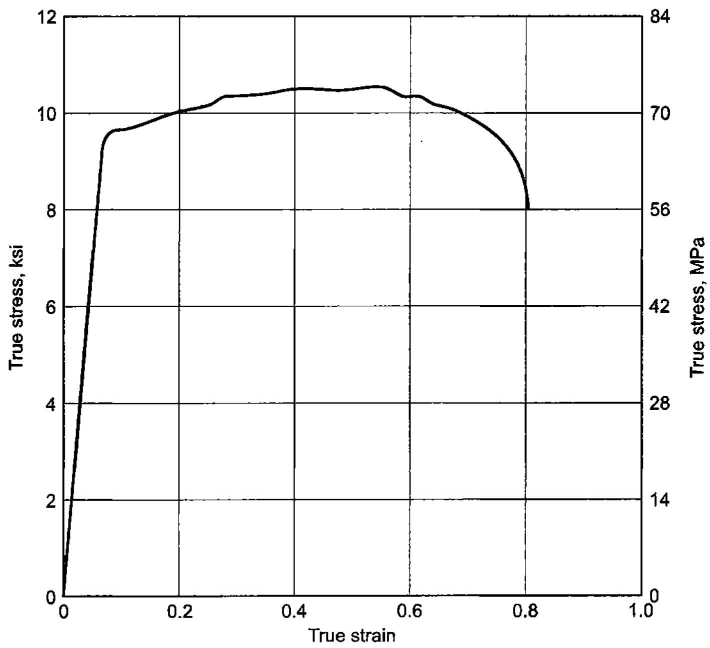
Source: "Research Investigation to Determine Mechanical Properties of Nickel and Cobalt Base Alloys for Inclusion in Military Handbook 5," Vol I, II, TDR No. ML-TDR-64-116, 1964. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4102, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 3



Ni.018 Inconel 702 nickel alloy sheet, compressive stress-strain curves at various temperatures

Test direction: transverse. Sheet thickness = 1.016 mm (0.040 in.). Heat treatment: 1079 °C (1975 °F), 0.5 h, air cooled + 760 °C (1400 °F), 5 h, air cooled. Composition: Ni-15Cr-3Al-0.5Ti. UNS N07702

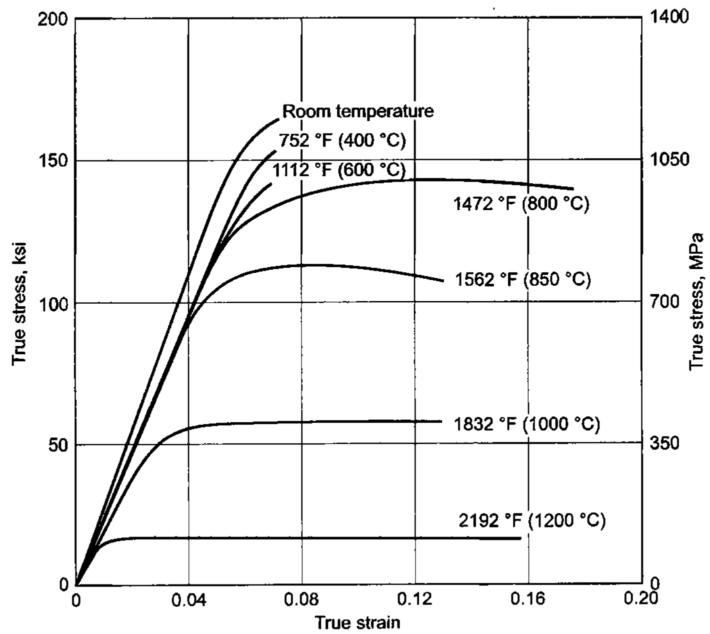
Source: "Research Investigation to Determine Mechanical Properties of Nickel and Cobalt Base Alloys for Inclusion in Military Handbook 5," Vol I, II, TDR No. ML-TDR-64-116, 1964. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4102, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 3



Ni.019 MA 6000 oxide-dispersion-strengthened nickel alloy, rolled product, tensile stress-strain curve at 1100 °C (2012 °F)

As hot rolled. Average grain diam 0.26 μm. Strain rate = ~2.0/s. Calculated assuming uniform deformation. Composition: Ni-15Cr-4.5Al-4.0W-2.5Ti-2.0Mo-2.0 Ta-1.1Y_2O_3

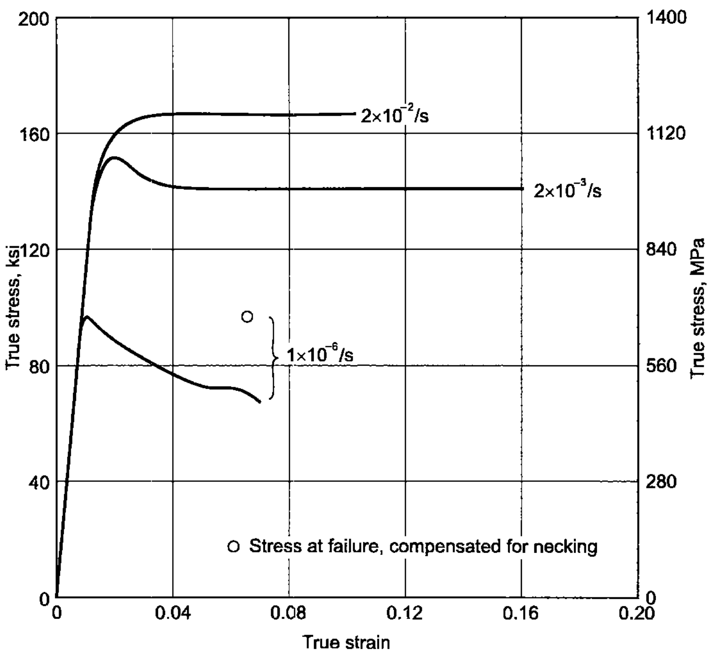
Source: J.K. Gregory, J.C. Gibeling, and W.D. Nix, High Temperature Deformation of Ultra-Fine-Grained Oxide Dispersion Strengthened Alloys, *Metall. Trans.*, Vol 16A (No. 5), 1985, p 777–787. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code #4122, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 16



Ni.020 MA 6000 oxide-dispersion-strengthened nickel alloy, bar, compressive stress-strain curves at room and elevated temperatures

Annealed at 1000 °C (1832 °F), 1 h, air cooled in argon-10% hydrogen. Grain aspect ratio = 17:1. Initial strain rate = 0.00015/s. Composition: Ni-15Cr-4.5Al-4.0W-2.5Ti-2.0Mo-2.0Ta-1.1Y_2O_3

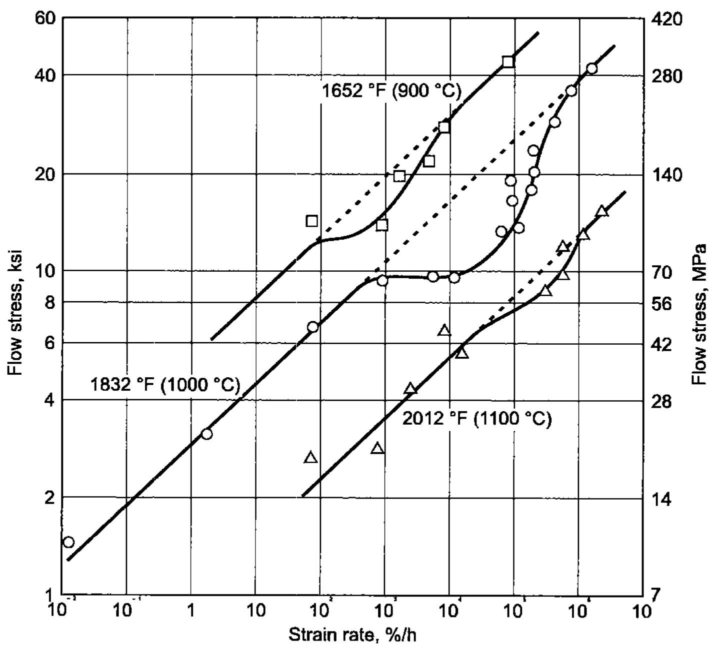
Source: B. Reppich, W. Listl, and T. Meyer, Particle-Strengthening Mechanisms in ODS Superalloys, *Conf. High Temperature Alloys for Gas Turbines and Other Applications 1986* (Liege, Belgium), 1986, Part II, p 1023–1035. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 4122, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 18



Ni.021 MA 6000 oxide-dispersion-strengthened nickel alloy bar, effect of strain rate on true stress-strain curves at 760 °C (1400 °F)

Test direction: longitudinal. Annealed bar with coarse, elongated grain structure. Composition: Ni-15Cr-4.5Al-4.0W-2.5Ti-2.0Mo-2.0Ta-1.1Y_2O_3

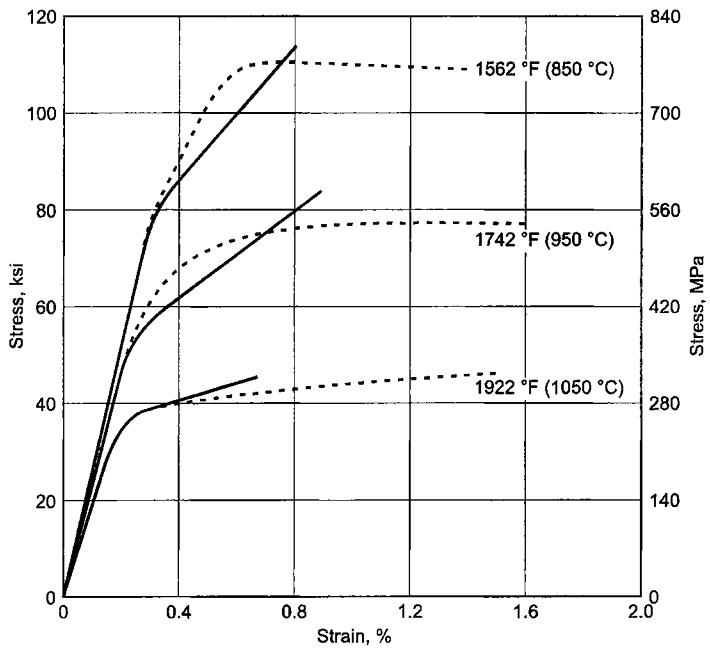
Source: E.G. Jacobs, "Understanding the Stress-Resisting Creep and Hot Tensile Deformation in ODS Superalloys," Dissertation, Columbia University, UMI Dissertation Information Service, 1990. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 4122, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 16



Ni.022 MA 6000 oxide-dispersion-strengthened nickel alloy bar, as hot rolled, effect of strain rate and temperature on flow stress of fine-grained alloy

Average grain diameter: 0.26 μm. Composition: Ni-15Cr-4.5Al-4.0W-2.5Ti-2.0Mo-2.0Ta-1.1Y_2O_3

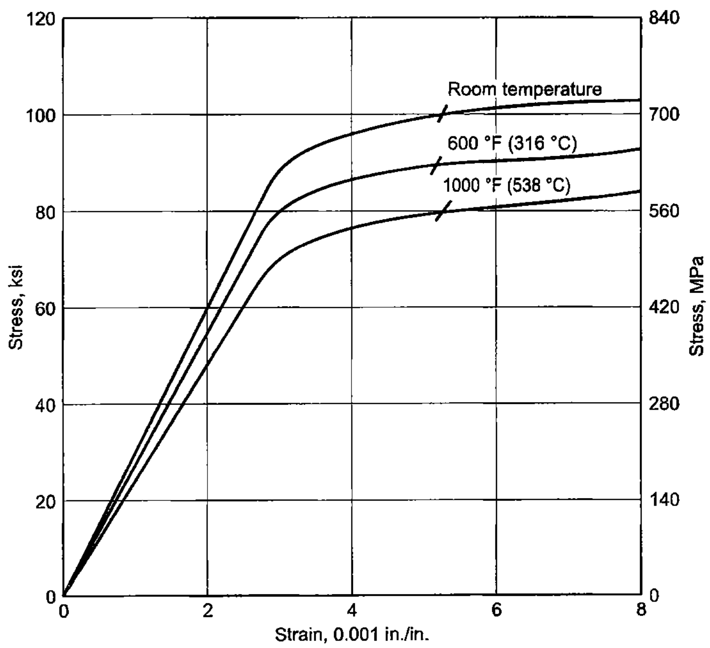
Source: J.K. Gregory, J.C. Gibeling, and W.D. Nix, High Temperature Deformation of Ultra-Fine-Grained Oxide Dispersion Strengthened Alloys, *Metall. Trans.*, Vol 16A (No. 5), 1985, p 777–787. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code #4122, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 18



Ni.023 MA 6000 oxide-dispersion-strengthened nickel alloy rod, cyclic and monotonic stress-strain curves at various temperatures

Annealed: 1232 °C (2250 °F), 0.5 h, air cooled, + 954 °C (1750 °F), 2 h, air cooled, + 843 °C (1550 °F), 24 h, air cooled. Solid line: Cyclic load, $R = -1$, strain rate = 10^{-2}/s. Dashed line monotonic, strain rate not reported. Composition: Ni-15Cr-4.5Al-4.0W-2.5Ti-2.0Mo-2.0 Ta-1.1Y_2O_3

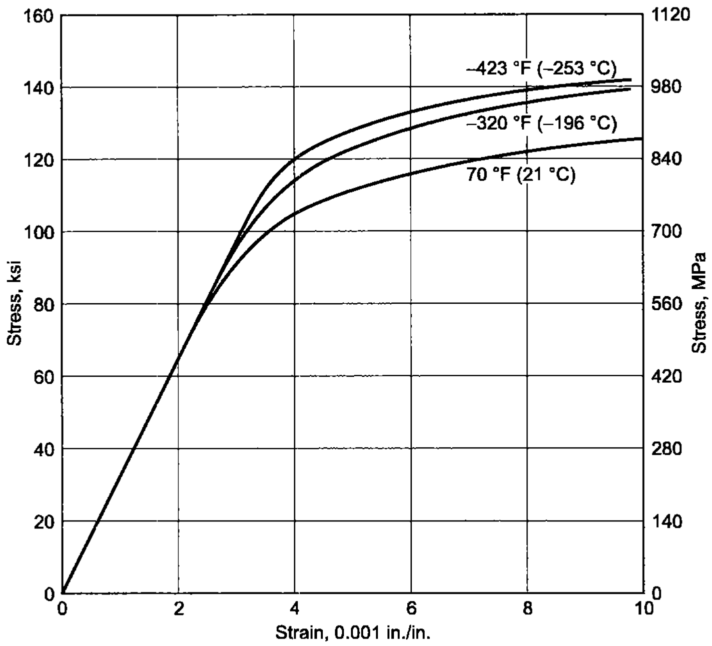
Source: M. Marchionni, D. Ranucci, and E. Picco, Influence of Environment on High Temperature Low Cycle Failure of an Oxide Dispersion Strengthened Nickel Base Superalloy, *Conf. High Temperature Materials for Power Engineering 1990* (Liege, Belgium), Part II, 1990, p 1195–1204. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4122, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 24



Ni.024 Inconel X-750 nickel alloy sheet, tensile stress-strain curves at room and elevated temperatures

Sheet heat treated to an ultimate strength of 1069 MPa (155 ksi). Composition: Ni-15Cr-7Fe-2.5Ti-1Nb-0.7Al. UNS N07750

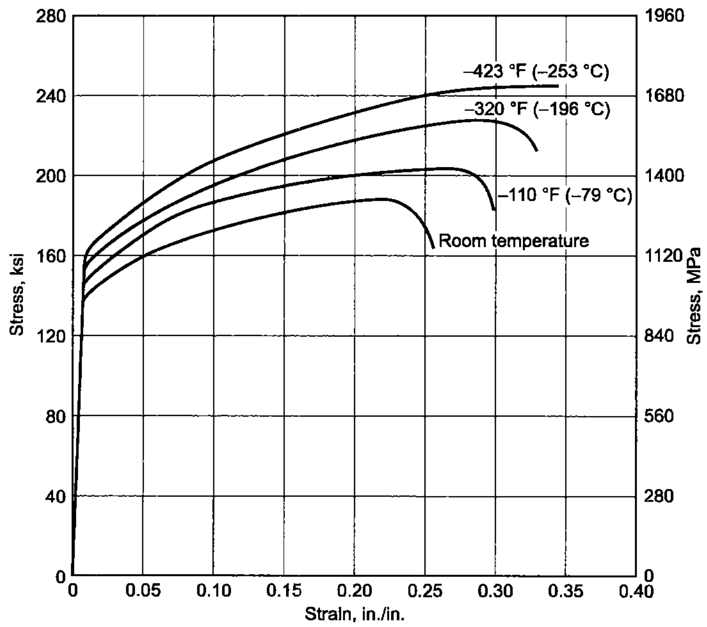
Source: *Aerospace Structural Metals Handbook,* Vol 4, Mechanical Properties Data Center, Battelle Columbus Laboratories, 1981, p 9



Ni.025 Inconel X-750 nickel alloy sheet, tensile stress-strain curves at room and low temperatures

Test direction: longitudinal. Sheet thickness = 1.27 mm (0.050 in.). Precipitation-treated condition: 982 °C (1800 °F), 1 h, force cooled to 704 °C (1300 °F), held 20 h, air cooled. Composition: Ni-15Cr-7Fe-2.5Ti-1Nb-0.7Al. UNS N07750

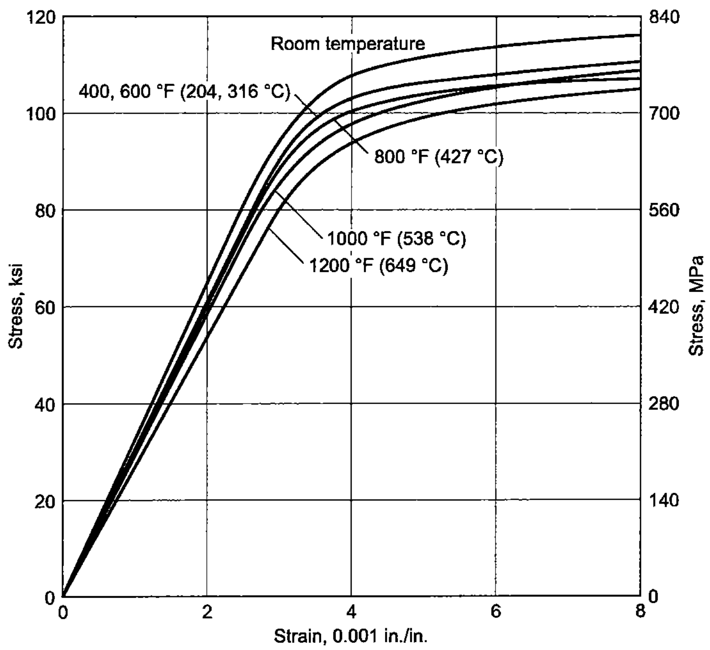
Source: E.H. Schmidt, "Fatigue Properties of Sheet, Bar and Cast Metallic Materials for Cryogenic Applications," Rocketdyne, R-7564, 30 Aug 1968. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4105, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 16



Ni.026 Inconel X-750 nickel alloy bar, complete stress-strain curves at room and low temperatures

Bar diameter = 3.81 mm (0.150 in.). Precipitation-treated condition: solution treated + 704 °C (1300 °F), 20 h, air cooled. Composition: Ni-15Cr-7Fe-2.5Ti-1Nb-0.7Al. UNS N07750

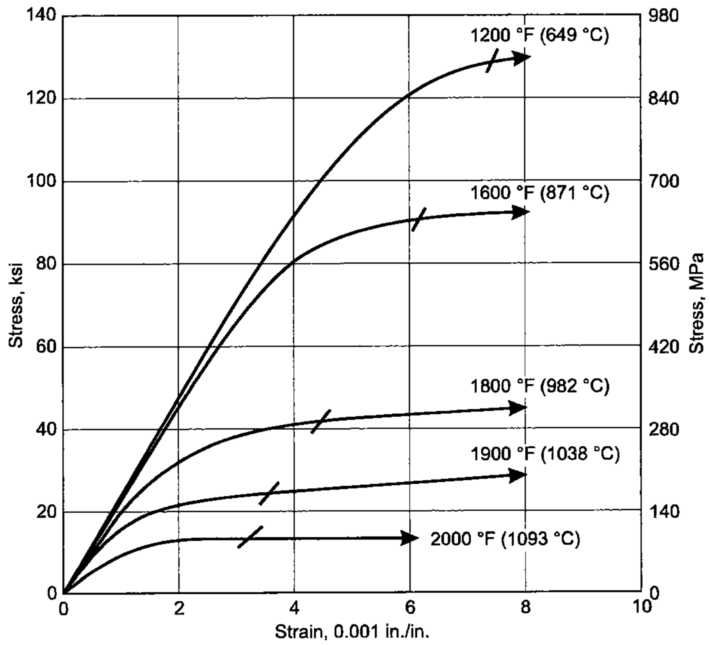
Source: K.A. Warren and R.P. Reed, "*Tensile and Impact Properties of Selected Materials From 20 to 300 K,*" Monograph 63, National Bureau of Standards, 1963. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4105, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 16



Ni.027 Inconel X-750 nickel alloy sheet, compressive stress-strain curves at room and elevated temperatures

Test direction: longitudinal and transverse. Sheet thickness = 1.63 mm (0.064 in.). Precipitation-treated condition: annealed, + 704 °C (1300 °F), 20 h, air cooled. Composition: Ni-15Cr-7Fe-2.5Ti-1Nb-0.7Al.
UNS N07750

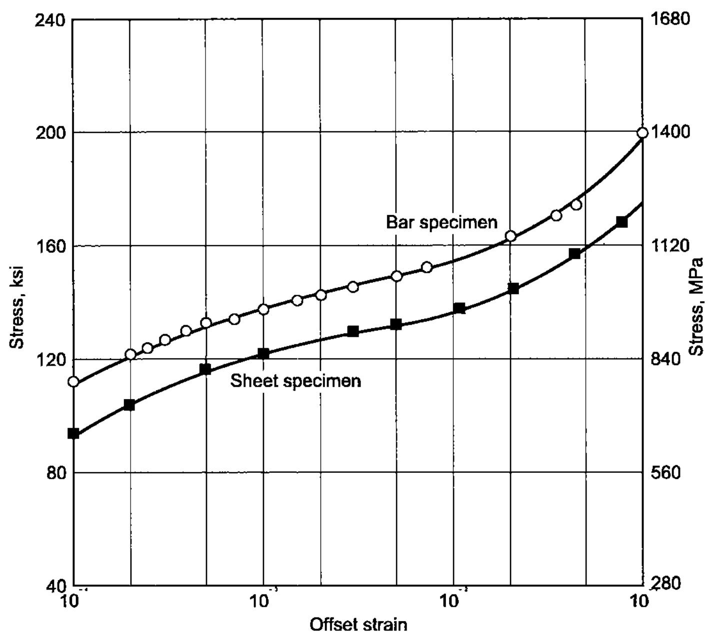
Source: P.J. Hughes, J.E. Inge, and S.B. Prasser, "Tensile and Compressive Stress-Strain Properties of Some High-Strength Sheet Alloys at Elevated Temperatures," NACA TN-3315, Nov 1954. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4105, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 19



Ni.028 Udimet 700 wrought nickel alloy, typical stress-strain curves at elevated temperatures

Fully heat treated. Composition: Ni-18Co-15Cr-5Mo-4.5Al-3.5Ti-0.03B

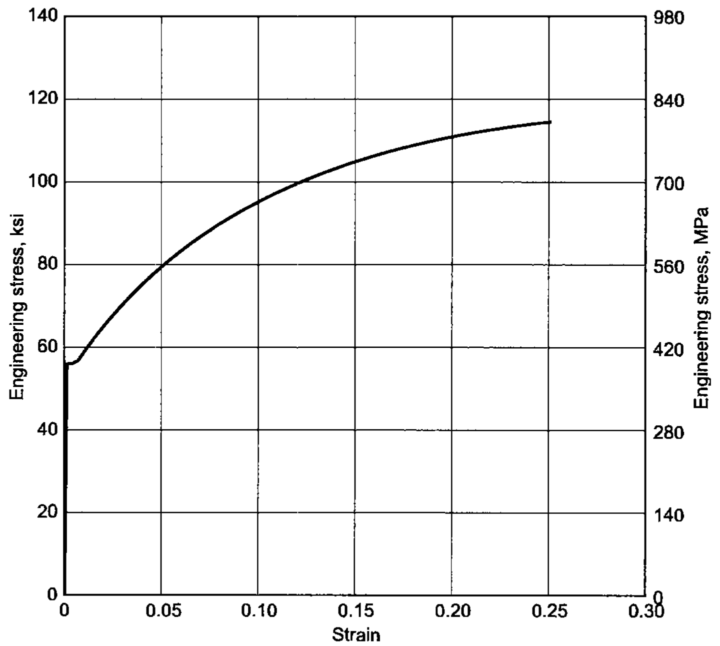
Source: "Udimet 700-Alloy Performance Data," Brochure No. 8595, Kelsey Hays Co., Metal Division, 1959. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4207, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 18



Ni.029 Udimet 700 nickel alloy bar, stress-offset strain curves at room temperature

Round bar (9.373 mm, or 0.369 in., diam) and sheet 0.368 × 0.012 in. (2 grains thick) specimens machined from 25.4 mm (1 in.) diam round bar. Heat treated in argon atmosphere: solution at 1163 °C (2125 °F) for 4 h, forced air cooled, primary age at 1079 °C (1975 °F), 4 h, forced air cooled, stabilized 843 °C (1550 °F), 4 h, forced air cooled, final aging 760 °C (1400 °F), 16 h, forced air cooled. Sheet was spark machined, hand polished, and electropolished from the round bar. Composition: Ni-18Co-15Cr-5Mo-4.5Al-3.5Ti-0.03B

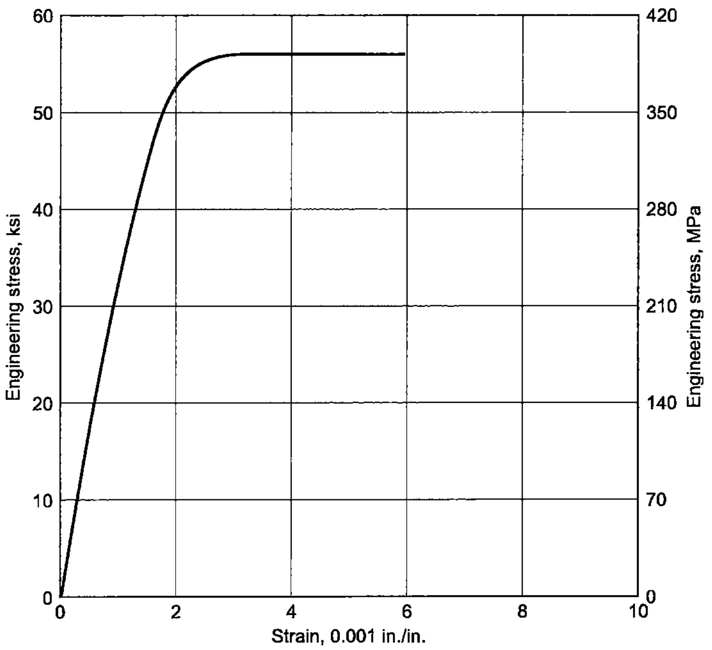
Source: C.H. Wells and C.P. Sullivan, The Low Cycle Fatigue Characteristics of a Nickel Base Superalloy at Room Temperature, *Trans. ASM Quart.*, Vol 57, 1964, p 841–855



Ni.030 Nimonic 75 annealed nickel alloy sheet, engineering stress-strain curve (full range)

Test direction: longitudinal. Sheet thickness = 3.0 mm (0.118 in.). 0.2% yield strength = 387 MPa (56.1 ksi); ultimate tensile strength = 797 MPa (115.6 ksi); elongation = 36.7%. Composition: Ni-19.5Cr-0.4Ti. UNS N06075

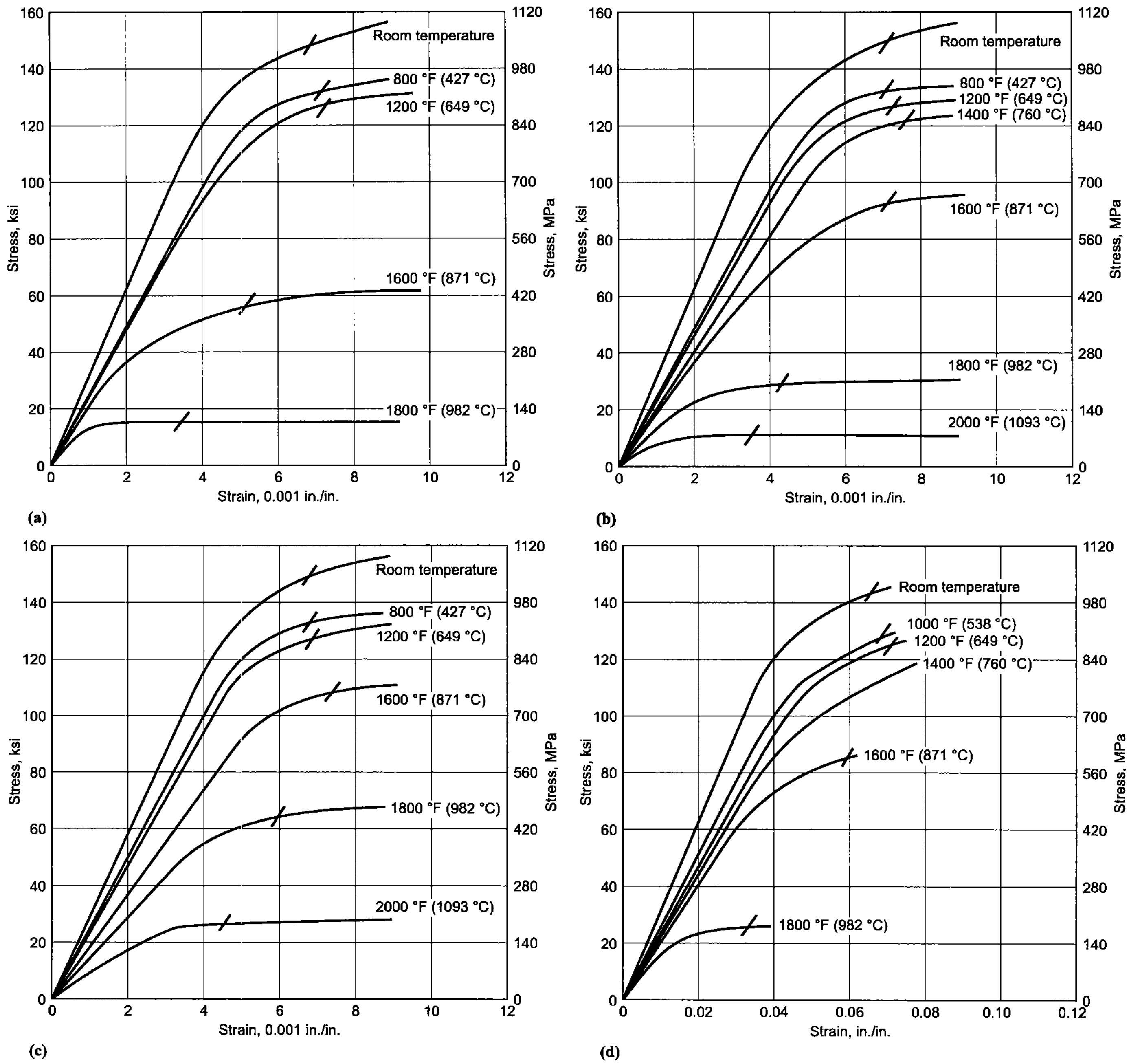
Courtesy of Special Metals Corporation



Ni.031 Nimonic 75 annealed nickel alloy sheet, engineering stress-strain curve (expanded range)

Test direction: longitudinal. Sheet thickness = 3.0 mm (0.118 in.). 0.2% yield strength = 385 MPa (55.9 ksi); ultimate tensile strength = 799 MPa (115.9 ksi); elongation = 36.7%. Composition: Ni-19.5Cr-0.4Ti. UNS N06075

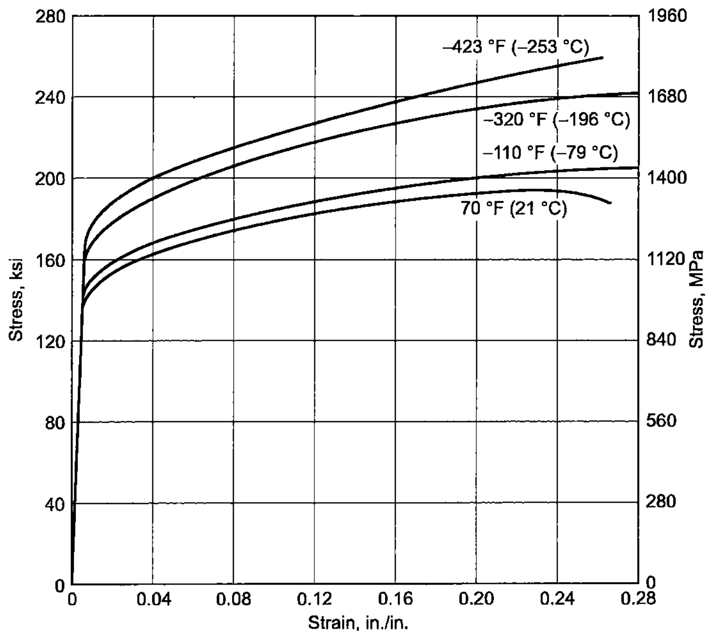
Courtesy of Special Metals Corporation



Ni.032 René 41 nickel alloy sheet, tensile stress-strain curves at room and elevated temperatures

Sheet solution treated 1066 °C (1950 °F), 0.5 h, rapid air cooled, aged 760 °C (1400 °F), 16 h, air cooled. (a) Sheet thickness = 1.27 mm (0.050 in.). Strain rate = 0.00060 in./in./min. (b) Sheet thickness = 1.27 mm (0.050 in.). Strain rate = 0.060 in./in./min. (c) Sheet thickness = 1.27 mm (0.050 in.). Strain rate = 6 in./in./min. (d) Sheet thickness = 3.175 mm (0.125 in.). Strain rate = 0.005 in./in./min. Composition: Ni-19Cr-11Co-9.8Mo-3.2Ti-1.5Al-0.006B. UNS N07041

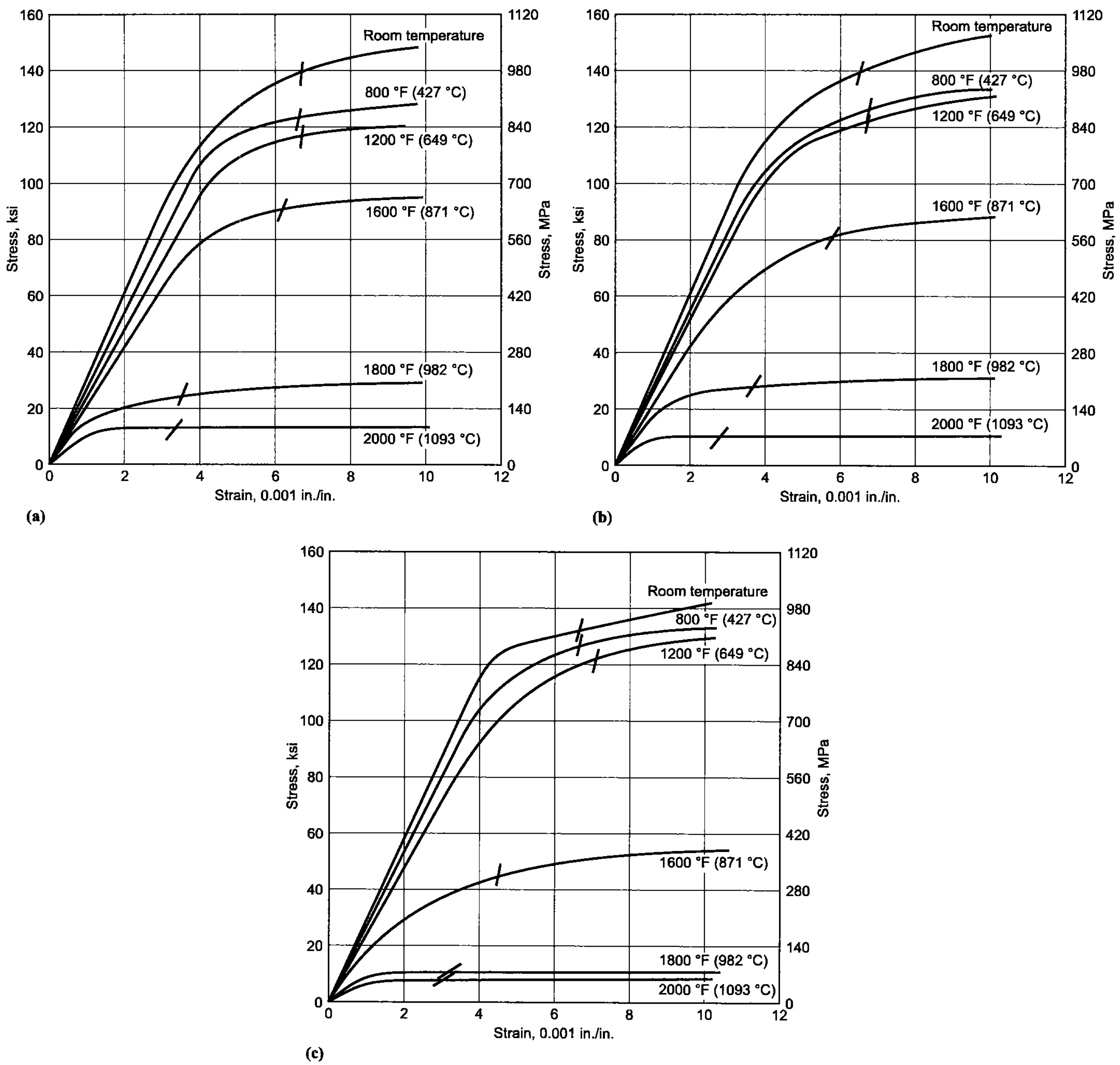
Source: "Mechanical Properties of René 41 Sheet Materials," Report No. BLR 61-21(M), Bell Aerosystem Co., 29 June 1962; "Tensile and Creep Properties of 0.010 and 0.050 Inch René 41 Alloy Sheet from Room Temperature to 2000F," Report PR 281-1Q-1, The Marquardt Corp., 12 Sept 1962. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4205, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 34



Ni.033 René 41 nickel alloy bar, tensile stress-strain curves at room and low temperatures

Bar diameter = 19.05 mm (0.750 in.). Heat treatment: 1079 °C (1975 °F), 4 h, water quenched, + 760 °C (1400 °F), 16 h, air cooled. Composition: Ni-19Cr-11Co-9.8Mo-3.2Ti-1.5Al-0.006B. UNS N07041

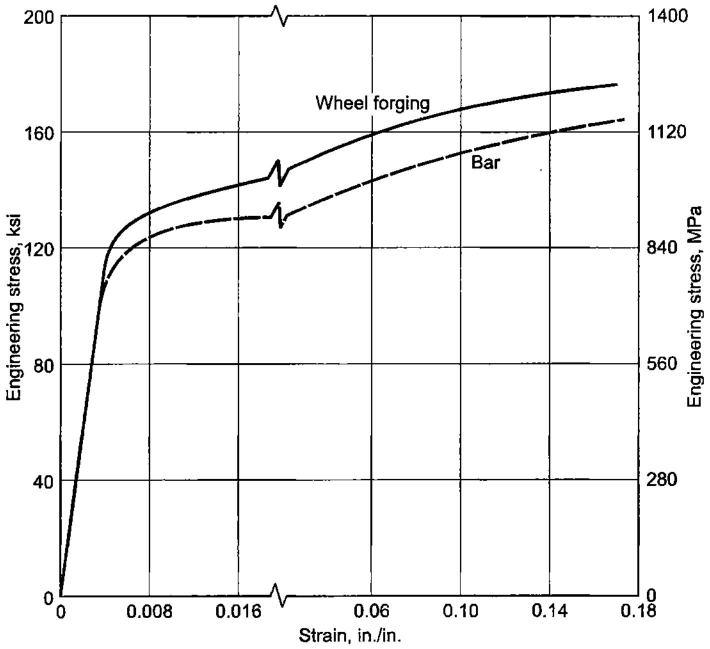
Source: F.R. Schwartzberg, S.H. Osgood, R.D. Keys, and T.F. Kieffer, "Cryogenic Materials Data Handbook," ML-TDR-64-280, Air Force Materials Laboratory Report, Aug 1964; K.A. Warren and R.P. Reed, "*Tensile and Impact Properties of Selected Materials from 20 to 300 degrees K,*" Monograph 63, National Bureau of Standards, June 1963. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4205, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 34



Ni.034 René 41 nickel alloy sheet, compressive stress-strain curves at room and elevated temperatures

Strain rate = (a) 6 in./in./min. (b) 0.6 in./in./min. (c) 0.0006 in./in./min. Heat treatment: 1079 °C (1975 °F), 0.5 h, water quenched + 760 °C (1400 °F), 16 h, air cooled. Composition: Ni-19Cr-11Co-9.8Mo-3.2Ti-1.5Al-0.006B. UNS N07041

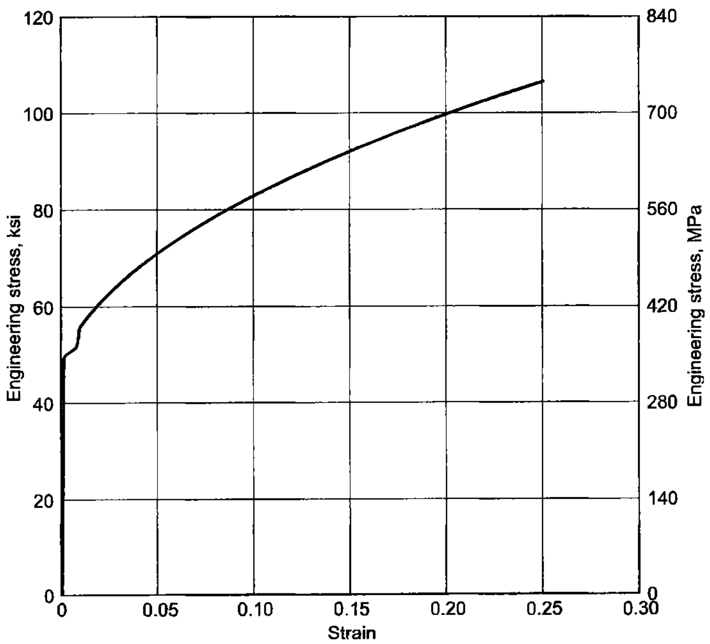
Source: P.R. Dioguardo and R.D. Lloyd, "Investigation of the Effects of Rapid Loading and Elevated Temperatures on the Mechanical Properties of Compressive and Column Members," ASD-TR-62-199, Jan 1962. As published in *Aerospace Structural Metals Handbook*, Vol 5, Code 4205, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 43



Ni.035 René 41 nickel alloy forged bar and turbine wheel forging, stress-strain curves at 538 °C (1000 °F)

Heat treatment: 1079 °C (1975 °F), 2 h, oil quenched, + 774 °C (1425 °F), 16 h, air cooled. Wheel yield strength = 883 MPa (128 ksi); ultimate strength = 1220 MPa (177 ksi). Bar yield strength = 841 MPa (122 ksi); ultimate strength = 1151 MPa (167 ksi). Composition: Ni-19Cr-11Co-9.8Mo-3.2Ti-1.5Al-0.006B. UNS N07041

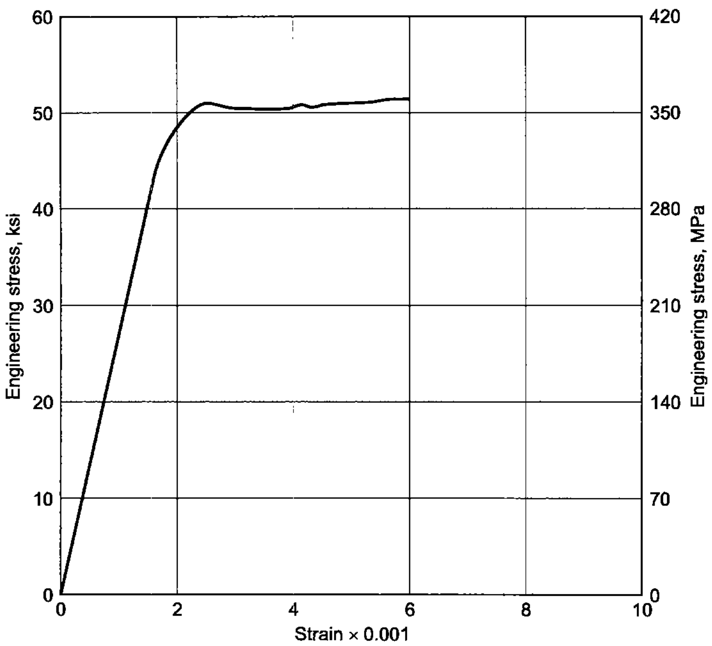
Source: *Aerospace Structural Metals Handbook,* Vol 5, Mechanical Properties Data Center, Battelle Columbus Laboratories, 1978, p 22



Ni.036 Inconel 718 annealed nickel alloy sheet, engineering stress-strain curve (full range)

Test direction: longitudinal. Sheet thickness = 1.524 mm (0.060 in.). 0.2% yield strength = 346 MPa (50.2 ksi); ultimate tensile strength = 820 MPa (118.9 ksi); elongation = 53.8%. Composition: Ni-19Cr-18Fe-5.1(Nb + Ta)-3Mo-0.9Ti-0.5Al. UNS N07718

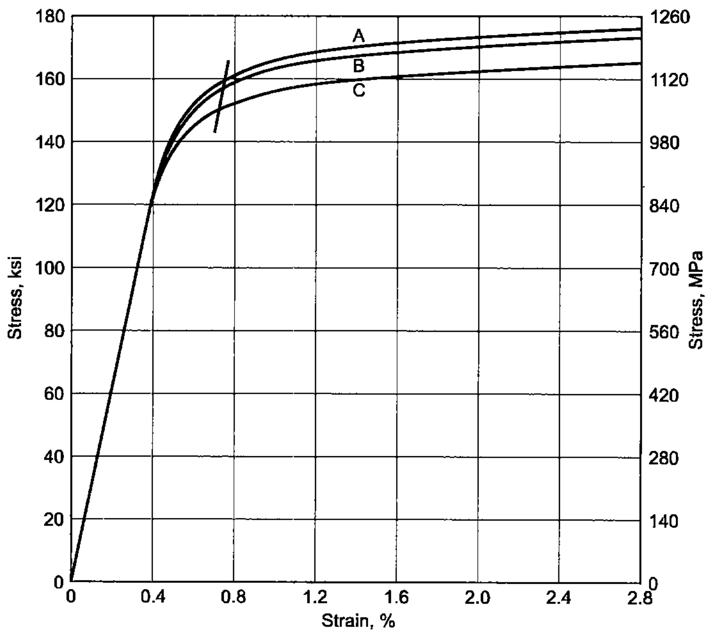
Courtesy of Special Metals Corporation



Ni.037 Inconel 718 annealed nickel alloy sheet, engineering stress-strain curve (expanded range)

Test direction: longitudinal. Sheet thickness = 1.524 mm (0.060 in.). 0.2% yield strength = 348 MPa (50.5 ksi); ultimate tensile strength = 821 MPa (119.0 ksi); elongation = 52.8%. Composition: Ni-19Cr-18Fe-5.1(Nb + Ta)-3Mo-0.9Ti-0.5Al. UNS N07718

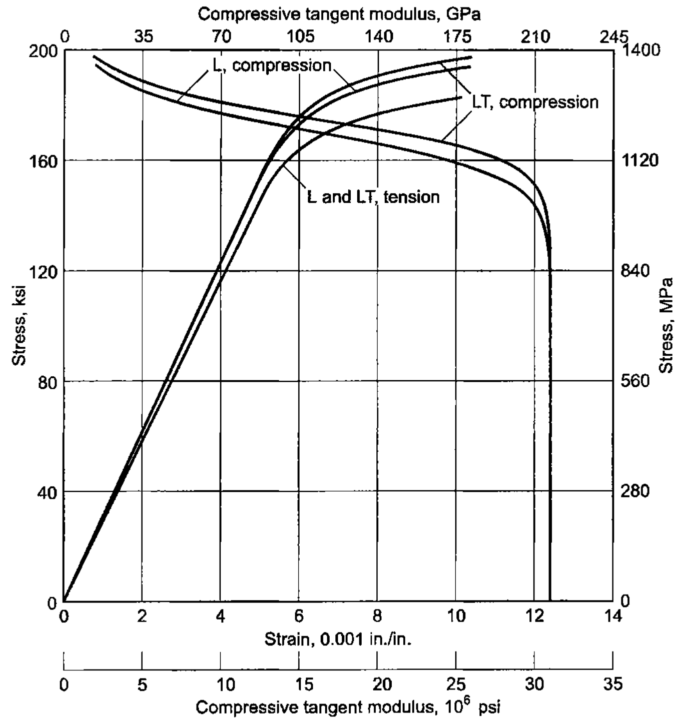
Courtesy of Special Metals Corporation



Ni.038 Inconel 718 nickel alloy sheet, stress-strain curves with effect of heat treatment conditions

Sheet thicknesses = 17.78 and 2.54 mm (0.70 and 0.100 in.). Heat treatment: A: 954 °C (1750 °F), 0.5 h, air cooled, + 718 °C (1325 °F), 10 h, force cooled, to 621 °C (1150 °F), + 621 °C (1150 °F) for total age time 20 h, air cooled. Or 1010 °C (1850 °F), 0.5 h, air cooled, + 718 °C (1325 °F), 10 h, force cooled to 635 °C (1175 °F), + 635 °C (1175 °F) for total age time 20 h, air cooled. B: 1066 °C (1950 °F), 0.5 h, air cooled, + 760 °C (1400 °F), 10 h, force cooled to 649 °C (1200 °F), + 649 °C (1200 °F) for total age time of 20 h, air cooled. C: 1121 °C (2050 °F), 0.5 h, air cooled + 760 °C (1400 °F), 10 h, force cooled to 649 °C (1200 °F), + 649 °C (1200 °F) for total age time of 20 h, air cooled. Composition: Ni-19Cr-18Fe-5.1(Nb + Ta)-3Mo-0.9Ti-0.5Al. UNS N07718

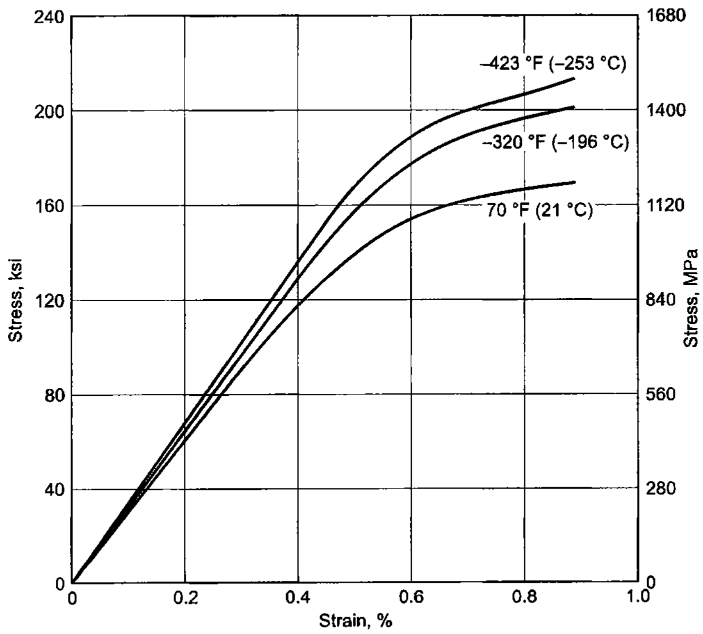
Source: "Effect of Heat Treatment and Surface Oxidation on the Low-Cycle Fatigue Life of Alloy 718," Report MPR No. 9-176A-77, Rocketdyne, May 1969. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 4103, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 42



Ni.039 Inconel 718 nickel alloy sheet, typical tensile and compressive stress-strain and compressive tangent modulus curves at room temperature

Test direction: longitudinal (L) and long transverse (LT). Sheet thickness = 0.254–6.35 mm (0.010–0.250 in.). Solution treated and aged Inconel 718, heat-resistant alloy (AMS 5596). Ramberg-Osgood parameters: n(L, tension) = 21; n(LT, tension) = 22; n(L, compression) = 21; n(LT, compression) = 24. Composition: Ni-19Cr-18Fe-5.1(Nb + Ta)-3Mo-0.9Ti-0.5Al. UNS N07718

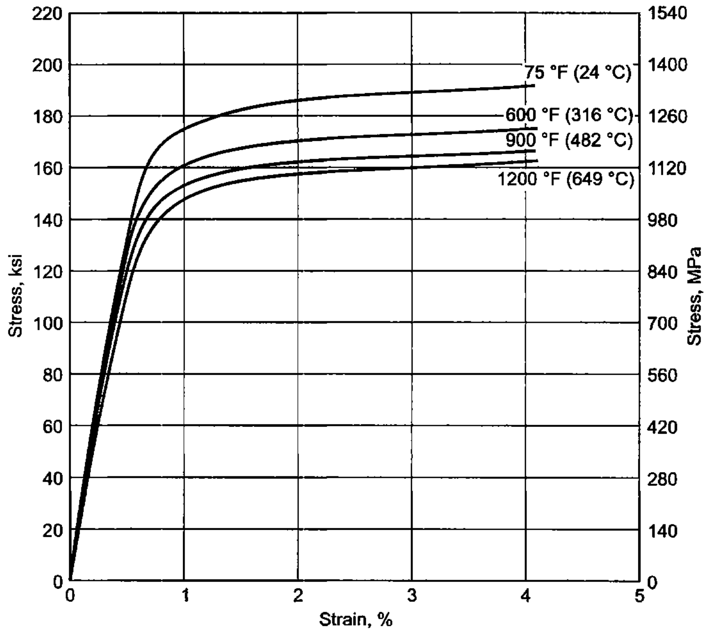
Source: *MIL-HDBK-5H,* Dec 1998, p 6–58



Ni.040 Inconel 718 nickel alloy sheet, tensile stress-strain curves at room and low temperatures

Heat-resistant alloy, solution annealed and aged (conditioning not reported). Composition: Ni-19Cr-18Fe-5.1(Nb + Ta)-3Mo-0.9Ti-0.5Al. UNS N07718

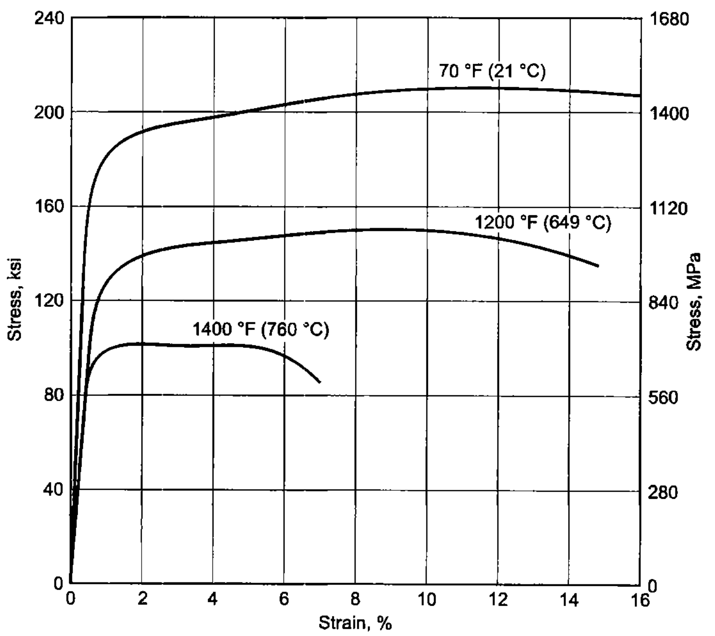
Source: E.H. Schmidt, "Fatigue Properties of Sheet, Bar, and Cast Metallic Materials for Cryogenic Applications," NASA CR-111396, 30 Aug 1968. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 4103, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 50



Ni.041 Inconel 718 nickel alloy plate, tensile stress-strain curves at room and elevated temperatures in hydrogen at 34.5 MPa (5.0 ksi)

Heat treatment: 1037 °C (1900 °F), 1 h, air cooled, + 760 °C (1400 °F), 10 h, force cooled to 649 °C (1200 °F) and held for total age time of 18 h, air cooled. Composition: Ni-19Cr-18Fe-5.1(Nb + Ta)-3Mo-0.9Ti-0.5Al. UNS N07718

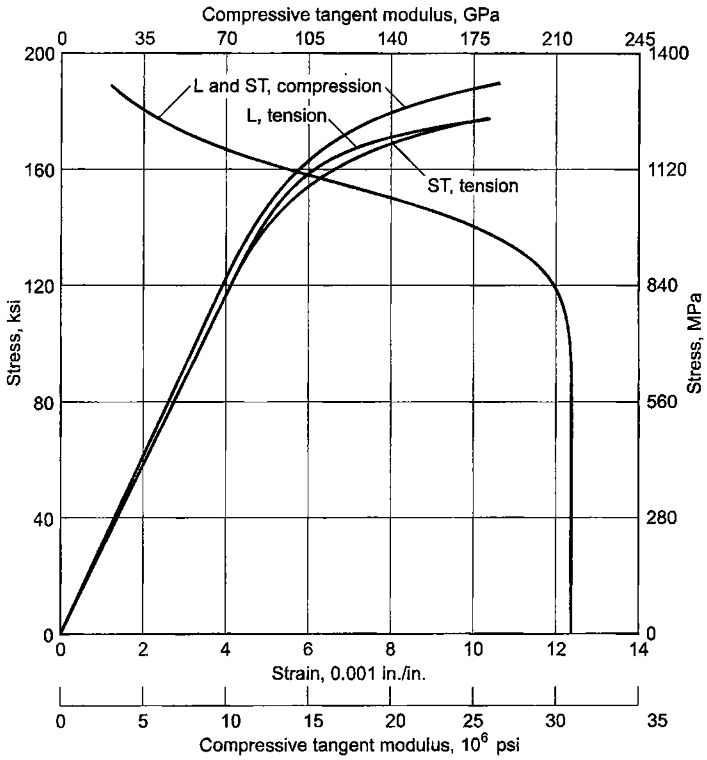
Source: J. Mucci and J.A. Harris, Sr., "Influence of Gaseous Hydrogen on Mechanical Properties of High Temperature Alloys," FR-7746, Pratt & Whitney Aircraft Group, July 1976. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4103, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 34



Ni.042 Inconel 718 nickel alloy bar, tensile stress-strain curves at room and elevated temperatures

Heat-resistant alloy, solution treated and aged (conditioning not reported). Composition: Ni-19Cr-18Fe-5.1(Nb + Ta)-3Mo-0.9Ti-0.5Al. UNS N07718

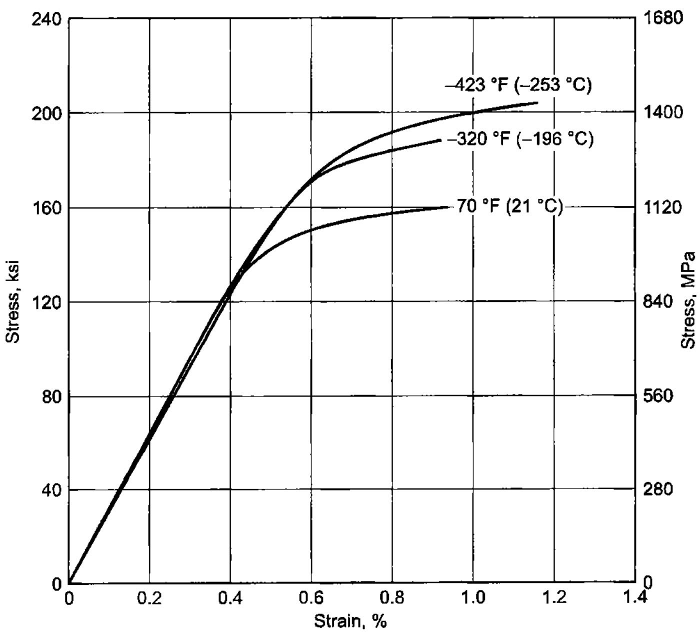
Source: G.L. Heslington and S.D. Foster, "Stress-Strain Diagrams in the Elastic and Plastic Regions at Elevated Temperatures," Report MPR 8-176A-37, Rocketdyne, 17 Oct 1968. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4103, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 39



Ni.043 Inconel 718 nickel alloy bar, typical tensile and compressive stress-strain and compressive tangent modulus curves

Test direction: longitudinal (L) and short transverse (ST). Solution treated and aged (creep rupture application). AMS 5662 and 5663. Ramberg-Osgood parameters: n(L, tension) = 18; n(ST, tension) = 14; n(L and ST, compression) = 13. Composition: Ni-19Cr-18Fe-5.1 (Nb + Ta)-3Mo-0.9Ti-0.5Al. UNS N07718

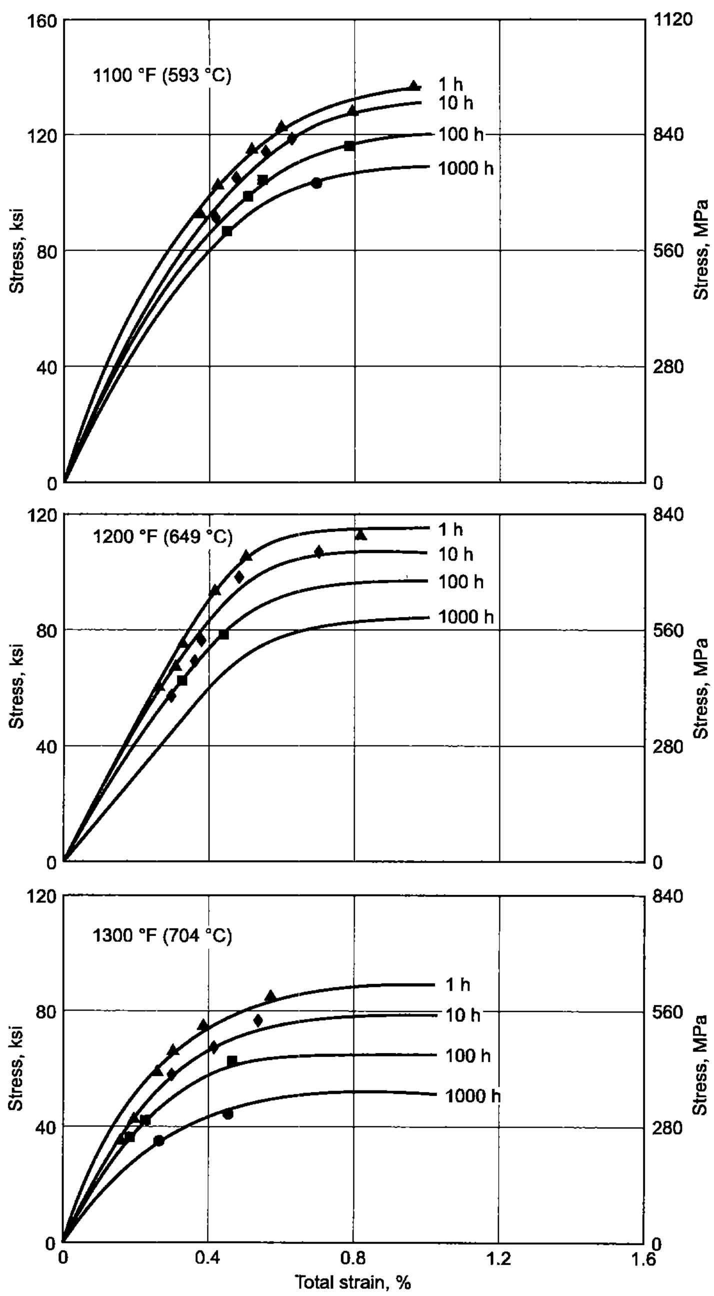
Source: *MIL-HDBK-5H,* Dec 1998, p 6–58



Ni.044 Inconel 718 nickel alloy bar, tensile stress-strain curves at room and low temperatures

Heat-resistant alloy, solution annealed and aged (conditioning not reported). Composition: Ni-19Cr-18Fe-5.1(Nb + Ta)-3Mo-0.9Ti-0.5Al. UNS N07718

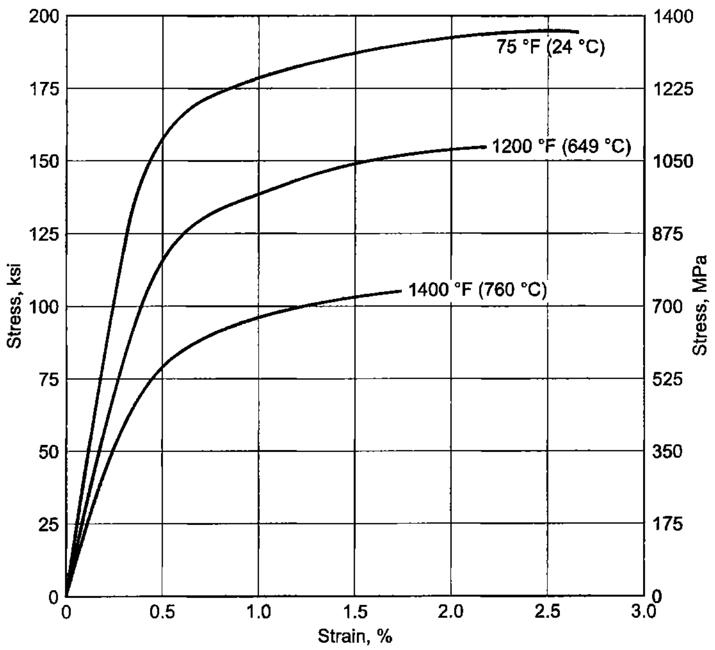
Source: E.H. Schmidt, "Fatigue Properties of Sheet, Bar, and Cast Metallic Materials for Cryogenic Applications," NASA CR-111396, 30 Aug 1968. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4103, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 50



Ni.045 Inconel 718 nickel alloy bar, isochronous stress-strain curves (actual and predicted) at various temperatures

Data points: actual data. Line: predicted from log-log curve. Heat-resistant alloy conditioned 982 °C (1800 °F), 2 h, air cooled + 718 °C (1325 °F), 8 h, force cooled 56 °C/h (100 °F/h) to 621 °C (1150 °F), held 8 h, air cooled. Composition: Ni-19Cr-18Fe-5.1(Nb + Ta)-3Mo-0.9Ti-0.5Al. UNS N07718

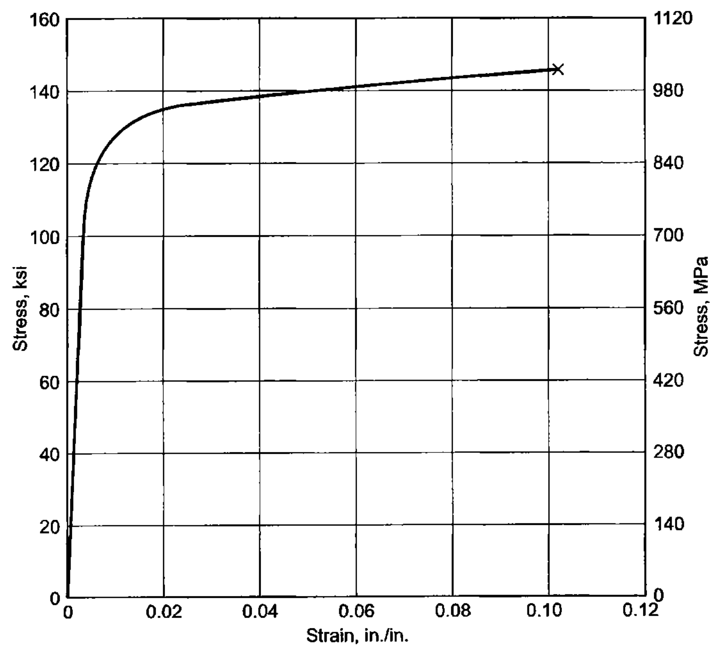
Source: R.M. Goldhoff, Methods for Constructing Isochronous Creep Curves, *The Generation of Isochronous Stress-Strain Curves,* ASME Pamphlet, Nov 1972, p 67–85. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4103, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 62



Ni.046 Inconel 718 nickel alloy roll-formed sheet L and E shapes, tensile stress-strain curves at room and elevated temperatures

Conditioned 996 °C (1825 °F) in hydrogen, + 718 °C (1325 °F), 8 h in argon, force cooled to 621 °C (1150 °F) at 639 °C/h (1150 °F/h), + 621 °C (1150 °F), 8 h, force cooled to room temperature in argon. Heat-resistant alloy. Composition: Ni-19Cr-18Fe-5.1(Nb + Ta)-3Mo-0.9Ti-0.5Al. UNS N07718

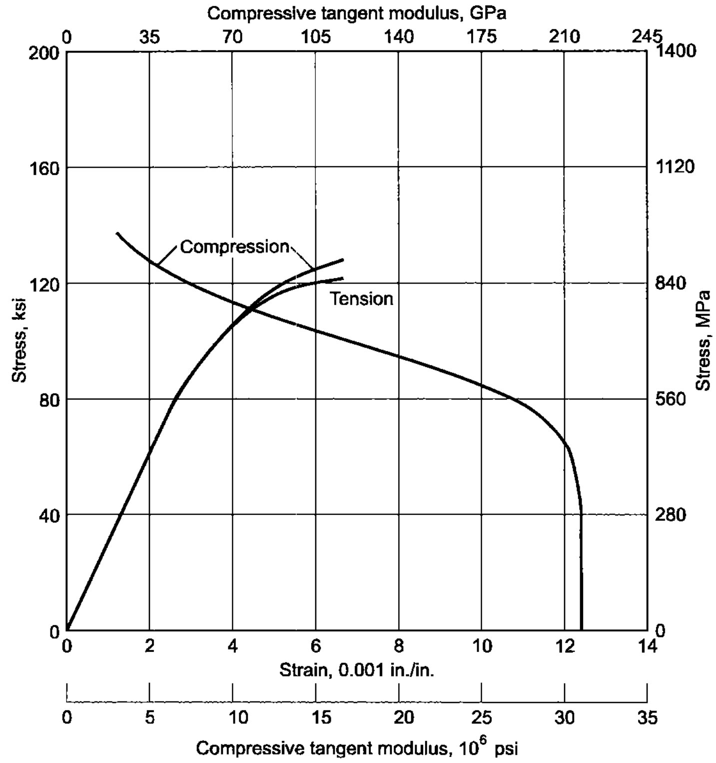
Source: G.N. Wassil et al., "Form Rolling Close Tolerance Shapes of Superalloys," A.F. Contract No. AF33(615)-3545. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4103, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 49



Ni.047 Inconel 718 nickel alloy investment casting, typical tensile stress-strain curve at room temperature (full range)

Heat-resistant alloy, solution treated and aged Inconel 718 (AMS 5383). Composition: Ni-19Cr-18Fe-5.1 (Nb + Ta)-3Mo-0.9Ti-0.5Al. UNS N07718

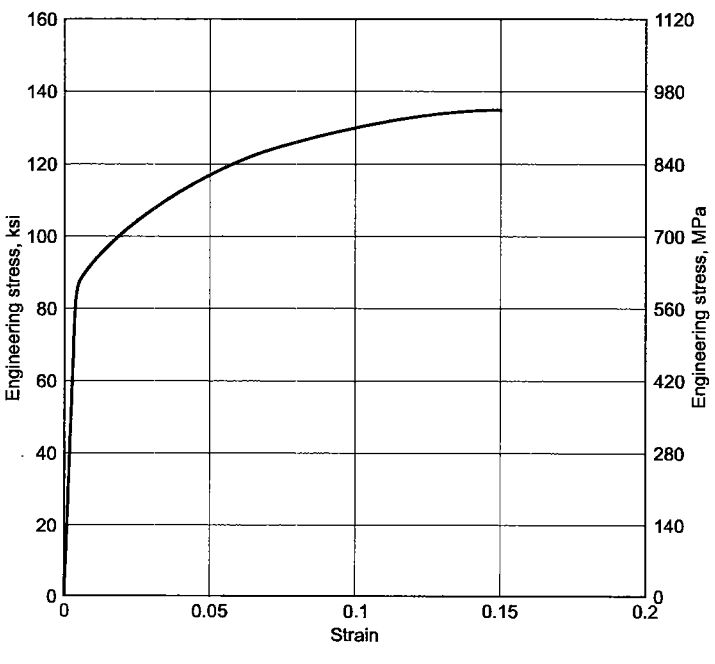
Source: *MIL-HDBK-5H,* Dec 1998, p 6–60



Ni.048 Inconel 718 nickel alloy investment casting, typical tensile and compressive stress-strain and compressive tangent modulus curves at room temperature

Test direction: longitudinal. Sheet thickness = 12.7 mm (0.500 in.). Heat-resistant alloy, solution treated and aged (AMS 5383). Composition: Ni-19Cr-18Fe-5.1(Nb + Ta)-3Mo-0.9Ti-0.5Al. UNS N07718

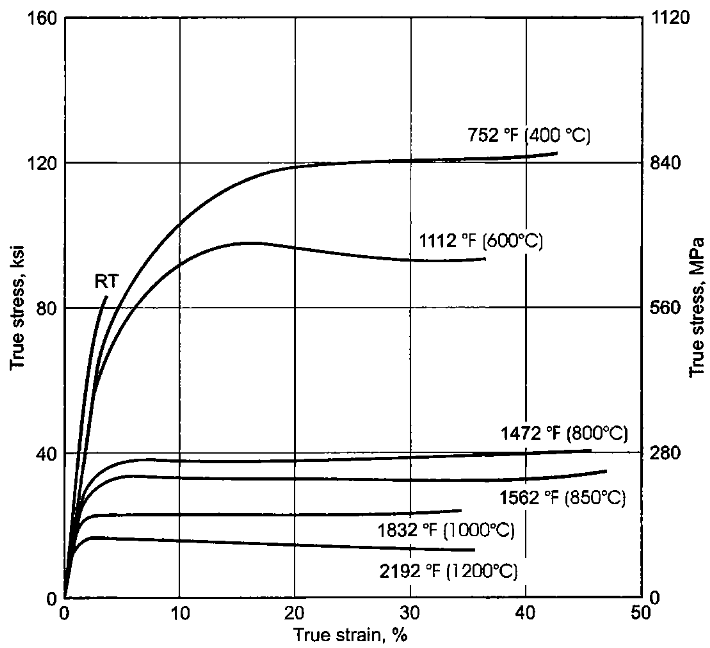
Source: *MIL-HDBK-5H,* Dec 1998, p 6–59



Ni.049 Inconel MA 754 oxide-dispersion-strengthened annealed nickel alloy sheet, engineering stress-strain curve

Test direction: longitudinal. Sheet thickness = 1.448 mm (0.057 in.). 0.2% yield strength = 614 MPa (89.0 ksi); ultimate tensile strength = 932 MPa (135.2 ksi); elongation = 16.6%, strain-hardening exponent (n) = 0.2245. Composition: Ni-20.0Cr-1.0Fe-0.5Ti-0.3 Al-0.05C-0.6Y_2O_3. UNS N07754

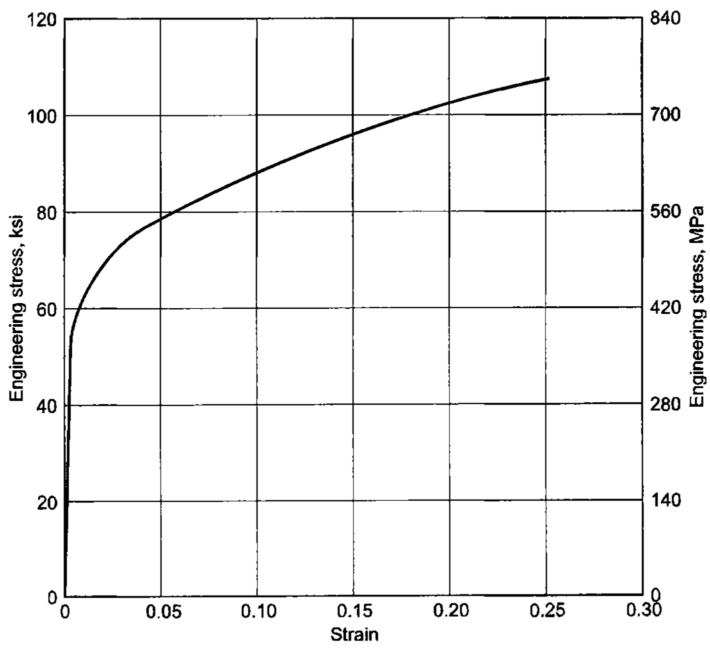
Courtesy of Special Metals Corporation



Ni.050 Inconel MA 754 oxide-dispersion-strengthened nickel alloy bar, compressive true stress-strain curve at room and elevated temperatures

Cylindrical specimens, 4.064 mm (0.16 in.) diam, 6.096 mm (0.24 in.) long. Strain rate = 1.5×10^{-4}/s. Average grain intercept 3.2 mm (longitudinal), 0.113 mm (transverse), aspect ratio = 28/1. Composition: Ni-20.0Cr-1.0Fe-0.5Ti-0.3Al-0.05C-0.6Y_2O_3. UNS N07754

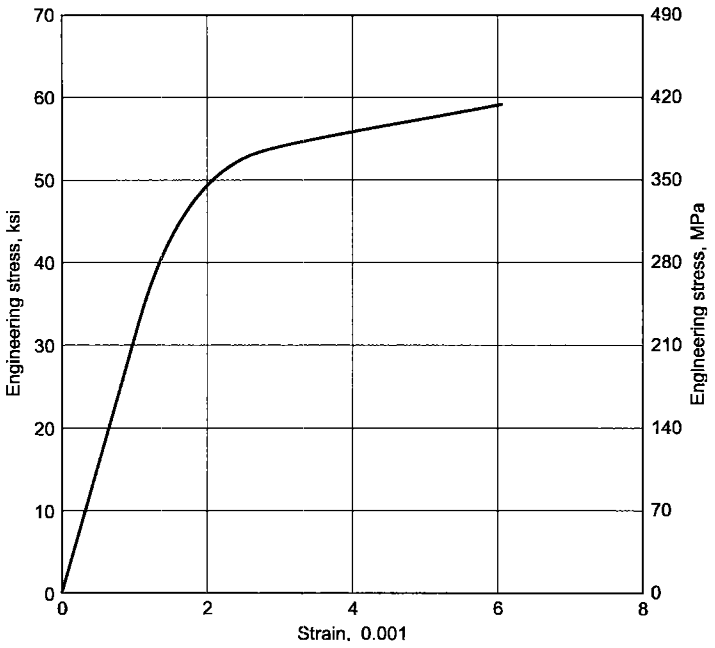
Source: B. Reppich, W. Listl, and T. Meyer, Particle-Strengthening Mechanisms in ODS Superalloys, *Conf. High Temperature Alloys for Gas Turbines and Other Applications 1986* (Liege, Belgium), Part 2, 1986, p 1023–1035. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 4106, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 16



Ni.051 Inconel 725 annealed nickel alloy sheet, engineering stress-strain curve (full range)

Test direction: longitudinal. Sheet thickness = 1.22 mm (0.048 in.). 0.2% yield strength = 387 MPa (56.1 ksi); ultimate tensile strength = 824 MPa (119.5 ksi); elongation = 57.4%. Composition: 57Ni-20.75Cr-8.25Mo-bal Fe. UNS N07725

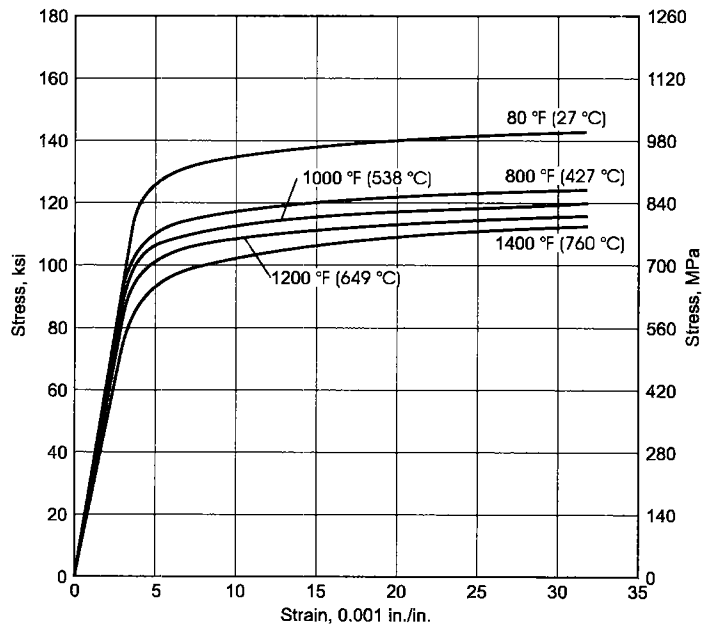
Courtesy of Special Metals Corporation



Ni.052 Inconel 725 annealed nickel alloy sheet, engineering stress-strain curve (expanded range)

Test direction: longitudinal. Sheet thickness = 1.22 mm (0.048 in.). 0.2% yield strength = 423 MPa (61.4 ksi); ultimate tensile strength = 825 MPa (119.6 ksi); elongation = 58.0%. Composition: 57Ni-20.75Cr-8.25Mo-bal Fe. UNS N07725

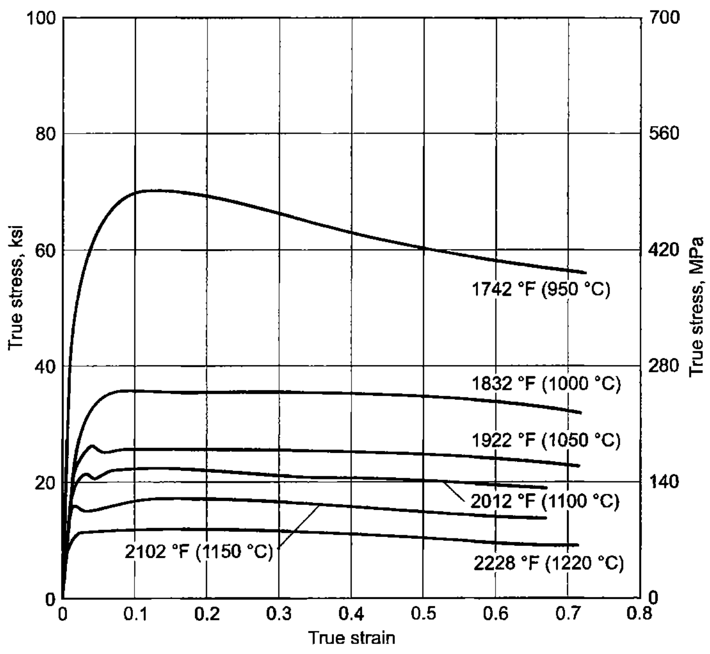
Courtesy of Special Metals Corporation



Ni.053 Waspaloy nickel alloy all products, typical tensile stress-strain curves at room and elevated temperatures

Heat-resistant alloy. Composition: Ni-20Cr-14Co-4Mo-3Ti-1Al. UNS N07001

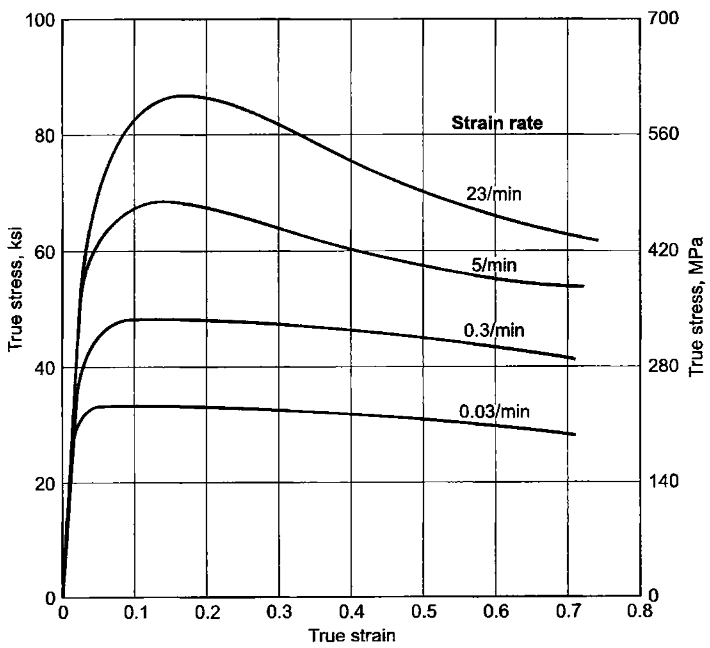
Source: *MIL-HDBK-5H,* Dec 1998, p 6–95



Ni.054 Waspaloy nickel alloy, effect of temperature on compressive flow curves

Solution annealed 0.5 h, 1200 °C (2192 °F), force cooled or heated to test temperature. Strain rate 5/min. Composition: Ni-20Cr-14Co-4Mo-3Ti-1Al. UNS N07001

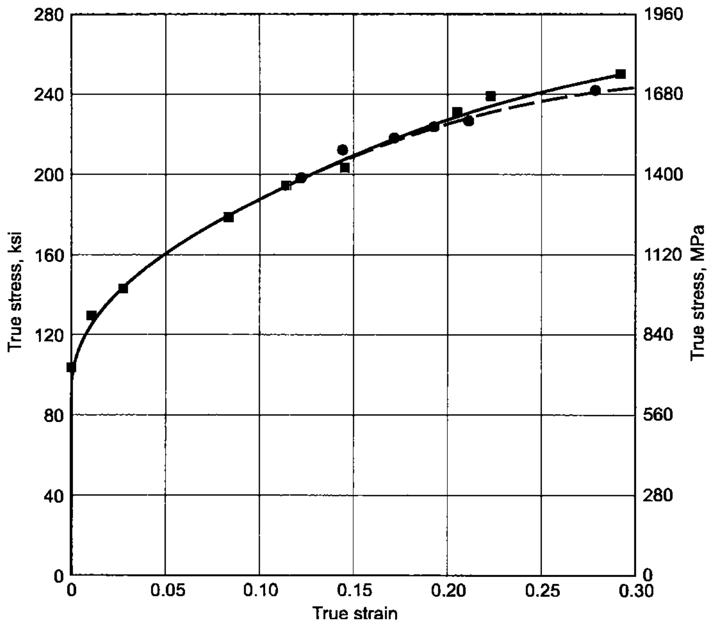
Source: A.A. Guimaraes and J.J. Jonas, Recrystallization and Aging Effects Associated with the High Temperature Deformation of Waspaloy and Inconel 718, *Metall. Trans.*, Vol 12A (No. 9), 9 Sept 1981, p 1655–1666. As published in *Aerospace Structural Metals Handbook*, Vol 5, Code 4208, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 23



Ni.055 Waspaloy nickel alloy, effect of strain rate on compressive flow curves at 950 °C (1742 °F)

Solution annealed 0.5 h, 1200 °C (2192 °F), force cooled to test temperature. Composition: Ni-20Cr-14Co-4Mo-3Ti-1Al. UNS N07001

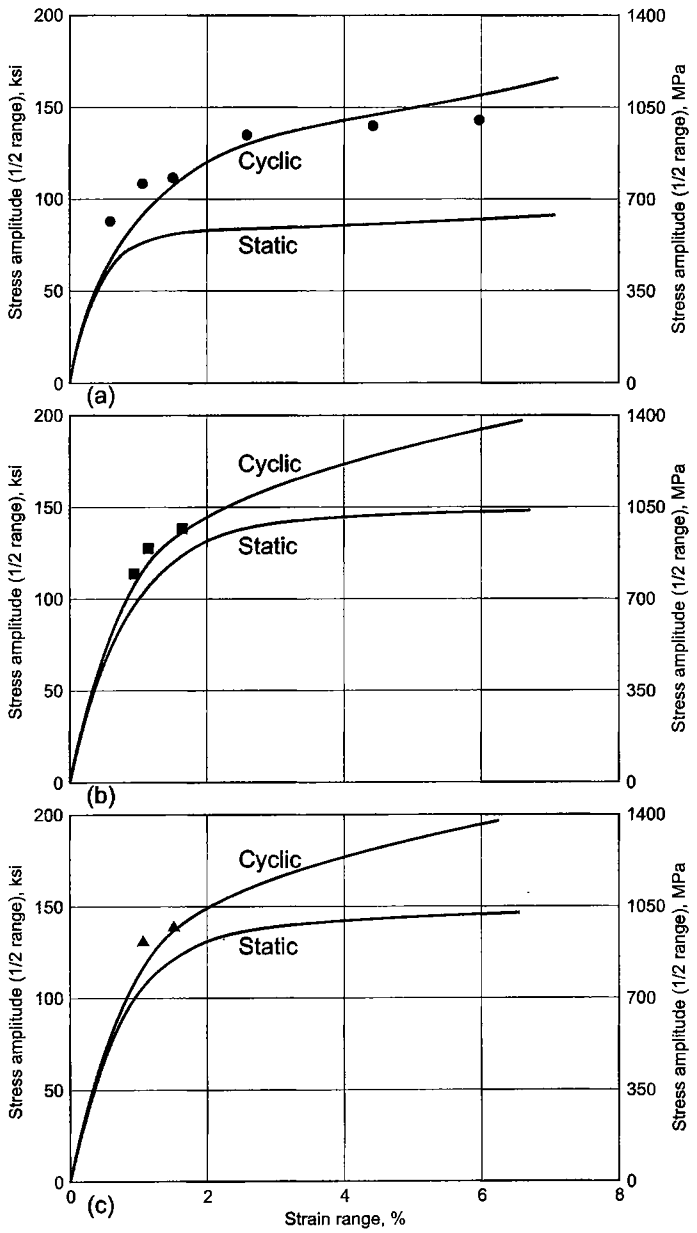
Source: A.A. Guimaraes and J.J. Jonas, Recrystallization and Aging Effects Associated with the High Temperature Deformation of Waspaloy and Inconel 718, *Metall. Trans.*, Vol 12A (No. 9), 9 Sept 1981, p 1655–1666. As published in *Aerospace Structural Metals Handbook*, Vol 5, Code 4208, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 23



Ni.056 Waspaloy nickel alloy forging, true stress-strain curves at room temperature

Square: Bar cut from turbine disk specimen 10.2 mm (0.4 in.) thick by 121.9 mm (4.8 in.) diam fully heat treated. Circle: Specimen from disk after overspeed burst, corrected for straining. Composition: Ni-20Cr-14Co-4Mo-3Ti-1Al. UNS N07001

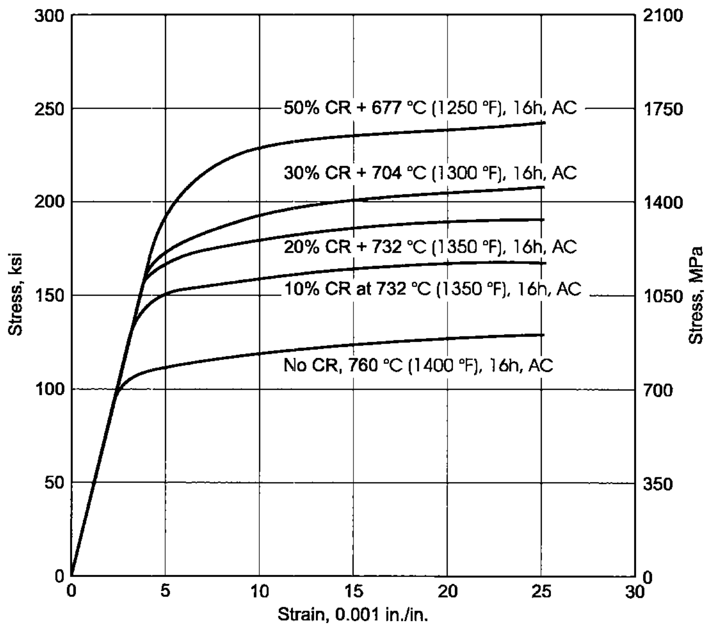
Source: L. Islip, Component Design and Material Selection, *Engineering in High Duty Materials,* Bulleid Memorial Lectures, Vol IV, University of Nottingham, 1967. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4208, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 17



Ni.057 Waspaloy nickel alloy forging, static and cyclic stress-strain curves at room temperature

Specimens 12.7 mm (0.5 in.) bar eloxed from turbine wheel forging, heat treated. Cyclic $R = -1$. Heat treatment: (a): 1079 °C (1975 °F), 4 h, air cooled, + 843 °C (1550 °F), 2–4 h, force cooled, + 760 °C (1400 °F), 16 h, force cooled. (b): 996–1010 °C (1825–1850 °F), 4 h, oil quenched, + 843 °C (1550 °F), 2–4 h, air cooled, + 760 °C (1400 °F), 16 h, air cooled. (c): Same as B from different vendor. Data points indicate half-life value. Composition: Ni-20Cr-14Co-4Mo-3Ti-1Al. UNS N07001

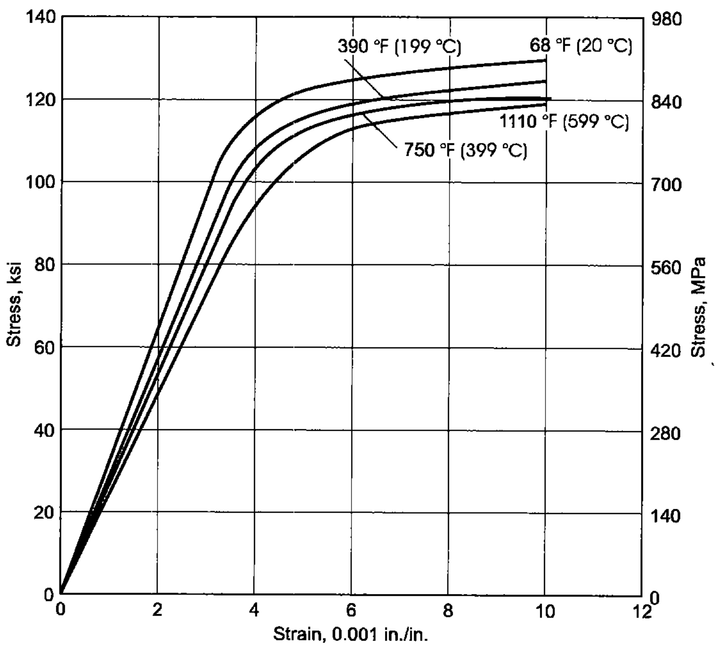
Source: J.D. Morrow and F.R. Tuler, Low Cycle Fatigue Evaluation of Inconel 713C and Waspaloy (Paper No. 64 MET-15), *Trans. ASME, J. Basic Eng.* As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4208, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 17



Ni.058 Nimonic 90 nickel alloy sheet, stress-strain curves at room temperature

Test direction: longitudinal. Sheet thickness = 1.575 mm (0.062 in.). Strain rate = 0.003/min. Sheet mill annealed with varying amounts of cold rolling (CR) and aging (air cooled, AC). Composition: Ni-20Cr-18Co-2.5Ti-1.5Al. UNS N07090

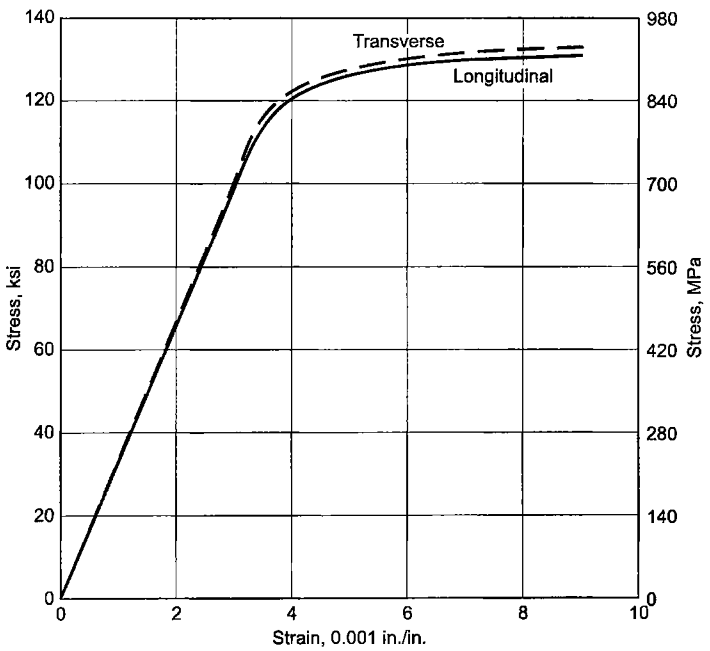
Source: J.R. Kattus, "Tensile and Creep Properties of Structural Alloys under Conditions of Rapid Heating, Rapid Loading, and Short Times at Temperatures," Southern Research Institute, for The International Nickel Co., Inc., April 1959; J.R. Kattus, "Tensile and Creep Properties of Structural Alloys under Conditions of Rapid Heating, Rapid Loading and Short Times at Temperature," Supplementary Report by Southern Research Institute, for The International Nickel Co., Inc., 5 June 1959. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4210, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 5



Ni.059 Nimonic 90 nickel alloy sheet, tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Sheet thickness = 1.778 mm (0.070 in.). Heat treatment: 954 °C (1750 °F), 0.25 h, air cooled, + 732 °C (1350 °F), 4.5 h, air cooled. Composition: Ni-20Cr-18Co-2.5Ti-1.5Al. UNS N07090

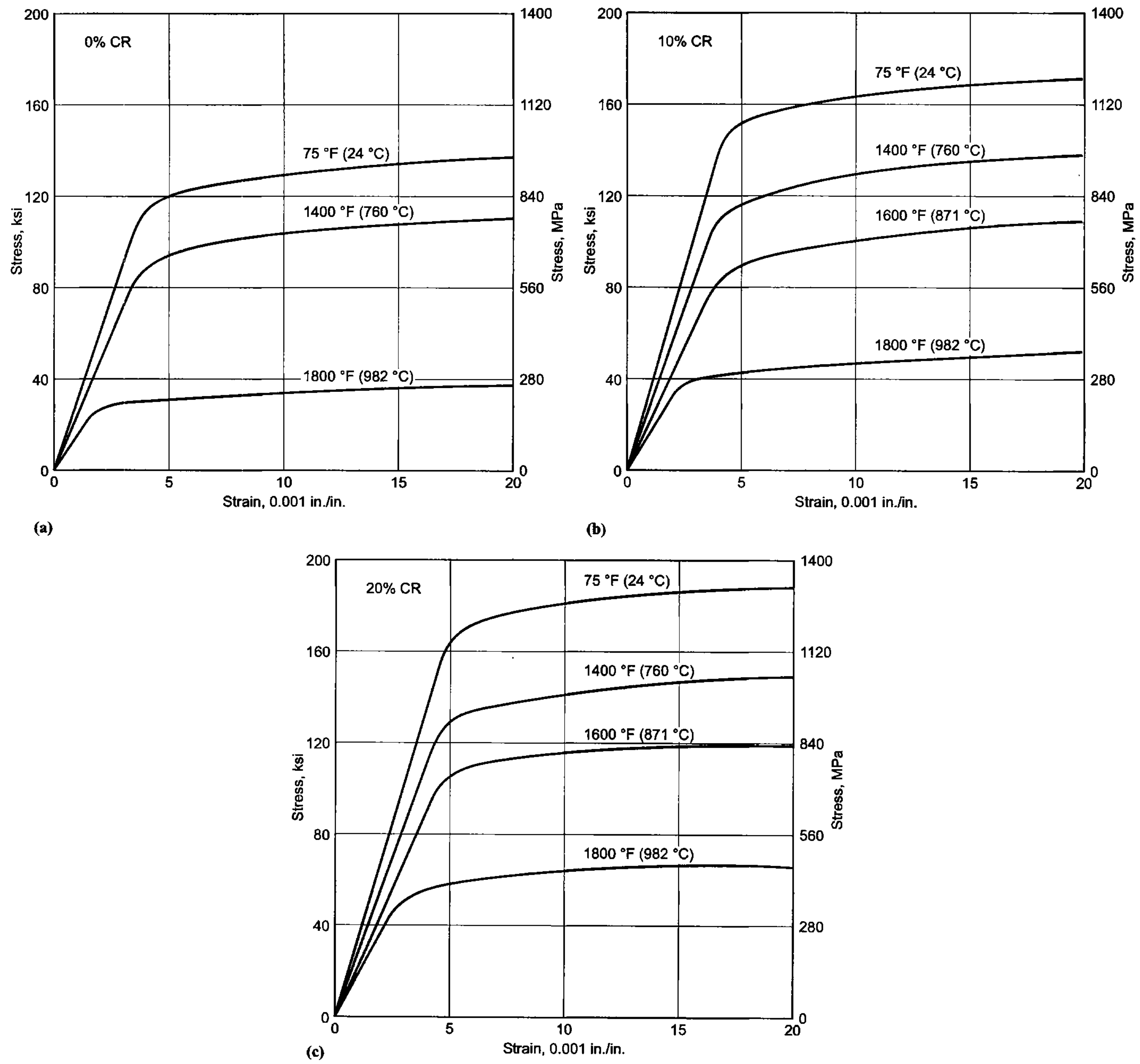
Source: D.C. Hayward, "The Mechanical Properties of Nimonic 80, 90 and 100 Sheet at Room and Elevated Temperatures," Technical Note No. Met. 266, Royal Aircraft Establishment, 1957. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4210, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 6



Ni.060 Nimonic 90 nickel alloy sheet, compressive stress-strain curves at room temperature

Test direction: longitudinal and transverse. Sheet thickness = 1.778 mm (0.070 in.). Heat treatment: 954 °C (1750 °F), 0.25 h, air cooled, + 732 °C (1350 °F), 4.5 h, air cooled. Compressive yield strength: longitudinal, 896 MPa (130 ksi); transverse, 903 MPa (131 ksi). Composition: Ni-20Cr-18Co-2.5Ti-1.5Al. UNS N07090

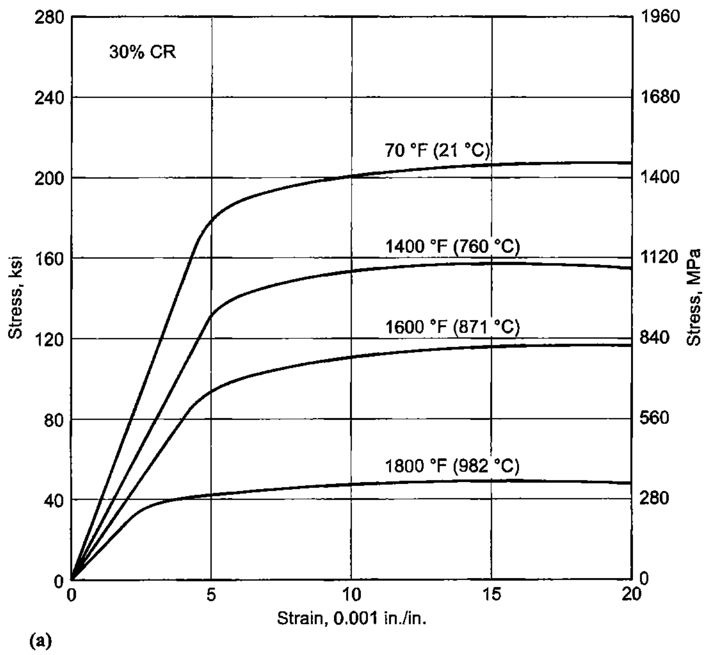
Source: D.C. Hayward, "The Mechanical Properties of Nimonic 80, 90 and 100 Sheet at Room and Elevated Temperatures," Technical Note No. Met. 266, Royal Aircraft Establishment, 1957. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4210, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 6



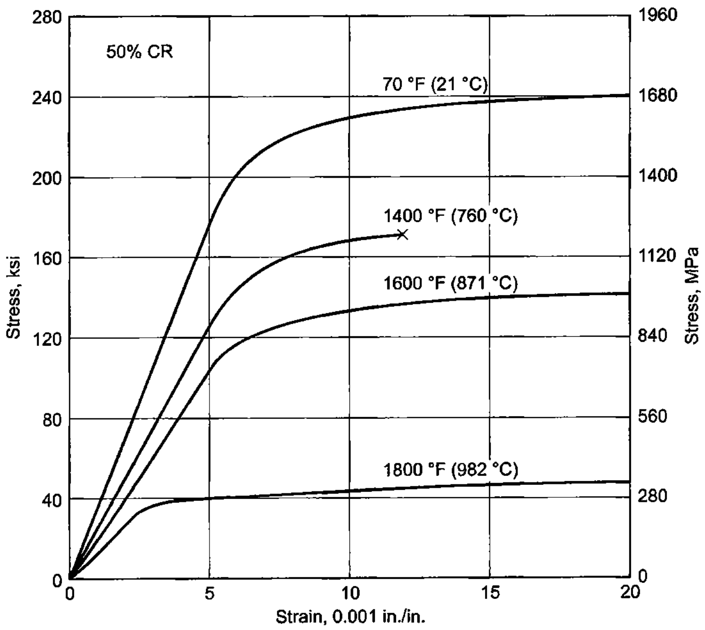
Ni.061 Nimonic 90 nickel alloy sheet, stress-strain curves at various temperatures showing effects of cold working

Test direction: longitudinal. Sheet thickness = 1.575 mm (0.062 in.). Sheet exposed to rapid heating, 10 s heat time, and rapid strain rate of 0.1/s. Treatment: mill annealed, varying amounts of cold rolling (CR); aging: 0% CR, 760 °C (1400 °F), 16 h, air cool; 10 and 20% CR, 732 °C (1350 °F), 16 h, air cooled. Composition: Ni-20Cr-18Co-2.5Ti-1.5Al. UNS N07090

Source: J.R. Kattus, "Tensile and Creep Properties of Structural Alloys under Conditions of Rapid Heating, Rapid Loading, and Short Times at Temperatures," Southern Research Institute, for The International Nickel Co., Inc., April 1959; J.R. Kattus, "Tensile and Creep Properties of Structural Alloys under Conditions of Rapid Heating, Rapid Loading and Short Times at Temperature," Supplementary Report by Southern Research Institute, for The International Nickel Co., Inc., 5 June 1959. As published in *Aerospace Structural Metals Handbook*, Vol 5, Code 4210, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 7



(a)

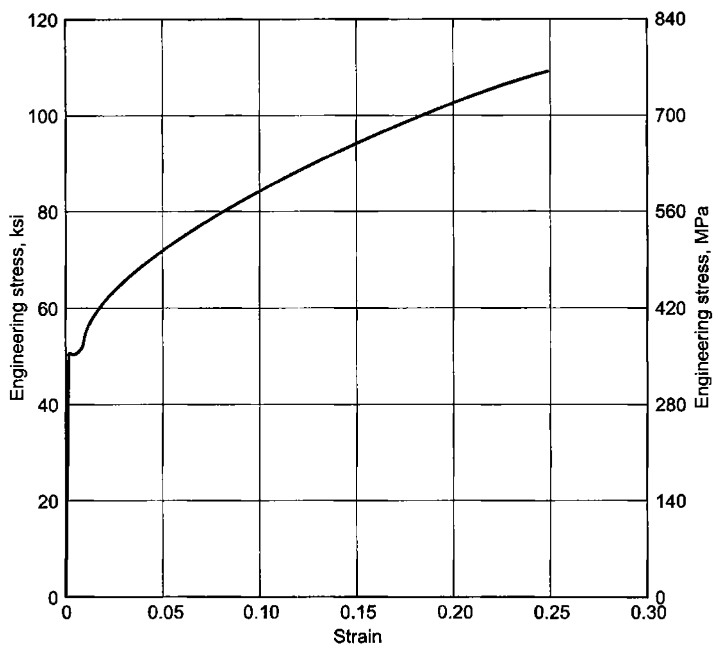


(b)

Ni.062 Nimonic 90 nickel alloy sheet, stress-strain curves at various temperatures showing effects of cold working

Test direction: longitudinal. Sheet thickness = 1.575 mm (0.062 in.). Sheet exposed to rapid heating, 10 s heat time, and rapid strain rate of 0.1/s. Treatment: mill annealed, varying amounts of cold rolling (CR); aging: 30% CR, 704 °C (1300 °F), 16 h, air cool; 50% CR, 677 °C (1250 °F), 16 h, air cooled. Composition: Ni-20Cr-18Co-2.5Ti-1.5Al. UNS N07090

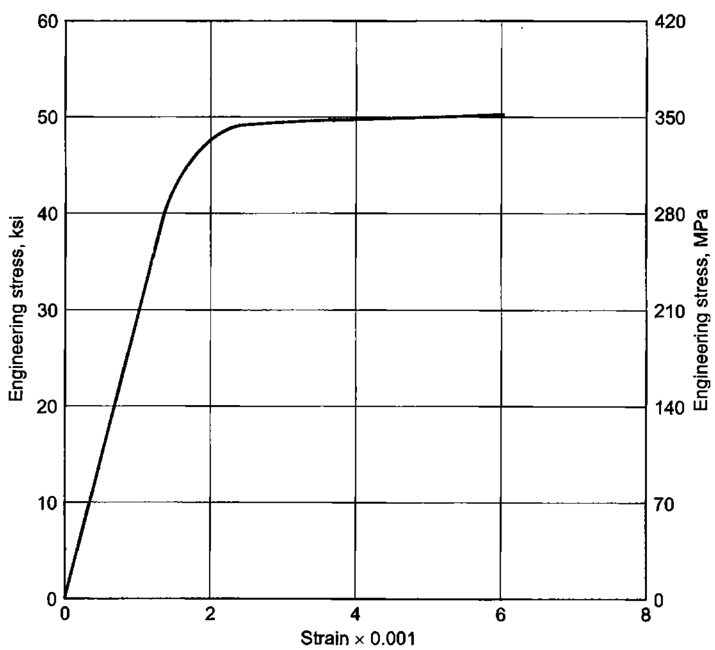
Source: J.R. Kattus, "Tensile and Creep Properties of Structural Alloys under Conditions of Rapid Heating, Rapid Loading and Short Times at Temperature," Supplementary Report by Southern Research Institute, for The International Nickel Co., Inc., 5 June 1959. As published in *Aerospace Structural Metals Handbook*, Vol 5, Code 4210, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 7



Ni.063 Nimonic 263 annealed nickel alloy sheet, engineering stress-strain curve (full range)

Test direction: longitudinal. Sheet thickness = 0.990 mm (0.039 in.). 0.2% yield strength = 345 MPa (50.0 ksi); ultimate tensile strength = 851 MPa (123.4 ksi); elongation = 54.3%. Composition: Ni-20Cr-20Co-2.15Ti. UNS N07263

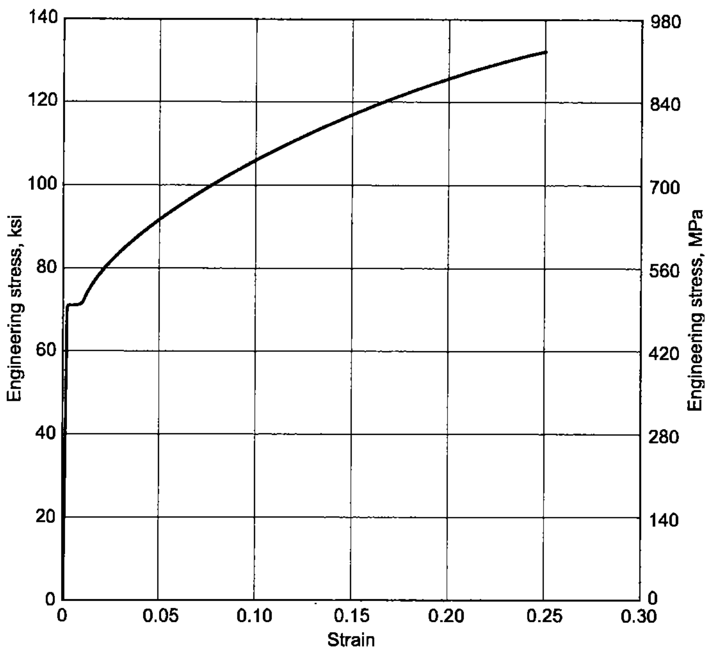
Courtesy of Special Metals Corporation



Ni.064 Nimonic 263 annealed nickel alloy sheet, engineering stress-strain curve (expanded range)

Test direction: longitudinal. Sheet thickness = 0.990 mm (0.039 in.). 0.2% yield strength = 345 MPa (50.0 ksi); ultimate tensile strength = 851 MPa (123.4 ksi); elongation = 54.3%. Composition: Ni-20Cr-20Co-2.15Ti. UNS N07263

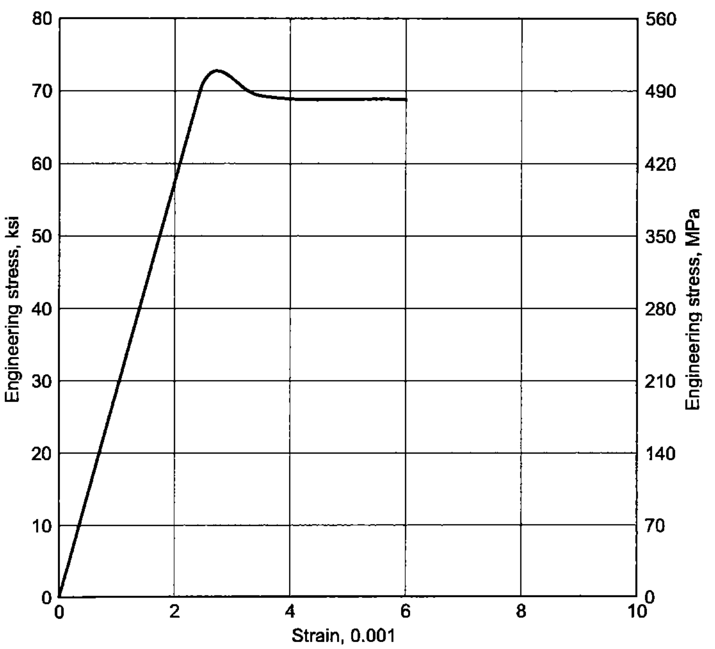
Courtesy of Special Metals Corporation



Ni.065 Inconel 625 annealed nickel alloy sheet, engineering stress-strain curve (full range)

Test direction: longitudinal. Sheet thickness = 0.940 mm (0.037 in.). 0.2% yield strength = 488 MPa (70.8 ksi); ultimate tensile strength = 963 MPa (139.6 ksi); elongation = 47.1%. Composition: 58Ni-21.5Cr-9Mo-3.65Nb-5Fe-1Co. UNS N06625

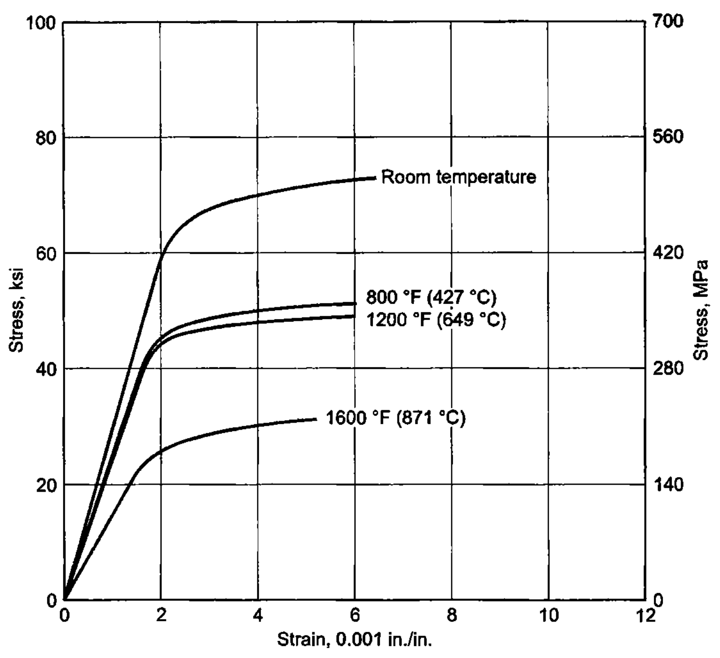
Courtesy of Special Metals Corporation



Ni.066 Inconel 625 annealed nickel alloy sheet, engineering stress-strain curve (expanded range)

Test direction: longitudinal. Sheet thickness = 0.940 mm (0.037 in.). 0.2% yield strength = 473 MPa (68.6 ksi); ultimate tensile strength = 927 MPa (134.5 ksi); elongation = 46.2%. Composition: 58Ni-21.5Cr-9Mo-3.65Nb-5Fe-1Co. UNS N06625

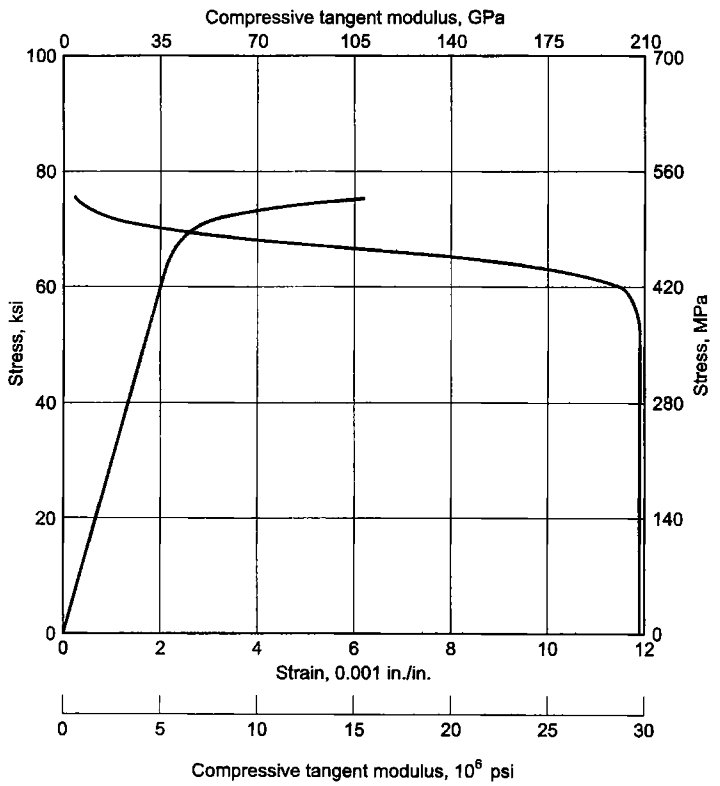
Courtesy of Special Metals Corporation



Ni.067 Inconel 625 annealed nickel alloy sheet, tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal and long transverse. Sheet thickness = 1.27–6.35 mm (0.050–0.250 in.). 0.5 h exposure to temperature. Ramberg-Osgood parameters: n(room temperature) = 23; n(800 °F) = 24; n(1200 °F) = 30; n(1600 °F) = 12. Composition: 58Ni-21.5Cr-9Mo-3.65Nb-5Fe-1Co. UNS N06625

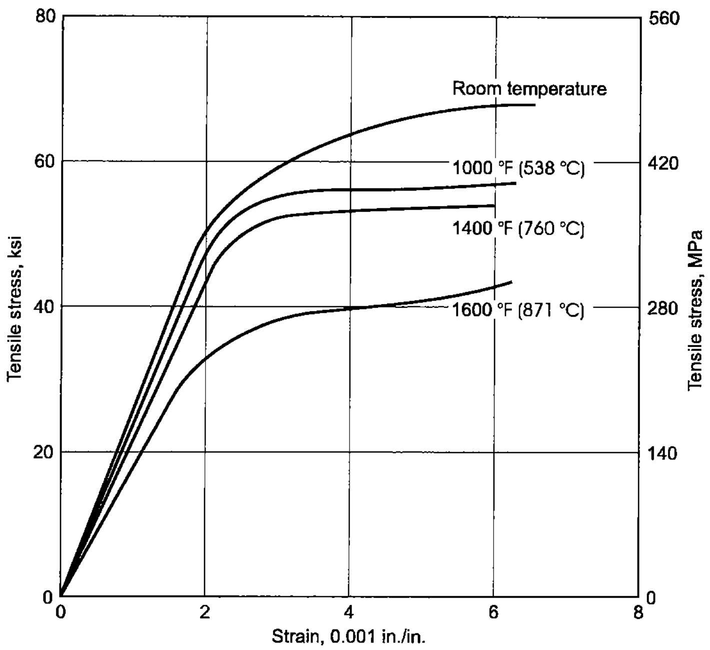
Source: *MIL-HDBK-5H*, Dec 1998, p 6–39



Ni.068 Inconel 625 annealed nickel alloy sheet, compressive stress-strain and compressive tangent modulus curves at room temperature

Test direction: longitudinal and long transverse. Sheet thickness = 1.27–6.35 mm (0.050–0.250 in.). 0.5 h exposure to temperature. Ramberg-Osgood parameter: n(room temperature) = 32. Composition: 58Ni-21.5Cr-9Mo-3.65Nb-5Fe-1Co. UNS N06625

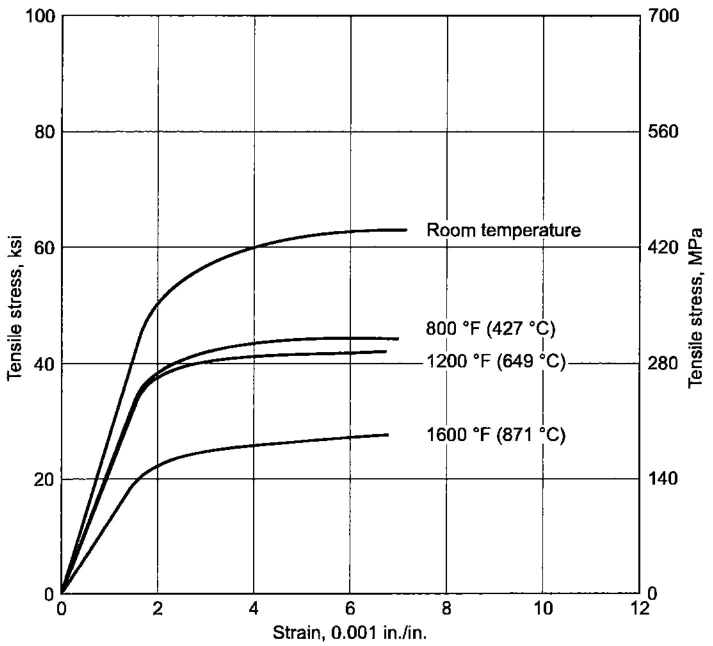
Source: *MIL-HDBK-5H*, Dec 1998, p 6–39



Ni.069 IN 625 nickel alloy sheet, tensile stress-strain curves at room and elevated temperatures

Sheet thickness = 1.575 mm (0.062 in.). Heat-resistant alloy annealed at 1038 °C (1900 °F), 5 min. Strain rate = 0.005/min to yield. Composition: 58Ni-21.5Cr-9Mo-3.65Nb-5Fe-1Co. UNS N06625

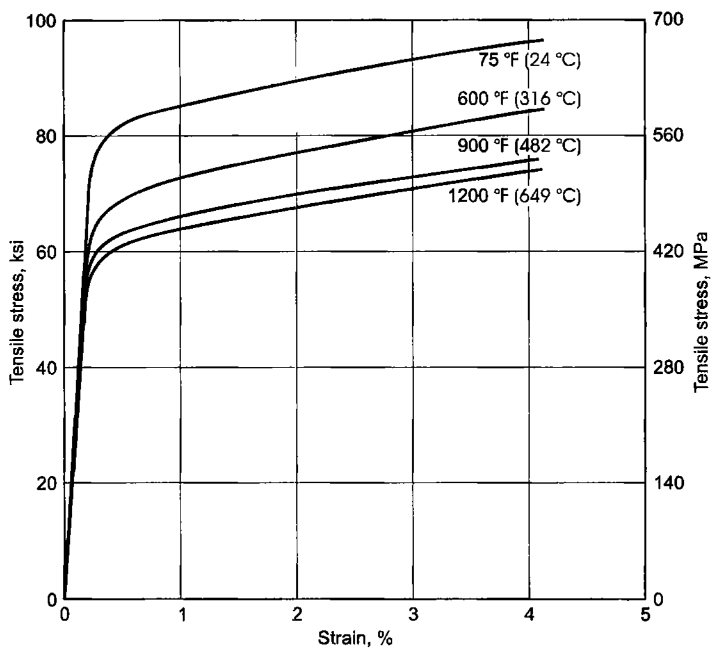
Source: J. Huebner, "Elevated Temperature Tensile Properties of Inconel 625 Nickel-Chromium Alloy," AF33(657)-7749 and BPSN: 2 (8-7381), McDonnell, 10 Jan 1963. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 4117, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 31



Ni.070 IN 625 nickel alloy sheet, tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal and transverse. Sheet thickness = 3.175 mm (0.125 in.). Heat-resistant alloy annealed at 1149 °C (2100 °F), 1 h. Composition: 58Ni-21.5Cr-9Mo-3.65Nb-5Fe-1Co. UNS N06625

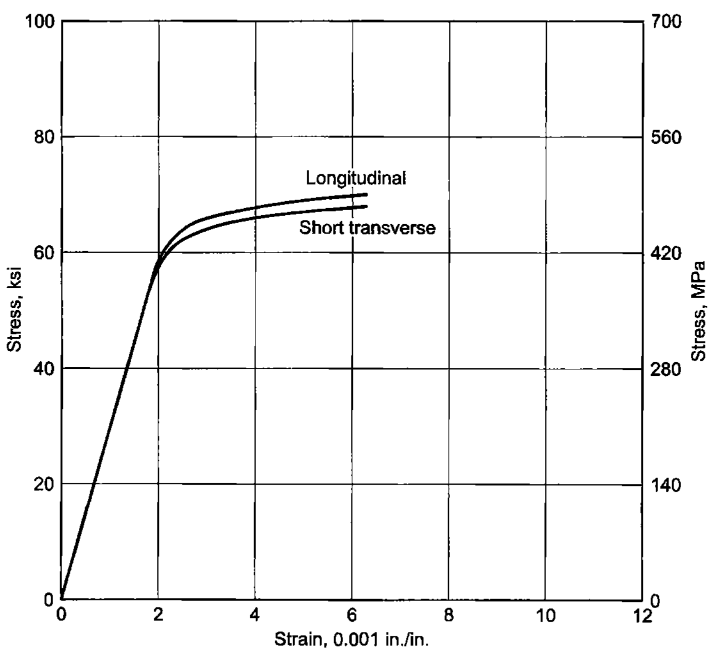
Source: "Preliminary Data Inconel Alloy 625," International Nickel Co., 1962; "Data Sheet, Inconel 625," International Nickel Co., Huntington Alloy Products Division, 1964



Ni.071 IN 625 nickel alloy plate, tensile stress-strain curves at room and elevated temperatures tested in pressurized helium

Heat treatment: annealed at 982 °C (1800 °F), 2 h, air cooled. Tested in 34.5 MPa (5000 psig) He. Composition: 58Ni-21.5Cr-9Mo-3.65Nb-5Fe-1Co. UNS N06625

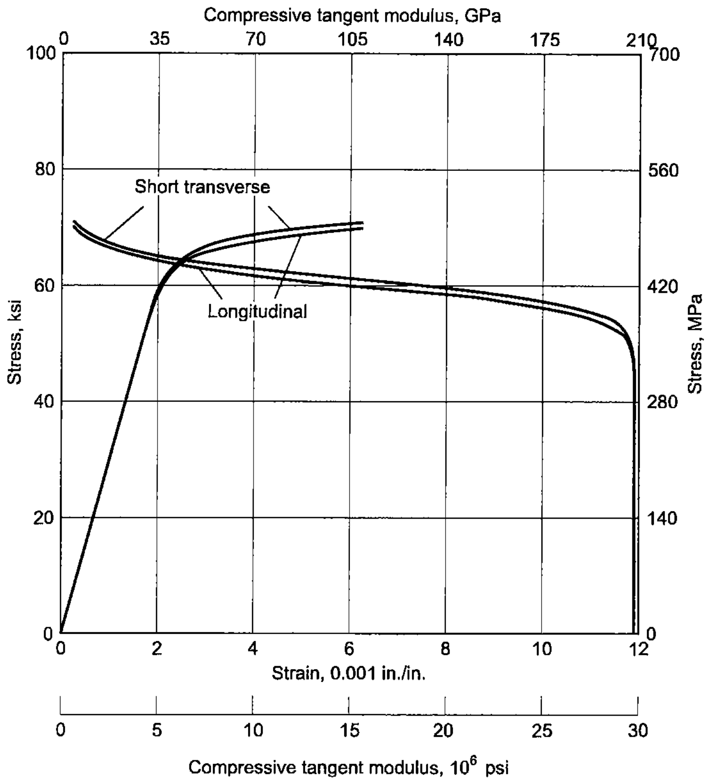
Source: "Data Sheet, Inconel 625," International Nickel Co., Huntington Alloy Products Division, 1964



Ni.072 Inconel 625 nickel alloy bar, typical tensile stress-strain curves at room temperature

Test direction: longitudinal and short transverse. Bar thickness = 12.7–101.6 mm (0.500–4.000 in.). Ramberg-Osgood parameters: n(longitudinal, tension) = 27; n(short transverse, tension) = 25. Composition: 58Ni-21.5Cr-9Mo-3.65Nb-5Fe-1Co. UNS N06625

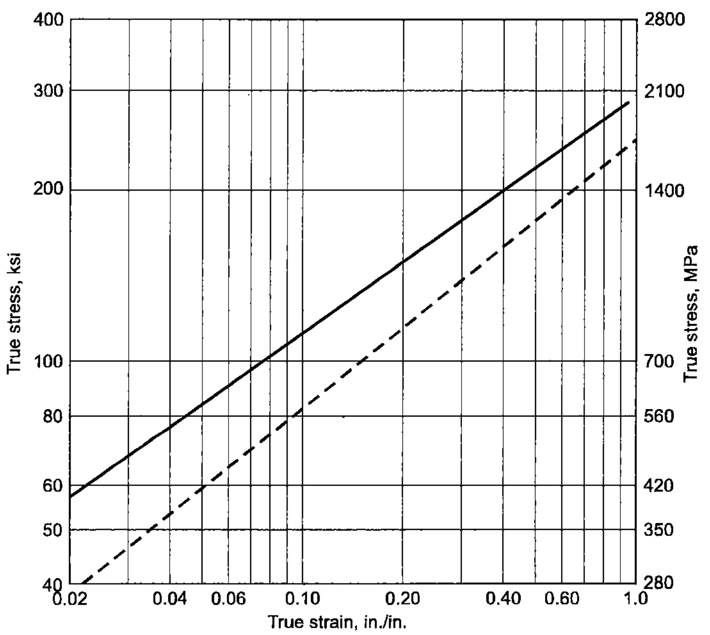
Source: *MIL-HDBK-5H,* Dec 1998, p 6–40



Ni.073 Inconel 625 nickel alloy bar, typical compressive stress-strain and compressive tangent modulus curves at room temperature

Test direction: longitudinal and short transverse. Bar thickness = 12.7–101.6 mm (0.500–4.000 in.). Ramberg-Osgood parameters: n(longitudinal, compression) = 26; n(short transverse, compression) = 27. Composition: 58Ni-21.5Cr-9Mo-3.65Nb-5Fe-1Co. UNS N06625

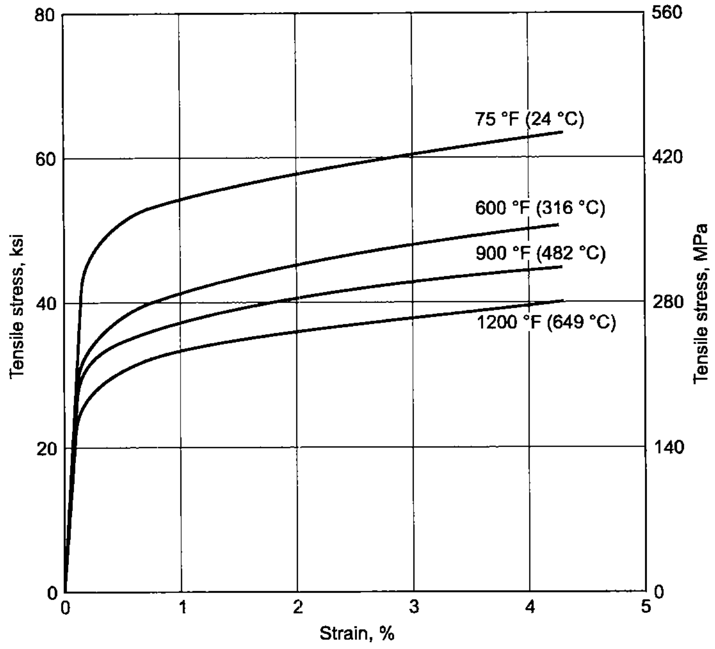
Source: *MIL-HDBK-5H,* Dec 1998, p 6–40



Ni.074 IN 625 nickel alloy rod, true stress-strain curves

Solid line for rod, cold drawn, annealed 982 °C (1800 °F), 1 h. Dashed line for rod hot rolled, annealed 1149 °C (2100 °F), 1 h. Composition: 58Ni-21.5Cr-9Mo-3.65Nb-5Fe-1Co. UNS N06625

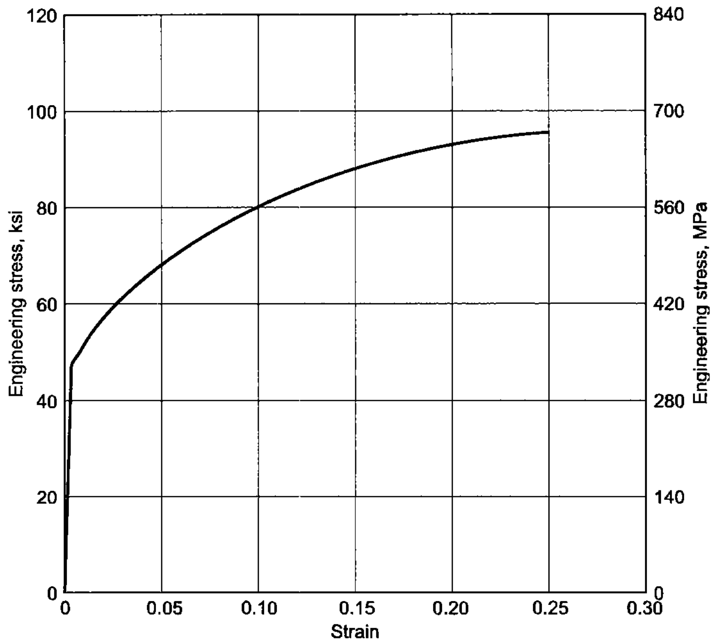
Source: "Inconel Alloy 625," International Nickel Co., Huntington Alloy Products Div., 1970. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4117, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 25



Ni.075 IN 625 cast nickel alloy, tensile stress-strain curves at room and elevated temperatures tested in pressurized helium

Heat treatment: annealed at 1149 °C (2100 °F), 2 h, force cooled. Tested in 34.5 MPa (5000 psi gage) He. Composition: 58Ni-21.5Cr-9Mo-3.65Nb-5Fe-1Co. UNS N06625

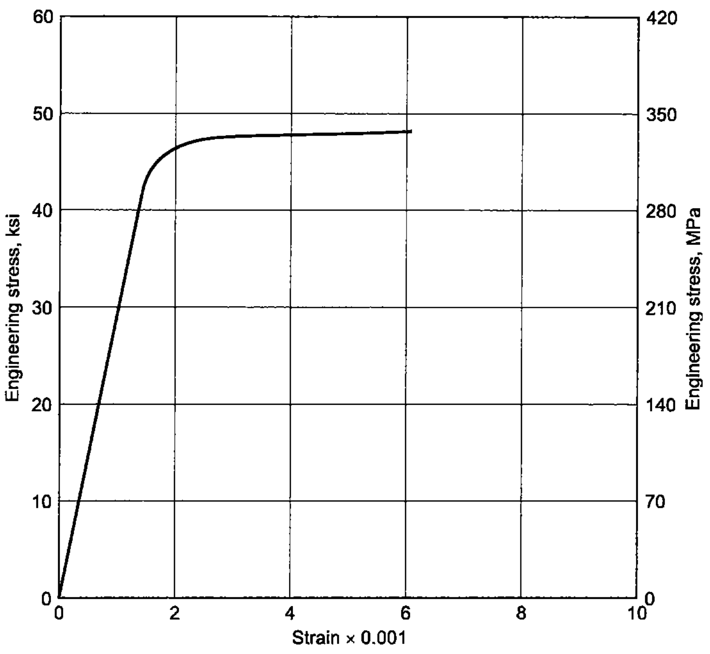
Source: J. Mucci and J.A. Harris, Jr., "Influence of Gaseous Hydrogen on the Mechanical Properties of High Temperature Alloys," NASA CR-149962, United Technologies Corp., 1976, p II-3. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 4117, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 32



Ni.076 Incoloy 800 annealed nickel alloy sheet, engineering stress-strain curve (full range)

Test direction: longitudinal. Sheet thickness = 1.193 mm (0.047 in.). 0.2% yield strength = 330 MPa (47.8 ksi); ultimate tensile strength = 665 MPa (96.5 ksi); elongation = 36.1%. Composition: 33Ni-21Cr-0.4Ti-0.4Al-bal Fe. UNS N08800

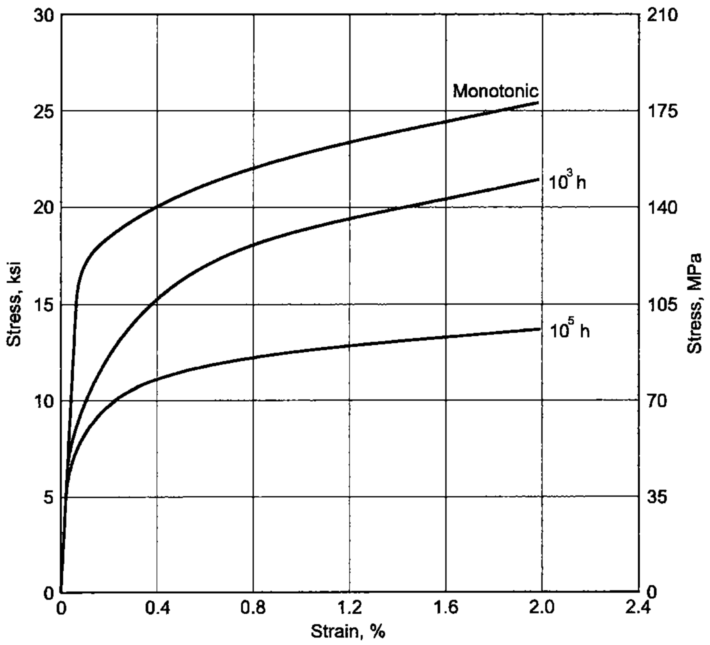
Courtesy of Special Metals Corporation



Ni.077 Incoloy 800 annealed nickel alloy sheet, engineering stress-strain curve (expanded range)

Test direction: longitudinal. Sheet thickness = 1.193 mm (0.047 in.). 0.2% yield strength = 327 MPa (47.4 ksi); ultimate tensile strength = 649 MPa (94.1 ksi); elongation = 36.7%. Composition: 33Ni-21Cr-0.4Ti-0.4Al-balFe. UNS N08800

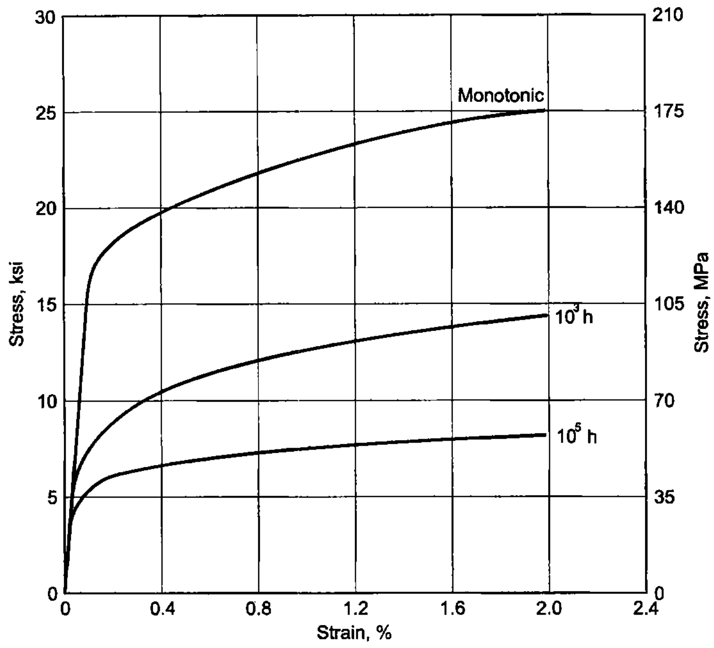
Courtesy of Special Metals Corporation



Ni.078 Incoloy 800H nickel alloy bar, isochronous stress-strain curves at 649 °C (1200 °F)

Monotonic curve from Case 1592. Other curves constructed from monotonic curve and creep data relations from M.K. Booker, V.B. Baylor, and B.L.P. Booker, "Survey of Available Creep and Tensile Data for Alloy 800H," ORNL/TM-6029, 1978. Composition: 32Ni-21Cr-0.75Mn-0.05C-bal Fe. UNS N08810

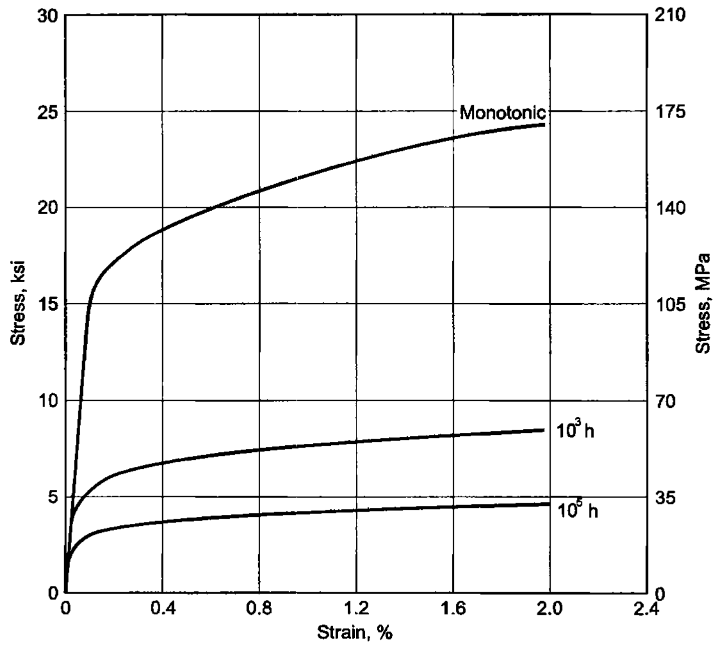
Source: ASME Boiler and Pressure Vessel Code Case 1592, Section VIII, 1977, 1, p 63. As published in *Aerospace Structural Metals Handbook*, Vol 2, Code 1615, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 11



Ni.079 Incoloy 800H nickel alloy bar, isochronous stress-strain curves at 704 °C (1300 °F)

Monotonic curve from Case 1592. Other curves constructed from monotonic curve and creep data relations from M.K. Booker, V.B. Baylor, and B.L.P. Booker, "Survey of Available Creep and Tensile Data for Alloy 800H," ORNL/TM-6029, 1978. Composition: 32Ni-21Cr-0.75Mn-0.05C-bal Fe. UNS N08810

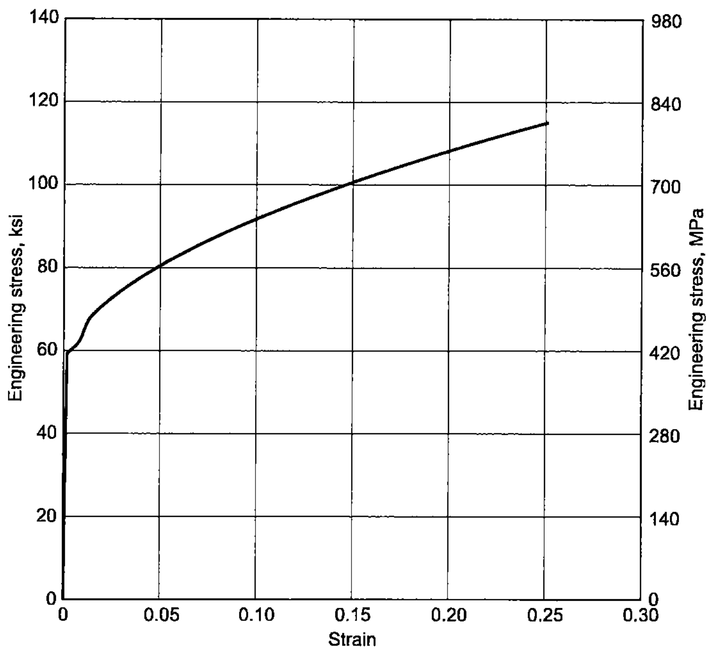
Source: ASME Boiler and Pressure Vessel Code Case 1592, Section VIII, 1977, 1, p 63. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1615, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 11



Ni.080 Incoloy 800H nickel alloy bar, isochronous stress-strain curves at 760 °C (1400 °F)

Monotonic curve from Case 1592. Other curves constructed from monotonic curve and creep data relations from M.K. Booker, V.B. Baylor, and B.L.P. Booker, "Survey of Available Creep and Tensile Data for Alloy 800H," ORNL/TM-6029, 1978. Composition: 32Ni-21Cr-0.75Mn-0.05C-bal Fe. UNS N08810

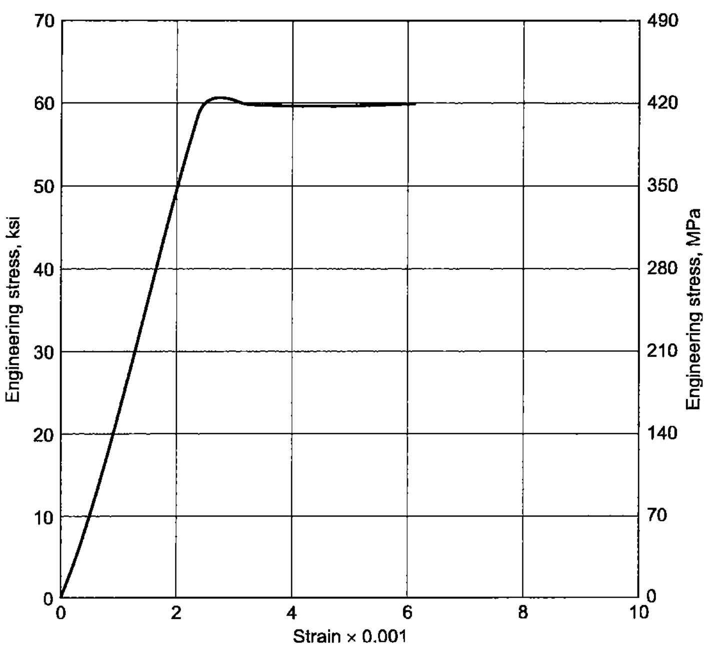
Source: ASME Boiler and Pressure Vessel Code Case 1592, Section VIII, 1977, 1, p 63. As published in *Aerospace Structural Metals Handbook,* Vol 2, Code 1615, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 11



Ni.081 Inconel 686 annealed nickel alloy sheet, engineering stress-strain curve (full range)

Test direction: longitudinal. Sheet thickness = 0.965 mm (0.038 in.). 0.2% yield strength = 419 MPa (60.8 ksi); ultimate tensile strength = 878 MPa (127.4 ksi); elongation = 56.5%. Composition: Ni-21Cr-16Mo-5 max Fe-3.7W. UNS N06686

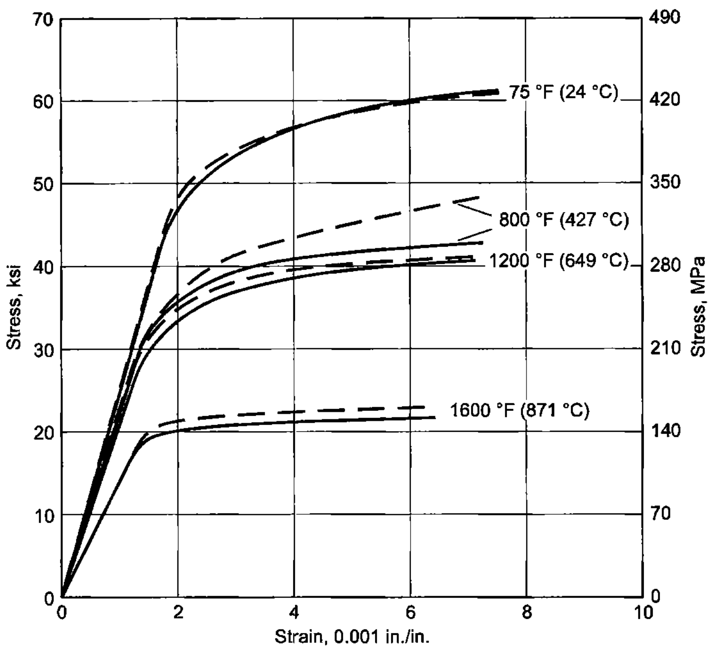
Courtesy of Special Metals Corporation



Ni.082 Inconel 686 annealed nickel alloy sheet, engineering stress-strain curve (expanded range)

Test direction: longitudinal. Sheet thickness = 0.965 mm (0.038 in.). 0.2% yield strength = 411 MPa (59.6 ksi); ultimate tensile strength = 848 MPa (123.0 ksi); elongation = 56.1%. Composition: Ni-21Cr-16Mo-5 max Fe-3.7W. UNS N06686

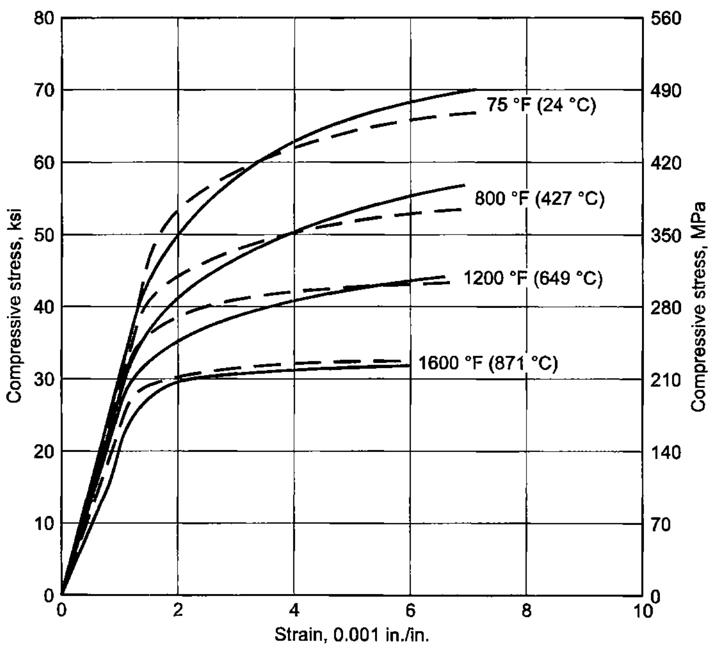
Courtesy of Special Metals Corporation



Ni.083 IN 617 nickel alloy sheet, tensile stress-strain curves at room and elevated temperatures

Sheet thickness = 1.194 mm (0.047 in.). Cold rolled and solution treated. Solid lines, longitudinal direction; dashed lines, transverse direction. Composition: Ni-22Cr-12.5Co-9Mo-1.5Fe-1.2Al. UNS N06617

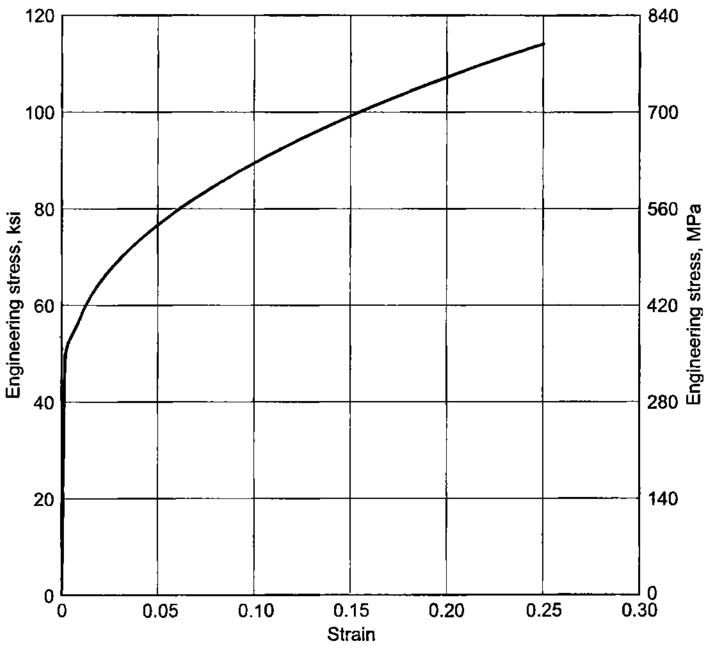
Source: O.L. Deel, "Engineering Data on New Aerospace Structural Materials," AFML-TR-75-97, Battelle-Columbus Laboratories, June 1975. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4215, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 18



Ni.084 IN 617 nickel alloy sheet, compressive stress-strain curves at room and elevated temperatures

Sheet thickness = 1.194 mm (0.047 in.). Cold rolled and solution treated. Solid lines, longitudinal direction; dashed lines, transverse direction. Composition: Ni-22Cr-12.5Co-9Mo-1.5Fe-1.2Al. UNS N06617

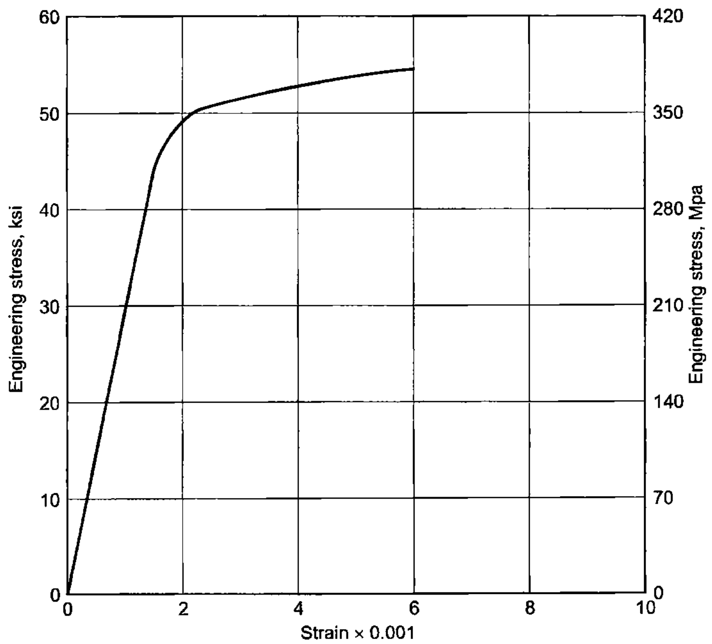
Source: O.L. Deel, "Engineering Data on New Aerospace Structural Materials," AFML-TR-75-97, Battelle-Columbus Laboratories, June 1975. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4215, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 20



Ni.085 Inconel 617 annealed nickel alloy sheet, engineering stress-strain curve (full range)

Test direction: longitudinal. Sheet thickness = 1.524 mm (0.060 in.). 0.2% yield strength = 361 MPa (52.3 ksi); ultimate tensile strength = 857 MPa (124.3 ksi); elongation = 52.8%. Composition: 44.5Ni-22Cr-13Co-9Mo-3Fe. UNS N06617

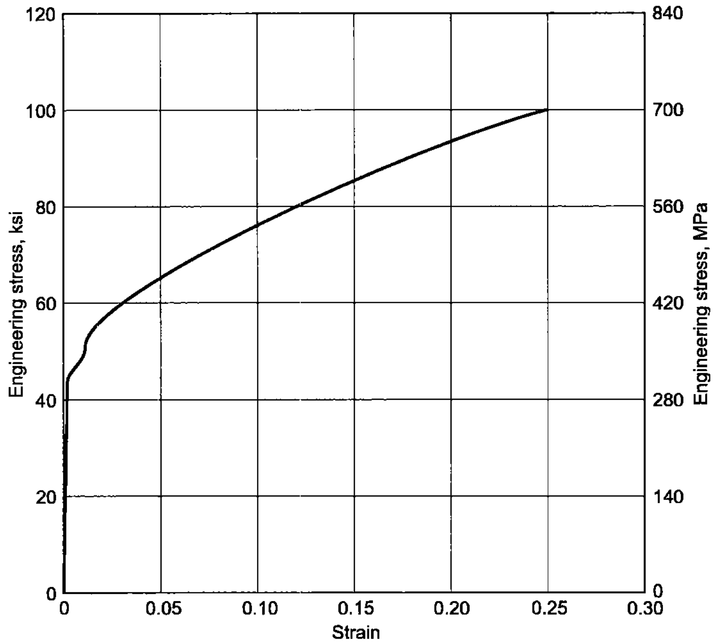
Courtesy of Special Metals Corporation



Ni.086 Inconel 617 annealed nickel alloy sheet, engineering stress-strain curve (expanded range)

Test direction: longitudinal. Sheet thickness = 1.524 mm (0.060 in.). 0.2% yield strength = 361 MPa (52.3 ksi); ultimate tensile strength = 847 MPa (122.8 ksi); elongation = 52.8%. Composition: 44.5Ni-22Cr-13Co-9Mo-3Fe. UNS N06617

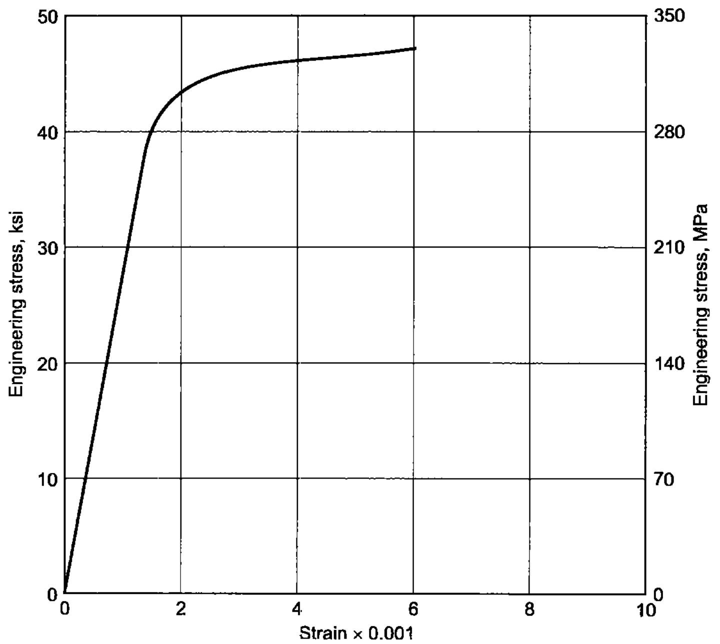
Courtesy of Special Metals Corporation



Ni.087 Inconel HX annealed nickel alloy sheet, engineering stress-strain curve (full range)

Test direction: longitudinal. Sheet thickness = 0.965 mm (0.038 in.). 0.2% yield strength = 312 MPa (45.3 ksi); ultimate tensile strength = 748 MPa (108.5 ksi); elongation = 49.8%. Composition: 47.5Ni-21.75Cr-18.5Fe-0.6W. UNS N06002

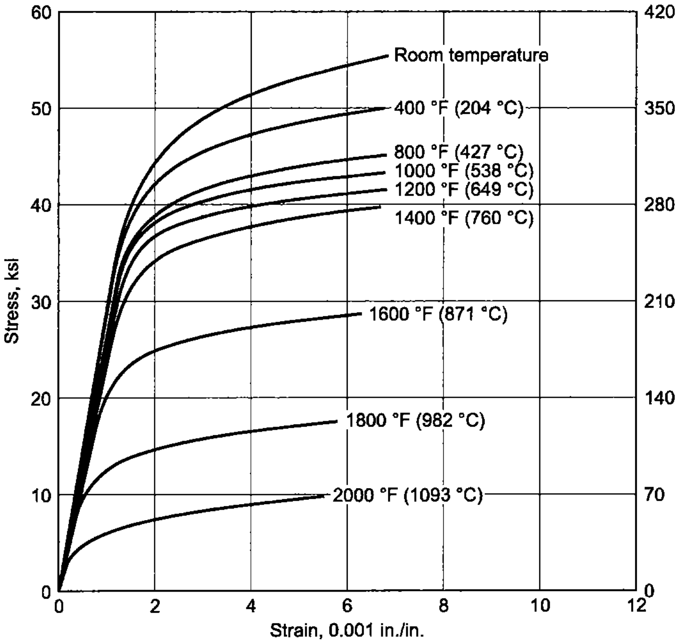
Courtesy of Special Metals Corporation



Ni.088 Inconel HX annealed nickel alloy sheet, engineering stress-strain curve (expanded range)

Test direction: longitudinal. Sheet thickness = 0.965 mm (0.038 in.). 0.2% yield strength = 316 MPa (45.8 ksi); ultimate tensile strength = 738 MPa (107.0 ksi); elongation = 51.0%. Composition: 47.5Ni-21.75Cr-18.5Fe-0.6W. UNS N06002

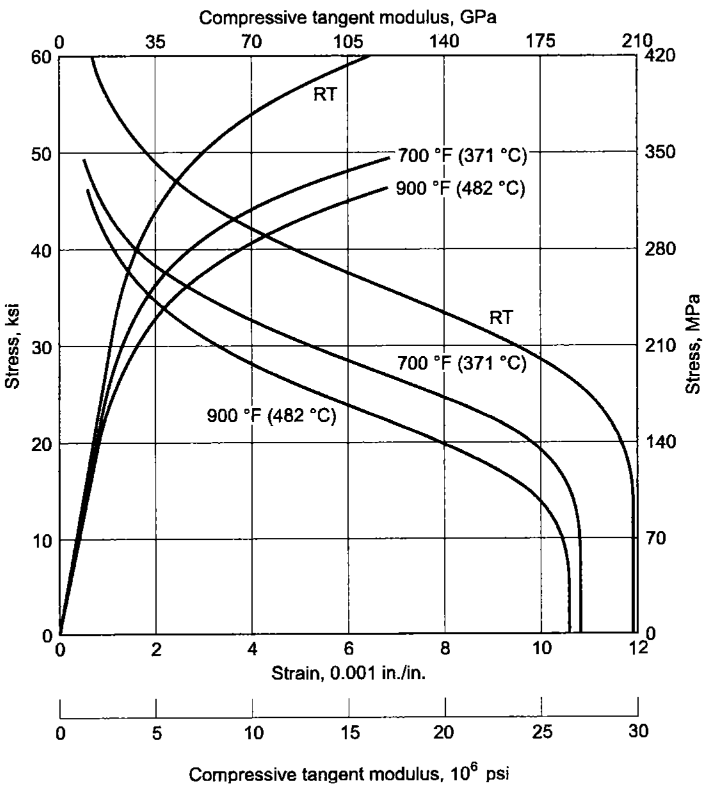
Courtesy of Special Metals Corporation



Ni.089 Hastelloy X nickel alloy sheet, typical tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal and long transverse. 0.5 h exposure to temperature. Ramberg-Osgood parameters: n(room temperature) = 10; n(400 °F) = 13; n(800 °F) = 15; n(1000 °F) = 18; n(1200 °F) = 19; n(400 °F) = 15; n(1600 °F) = 12; n(1800 °F) = 7.7; n(2000 °F) = 3.8. Composition: Ni-22Cr-18Fe-9Mo-1.5Co-0.5W. UNS N06002

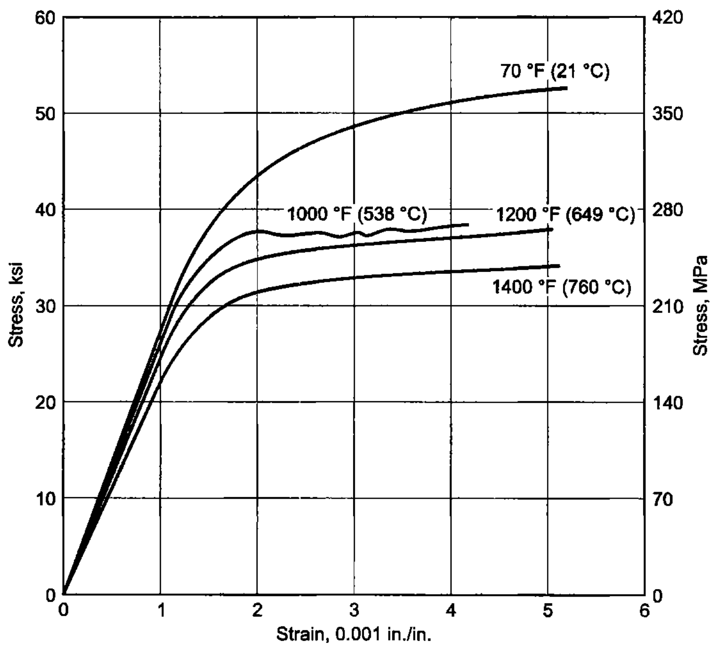
Source: *MIL-HDBK-5H,* Dec 1998, p 6–25



Ni.090 Hastelloy X nickel alloy bar, typical compressive stress-strain and compressive tangent modulus curves at room and elevated temperature

Specimens were exposed to temperature 0.5 h. RT, room temperature. Ramberg-Osgood parameters: n(RT) = 6.9; n(700 °F) = 6.7; n(900 °F) = 5.6. Heat-resistant alloy. Composition: Ni-22Cr-18Fe-9Mo-1.5Co-0.5W. UNS N06002

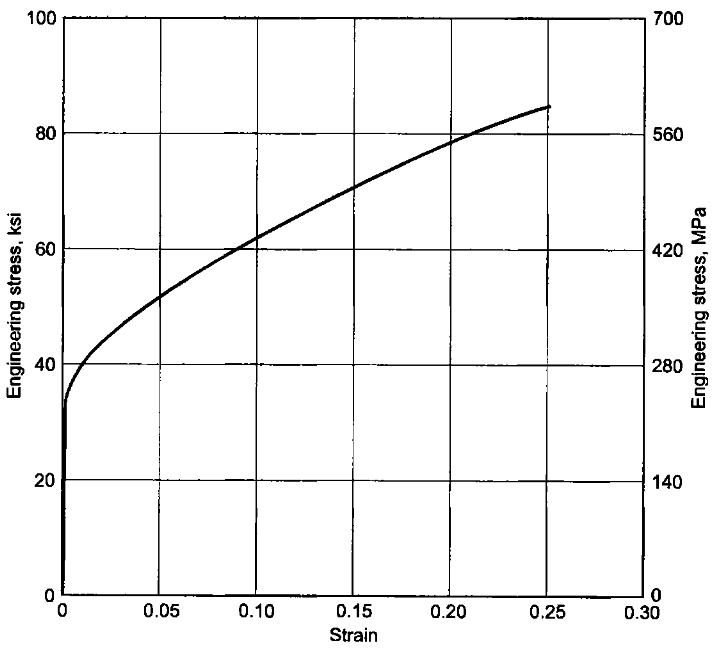
Source: *MIL-HDBK-5H,* Dec 1998, p 6–26



Ni.091 Hastelloy X solution treated nickel alloy bar, tensile stress-strain curves at room and elevated temperatures

Bar thickness: 19.05 mm (0.75 in.).
Composition: Ni-22Cr-18Fe-9Mo-1.5Co-0.5W.
UNS N06002

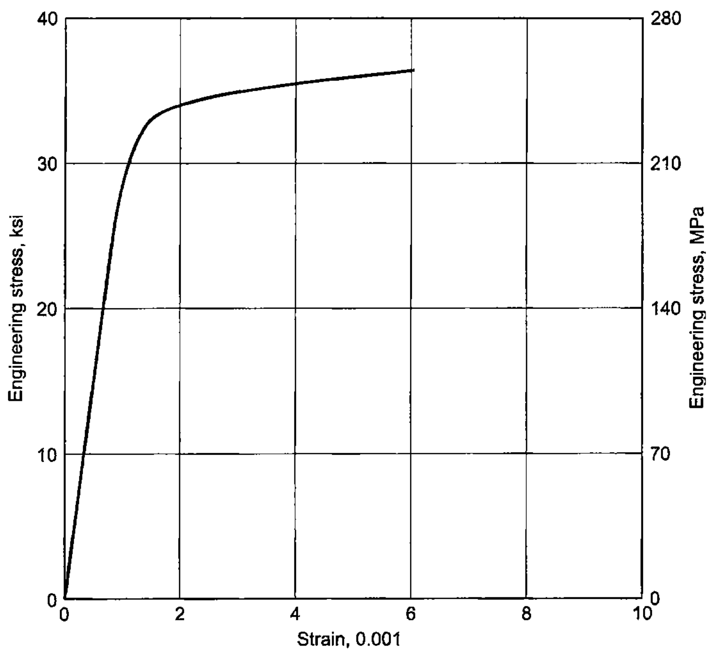
Source: C.E. Jaske et al., "Low-Cycle Fatigue of Type 347 Stainless Steel and Hastelloy Alloy X in Hydrogen Gas and in Air at Elevated Temperatures," NASA-CR-135022, May 1976. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4112, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 14



Ni.092 Inconel 601 annealed nickel alloy sheet, engineering stress-strain curve (full range)

Test direction: longitudinal. Sheet thickness = 1.27 mm (0.050 in.). 0.2% yield strength = 239 MPa (34.6 ksi); ultimate tensile strength = 657 MPa (95.3 ksi); elongation = 48.2%. Composition: 60.5Ni-23 Cr-bal Fe.
UNS N06601

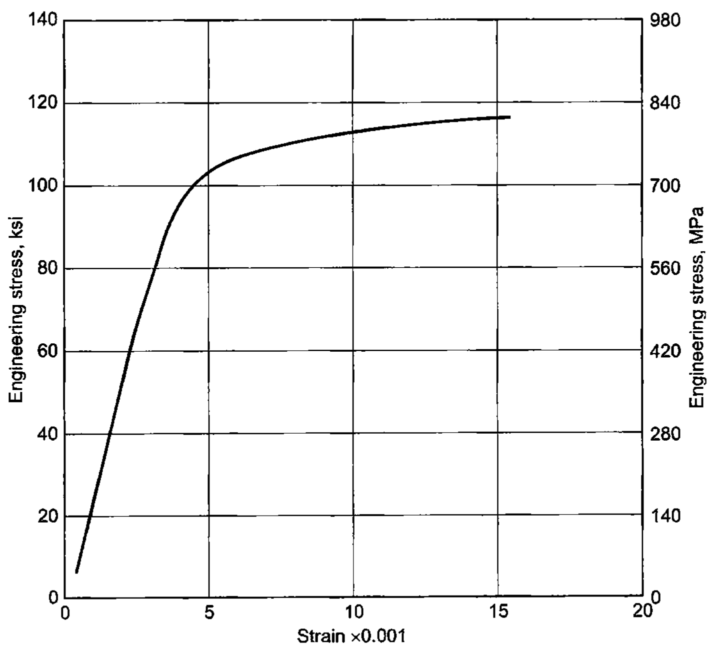
Courtesy of Special Metals Corporation



Ni.093 Inconel 601 annealed nickel alloy sheet, engineering stress-strain curve (expanded range)

Test direction: longitudinal. Sheet thickness = 1.27 mm (0.050 in.). 0.2% yield strength = 243 MPa (35.2 ksi); ultimate tensile strength = 652 MPa (94.6 ksi); elongation = 47.7%. Composition: 60.5Ni-23 Cr-bal Fe. UNS N06601

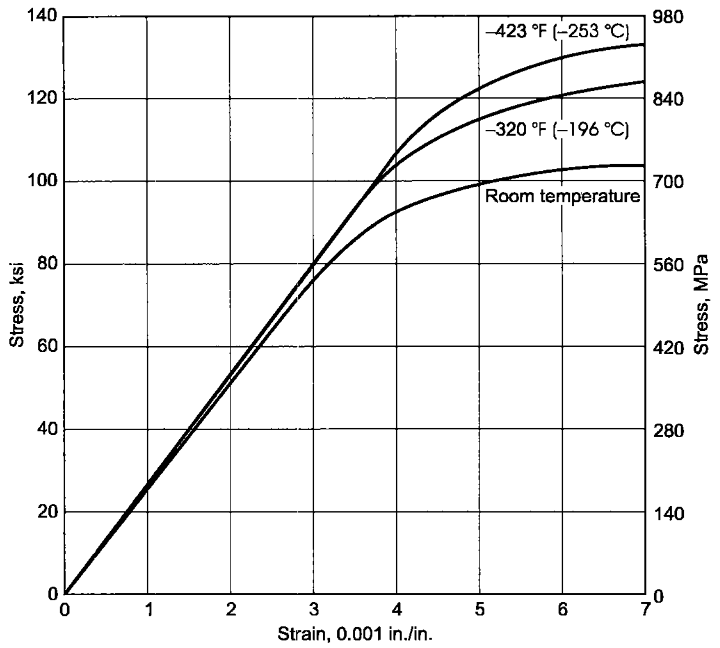
Courtesy of Special Metals Corporation



Ni.094 Monel K-500 age-hardened nickel alloy 36 mm (1.4 in.) diam rod, engineering stress-strain curve

Test direction: longitudinal. 0.2% yield strength = 740 MPa (107.3 ksi), ultimate tensile strength = 1118 MPa (162.2 ksi); elongation = 25.6%; reduction in area = 46%; modulus of elasticity = 179 GPa (26.0 × 10^6 psi). Composition: 66Ni-29Cu-3Al-0.5Ti. UNS N05500

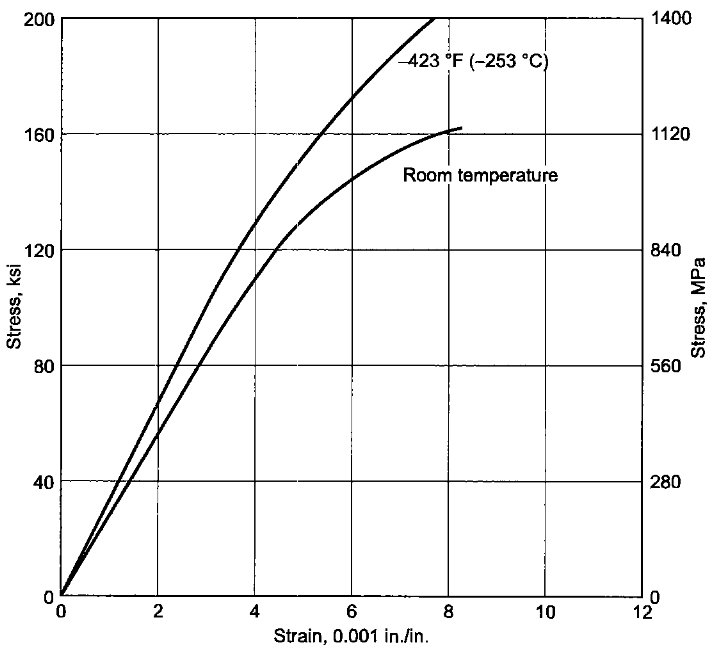
Courtesy of Special Metals Corporation



Ni.095 Monel K-500 annealed and aged nickel alloy sheet, tensile stress-strain curves at room and low temperatures

Sheet thickness = 1.27 mm (0.050 in.).
Composition: 66Ni-29Cu-3Al-0.5Ti. UNS N05500

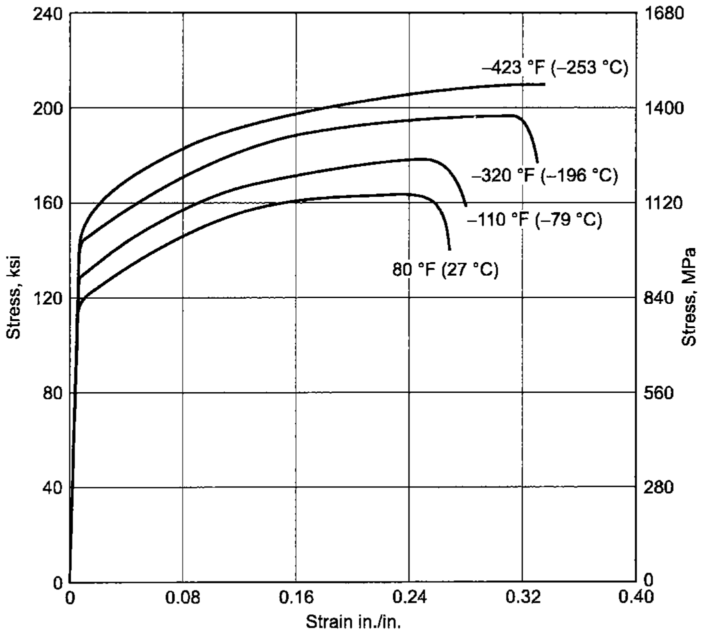
Source: E.H. Schmidt, "Fatigue Properties of Sheet, Bar and Cast Metallic Materials for Cryogenic Applications," Report No. R-7564, Rocketdyne, 30 Aug 1968, p K-9; See Also NASA Tech. Brief 70-10199. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 4116, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 17



Ni.096 Monel K-500 age-hardened nickel alloy, cold-rolled product, tensile stress-strain curves at room and low temperature

Composition: 66Ni-29Cu-3Al-0.5Ti. UNS N05500

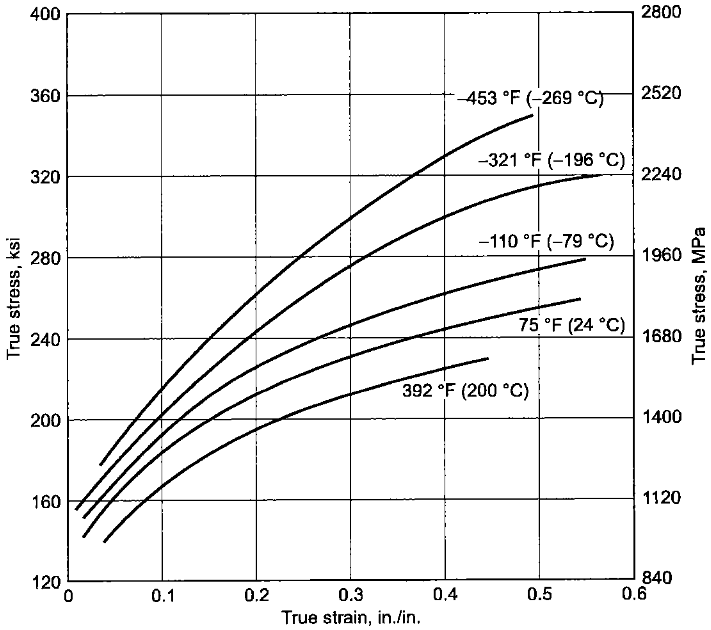
Source: D.N. Gideon, R.J. Favor, A. Koppenhafer, H.J. Grovern, and G.M. McClure, "Investigation of Notch Fatigue Behavior of Certain Alloys in the Temperature Range of Room Temperature to −423F)," ASD-TDR-62-351, Aug 1962, p 13. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 4116, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 17



Ni.097 Monel K-500 nickel alloy bar, tensile stress-strain curves at room and low temperatures

Bar specimen (3.658 mm, or 0.144 in., diam) taken from 19.05 mm (0.75 in.) diam bar aged at 593 °C (1100 °F), 21 h, + 538 °C (1000 °F), 8 h, air cooled. Composition: 66Ni-29Cu-3Al-0.5Ti. UNS N05500

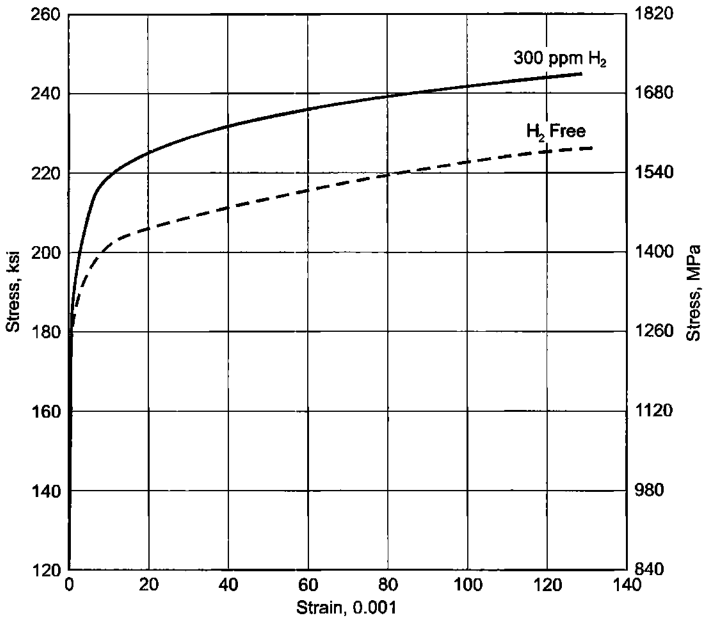
Source: K.A. Warren and R.P. Reed, *Tensile and Impact Properties of Selected Materials from 20 to 300K,* Monograph 63, National Bureau of Standards, 28 June 1963. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4116, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 18



Ni.098 Monel K-500 cold drawn and aged nickel alloy bar, true stress-strain curves at various temperatures

Bar diameter = 6.35 mm (0.25 in.). Specimen gage length = 31.75 mm (1.25 in.). Composition: 66Ni-29Cu-3Al-0.5Ti. UNS N05500

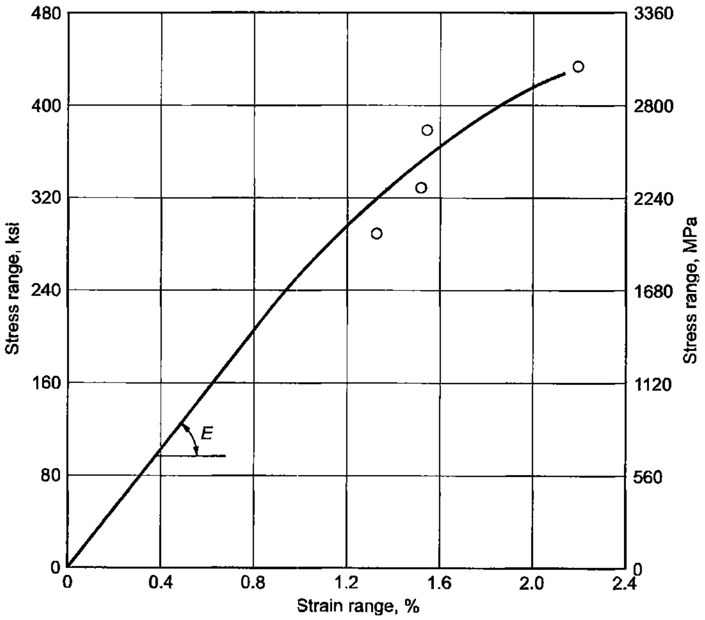
Source: E.B. Kula and T.S. DeSisto, "Plastic Behavior of Metals at Cryogenic Temperatures," Technical Report AMRA TR 65-32, Materials Engineering Division, U.S. Army Materials Research Agency, p 3. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4116, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 18



Ni.099 Monel K-500 nickel alloy wire, stress-strain curves at –196 °C (–321 °F) for hydrogen-free and hydrogenated wire

Wire diameter = 0.711 mm (0.028 in.). Treatment: 527 °C (980 °F), 8 h, + slow cooled (8.3–13.9 °C/h, or 15–25 F/h) to 482 °C (900 °F), ultimate strength = ~1275 MPa (~185 ksi), cathodically charged for 96 h at 0.16 amps/cm^2 (1 amp/in.^{2}) in 80 °C (176 °F) electrolyte of 4% sulfuric acid poisoned with sodium arsenate to saturation and baked 488 °C (910 °F), 4 min, water quenched. Strain rate = 2.2 × 10^{-4}/s. Composition: 66Ni-29Cu-3Al-0.5Ti. UNS N05500

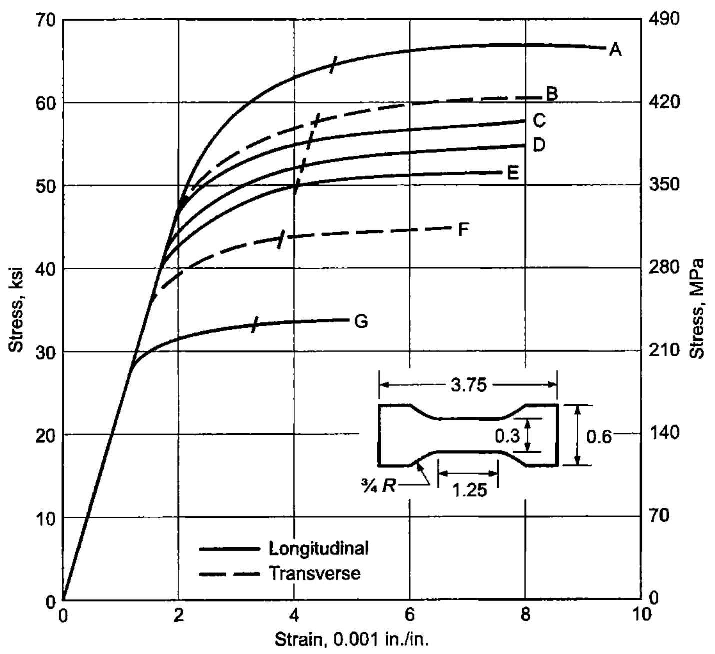
Source: W.M. Cain, C.C. Koch, J.L. Mihelich, and A.R. Troiano, "Solute Induced Embrittlement in Steel and Several Face-Centered Cubic Alloys," Report ARL 64-101, Aerospace Research Laboratories, June 1964, p 40. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 4116, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 18



Ni.100 Monel K-500 nickel alloy plate, cyclic stress-strain curve

Plate thickness = 25.4 mm (1 in.). Specimen heat treated to ultimate strength, 1172 MPa (170 ksi); yield strength, 862 MPa (125 ksi); elongation in 2 in., 24%; reduction in area, 36%. Data points from low-cycle fatigue (LCF) tests. Curve generated from LCF and modulus of elasticity (E = 1796 GPa, or 26 × 10^6 psi). Composition: 66Ni-29Cu-3Al-0.5Ti. UNS N05500

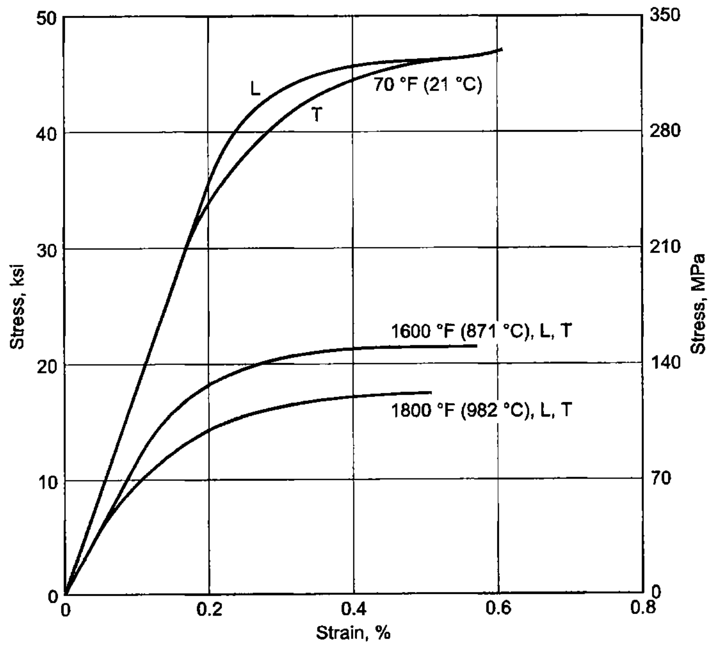
Source: M.R. Gross, "Low-Cycle Fatigue of Materials for Submarine Construction," NAVENGRXSTA Report 91 197D, 14 Feb 1963, p A-7. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 4116, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 27



Ni.101 TD nickel alloy sheet, tensile stress-strain curves at room temperature

Sheet thickness = 0.635–1.27 mm (0.025–0.050 in.). Specimen tested in longitudinal or transverse directions after various conditioning: A and B, as received; C and D, preoxidized, 1316 °C (2400 °F), 24 h; E, F, G calorized; E, unexposed; F, 1204 °C (2200 °F), 192 h; G, 1316 °C (2400 °F), 88 h. Composition: Ni-$2ThO_2$. Dimensions in inset given in inches (1 in. = 25.4 mm)

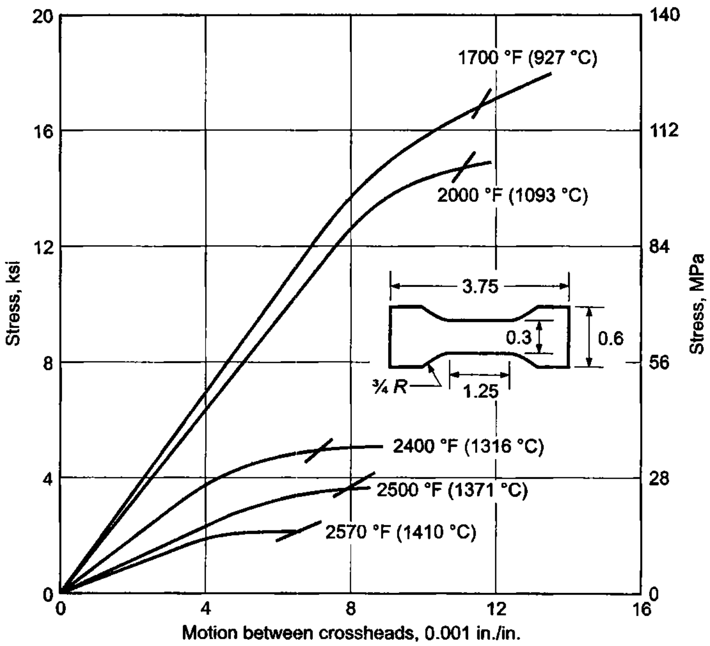
Source: C.R. Manning, Jr. et al., "An Investigation of a New Nickel Alloy Strengthened by Dispersed Thoria," NASA Technical Note D-1944, 1963. Calorized data from R.M. Burns and W.W. Bradley, *Protective Coatings for Metals,* Rhinehold Publishing, 1955. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4115, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 9



Ni.102 TD nickel alloy sheet, tensile stress-strain curves at room and elevated temperatures

Sheet was stress relieved and tested in longitudinal (L) and transverse (T) directions. Composition: Ni-$2ThO_2$

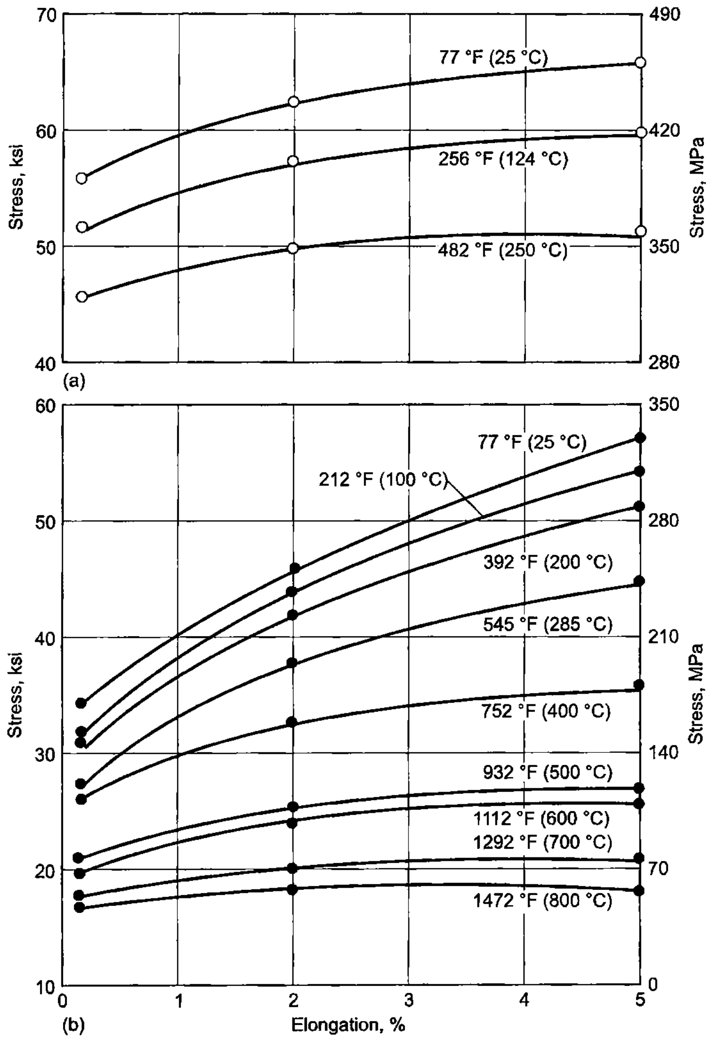
Source: O.L. Deel and W.S. Hyler, "Engineering Data on Newly Developed Structural Materials," AFML-TR-67-418, April 1968, p 54. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4115, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 11



Ni.103 TD nickel alloy sheet, tensile stress-extension curves at elevated temperatures

Sheet thickness = 0.635–1.27 mm (0.025–0.050 in.). Composition: Ni-$2ThO_2$. Dimensions in inset given in inches (1 in. = 25.4 mm)

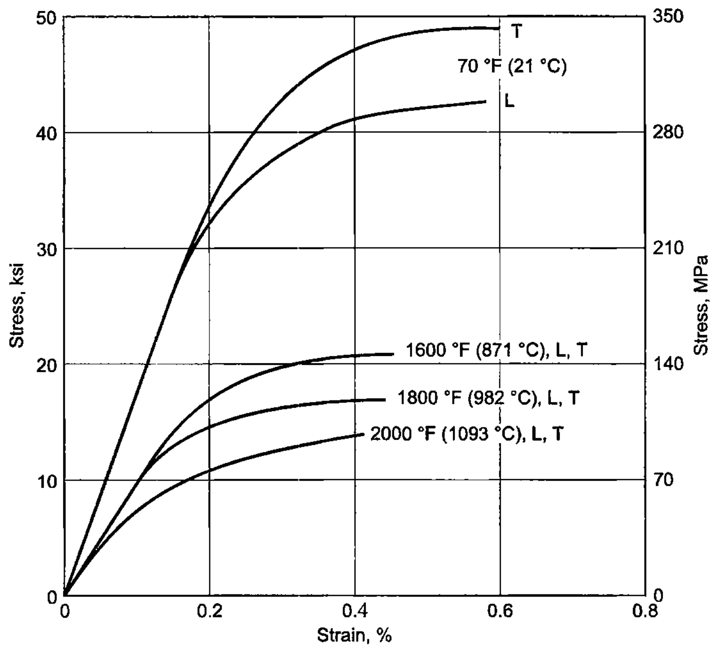
Source: C.R. Manning, Jr. et al., "An Investigation of a New Nickel Alloy Strengthened by Dispersed Thoria," NASA Technical Note D-1944, 1963. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4115, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 11



Ni.104 TD nickel alloy bar (a) and sheet (b), stress-strain curves at room and elevated temperatures

Bar 12.7 mm (0.5 in.) diam, as received. Recrystallized sheet 0.508 mm (0.020 in.) thick, 1300 °C (2372 °F), 3 h. Tested at strain rate of 0.000167/s. Composition: $Ni\text{-}2ThO_2$

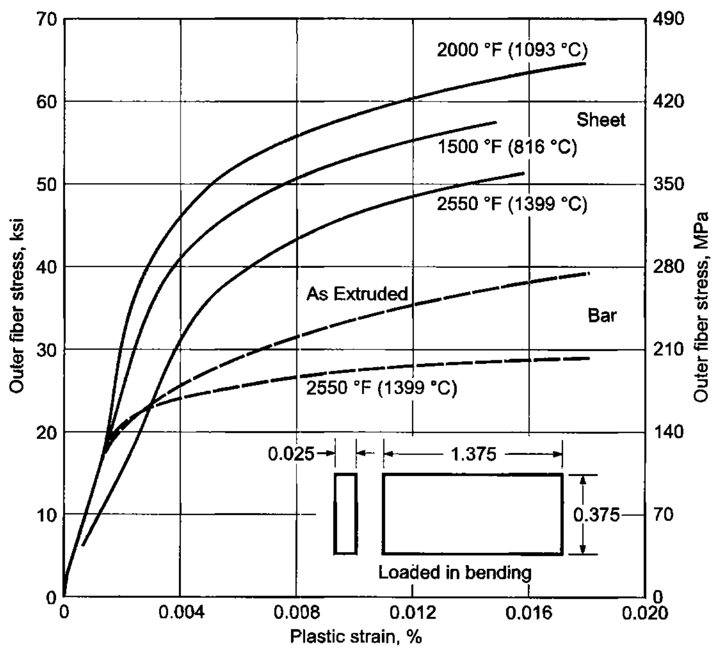
Source: B.A. Wilcox and A.H. Clauer, "High Temperature Deformation of Dispersion Strengthened Nickel Alloys," NASA CR-72367, 29 Feb 1968, p 11. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 4115, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 11



Ni.105 TD nickel alloy sheet, compressive stress-strain curves at room and elevated temperatures

Stress relieved and tested in longitudinal (L) and transverse (T) directions. Composition: Ni-$2ThO_2$

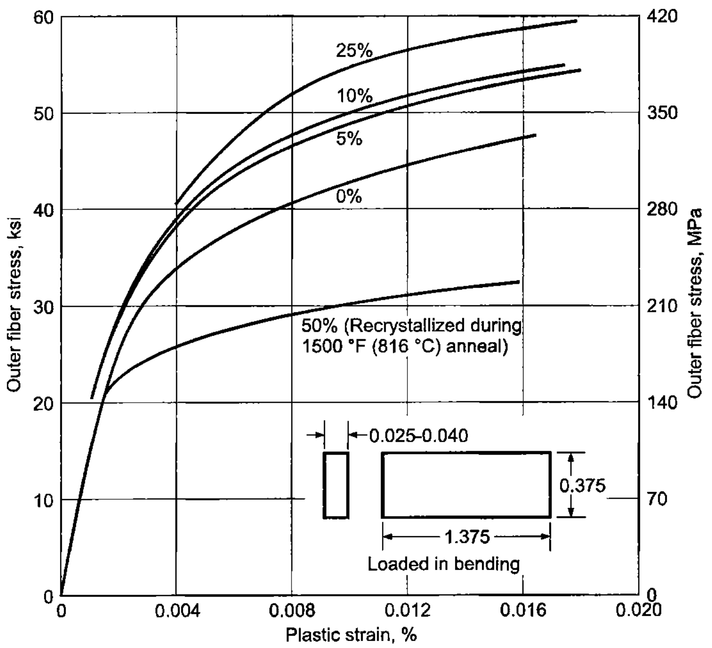
Source: O.L. Deel and W.S. Hyler, "Engineering Data on Newly Developed Structural Materials," AFML-TR-67-418, April 1968, p 54. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4115, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 17



Ni.106 TD nickel alloy sheet and bar, stress-plastic strain curves in bending with effect of vacuum annealing at various temperatures

0.635 mm (0.025 in.) sheet (solid curve) and machined bar (dashed curve) vacuum annealed at temperature indicated for 1 h. Composition: Ni-$2ThO_2$. Dimensions in inset given in inches (1 in. = 25.4 mm)

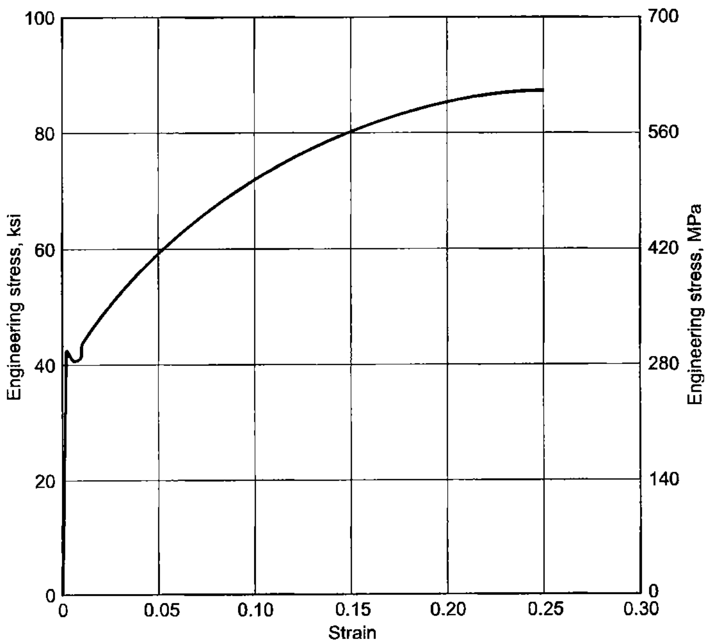
Source: J.E. White and R.D. Carnahan, A Microplasticity Study of Dispersion Strengthening in TD Nickel, *AIME Trans.*, Vol 230, Oct 1964, p 1300. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4115, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 10



Ni.107 TD nickel alloy bar, stress-plastic strain curves in bending with effect of cold rolling followed by vacuum annealing

Bar extruded at 1204 °C (2200 °F). Reduced by rolling at percentage indicated then vacuum annealed 816 °C (1500 °F), 1 h. Composition: Ni-2ThO_2. Dimensions in inset given in inches (1 in. = 25.4 mm)

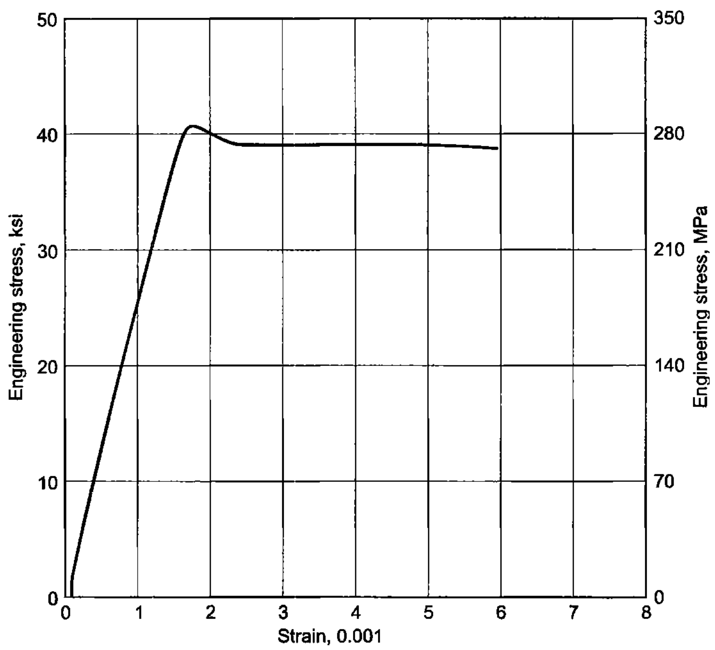
Source: J.E. White and R.D. Carnahan, A Microplasticity Study of Dispersion Strengthening in TD Nickel, *AIME Trans.*, Vol 230, Oct 1964, p 1302. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 4115, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 10



Ni.108 Monel 400 annealed nickel alloy sheet, engineering stress-strain curve (full range)

Test direction: longitudinal. Sheet thickness = 0.432 mm (0.017 in.). 0.2% yield strength = 281 MPa (40.8 ksi); ultimate tensile strength = 612 MPa (88.7 ksi); elongation = 38.0%; strength coefficient (K) = 196.4; strain-hardening exponent (n) = 0.385. Composition: 63Ni-30Cu-2.5Fe. UNS N04400

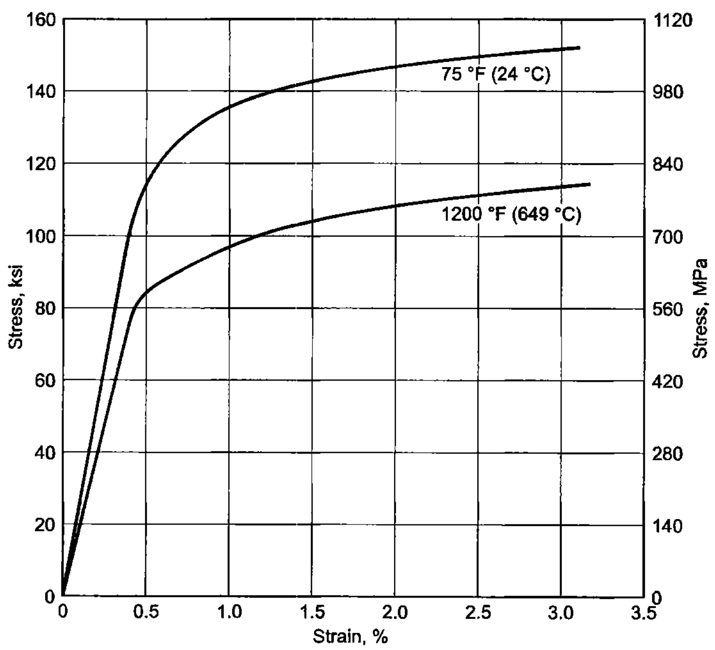
Courtesy of Special Metals Corporation



Ni.109 Monel 400 annealed nickel alloy sheet, engineering stress-strain curve (expanded range)

Test direction: longitudinal. Sheet thickness = 0.432 mm (0.017 in.). 0.2% yield strength = 268 MPa (38.9 ksi); ultimate tensile strength = 563 MPa (81.7 ksi); elongation = 38.0%. Composition: 63Ni-30Cu-2.5Fe. UNS N04400

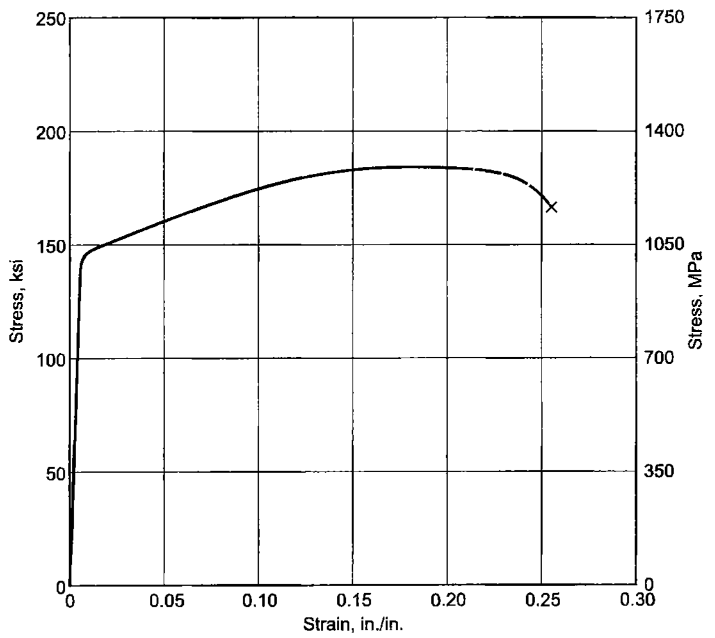
Courtesy of Special Metals Corporation



Ni.110 Incoloy 901 solution treated and aged nickel alloy bar, stress-strain curves at room and elevated temperature

Composition: Ni-35Fe-13Cr-6Mo-2.5Ti. UNS N09901

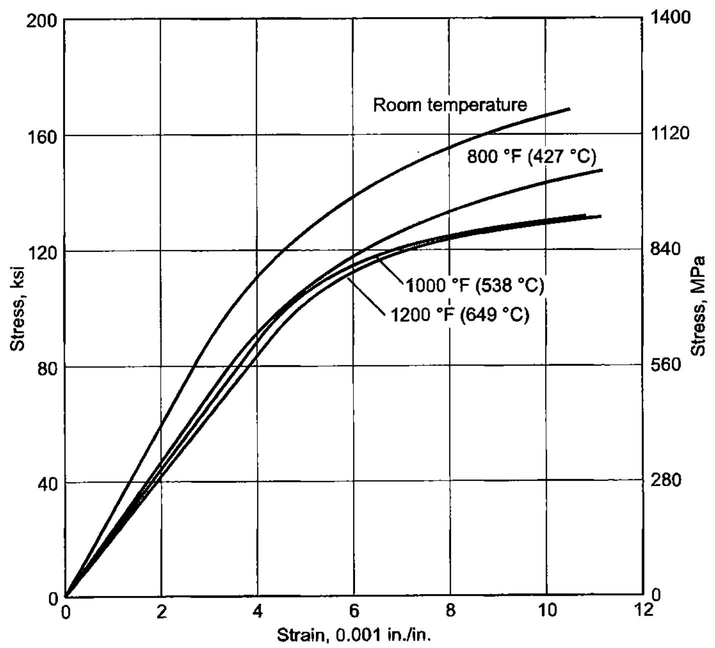
Source: DMIC Data Sheet 6803-005, March 1968. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 4107, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 5



Ni.111 Inconel 706 nickel alloy bar and sheet, typical tensile stress-strain curve (full range)

Heat-resistant alloy at room temperature (creep rupture heat treatment). Composition: Ni-37Fe-16Cr-2.9Nb-1.8Ti. UNS N09706

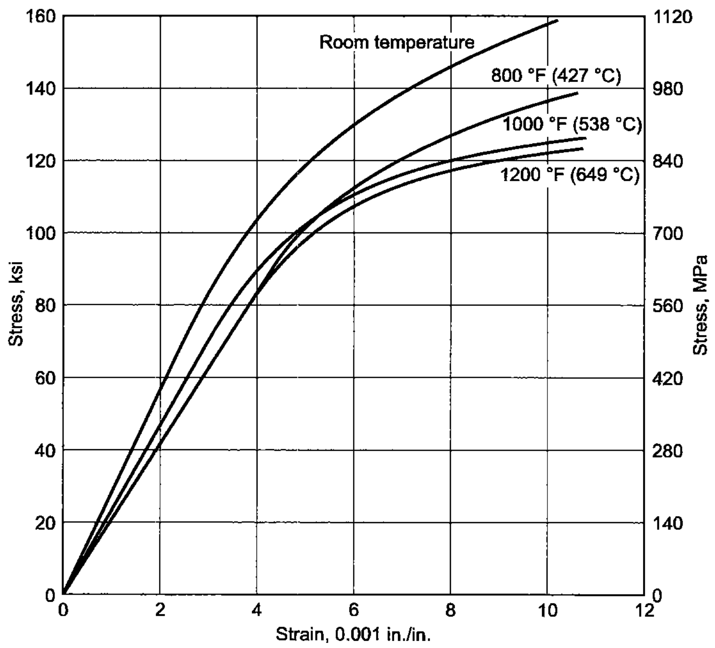
Source: *MIL-HDBK-5H*, Dec 1998, p 6–50



Ni.112 Inconel 706 solution treated and aged nickel alloy forged bar, typical tensile stress-strain curves at room and elevated temperature

Test direction: longitudinal and long transverse. Bar thickness = 50.8 mm (2.000 in.). Creep rupture heat treatment and 0.5 h exposure to elevated temperatures. Ramberg-Osgood parameters: *n*(room temperature) = 6.7; *n*(800 °F) = 7.0; *n*(1000 °F) = 13; *n*(1200 °F) = 13. Composition: Ni-37Fe-16Cr-2.9Nb-1.8Ti. UNS N09706

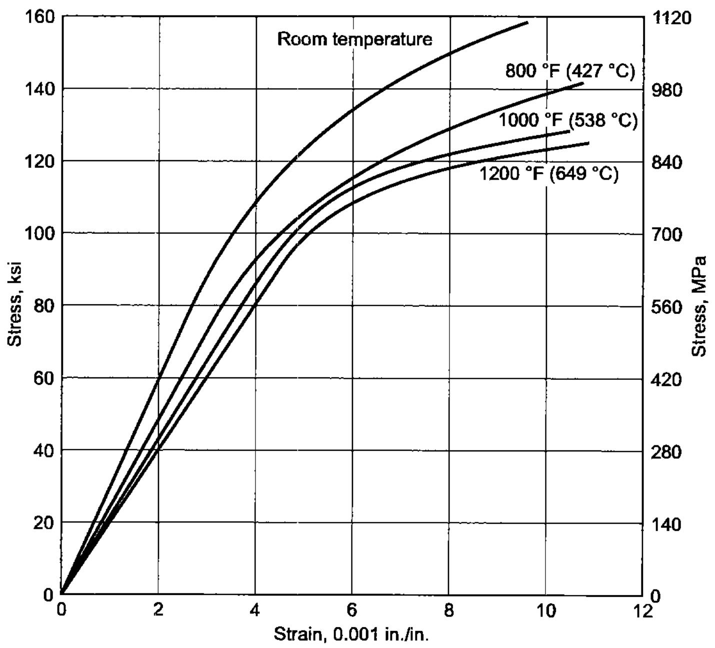
Source: *MIL-HDBK-5H*, Dec 1998, p 6–49



Ni.113 Inconel 706 nickel alloy bar, tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal. 152.4 mm (6 in.) square bar pressed into 50.8 × 152.4 mm (2 × 6 in.) bar, treated at 982 °C (1800 °F), 2 h, air cooled, + 843 °C (1550 °F), 3 h, air cooled, + 718 °C (1325 °F), force cooled to 621 °C (1150 °F), 18 h, air cooled. Composition: Ni-37Fe-16Cr-2.9Nb-1.8Ti. UNS N09706

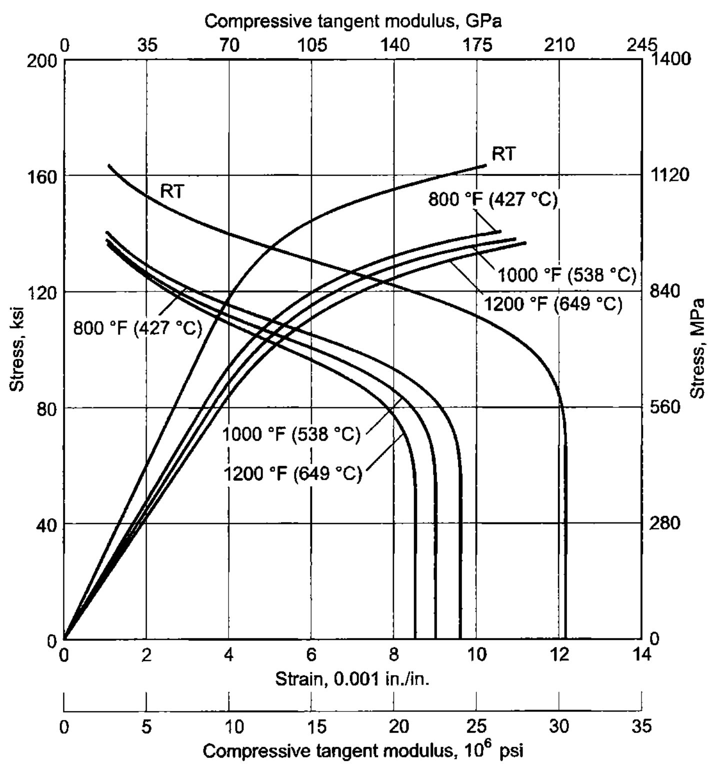
Source: O.L. Deel and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," Technical Report AFM6-TR-72-196, Vol II, Sept 1972, p 113, 125. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4110, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 10



Ni.114 Inconel 706 nickel alloy bar, tensile stress-strain curves at room and elevated temperatures

Test direction: transverse. 152.4 mm (6 in.) square bar pressed into 50.8 × 152.4 mm (2 × 6 in.) bar, treated at 982 °C (1800 °F), 2 h, air cooled, + 843 °C (1550 °F), 3 h, air cooled, + 718 °C (1325 °F), force cooled to 621 °C (1150 °F), 18 h, air cooled. Composition: Ni-37Fe-16Cr-2.9Nb-1.8Ti. UNS N09706

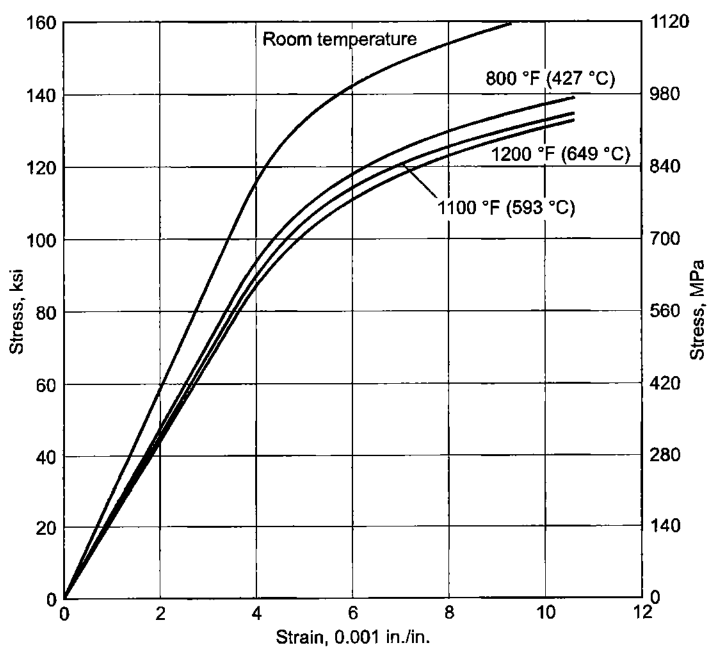
Source: O.L. Deel and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," Technical Report AFM6-TR-72-196, Vol II, Sept 1972, p 113, 126. As published in *Aerospace Structural Metals Handbook,* Vol 4, Code 4110, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 10



Ni.115 Inconel 706 solution treated and aged nickel alloy forged bar, typical compressive stress-strain and compressive tangent modulus curves at room and elevated temperatures

Test direction: longitudinal and long transverse. Bar thickness = 50.8 mm (2.000 in.). Creep rupture heat treatment and 0.5 h exposure to elevated temperatures. RT, room temperature. Ramberg-Osgood parameters: n(RT) = 11; n(800 °F) = 10; n(1000 °F) = 9.7; n(1200 °F) = 9.2. Composition: Ni-37Fe-16Cr-2.9Nb-1.8Ti. UNS N09706

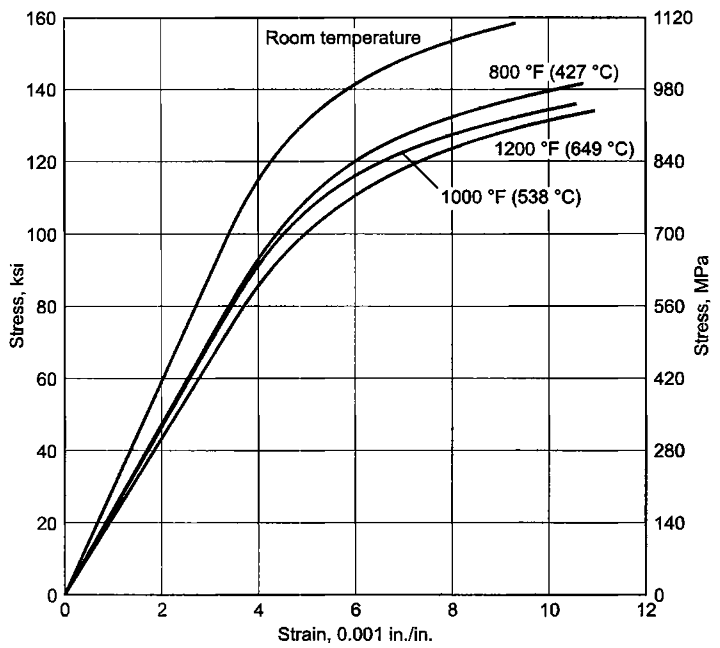
Source: *MIL-HDBK-5H*, Dec 1998, p 6–49



Ni.116 Inconel 706 nickel alloy bar, compressive stress-strain curves at room and elevated temperature

Test direction: longitudinal. 152.4 mm (6 in.) square bar pressed into 50.8 × 152.4 mm (2 × 6 in.) bar, treated at 982 °C (1800 °F), 2 h, air cooled, + 843 °C (1550 °F), 3 h, air cooled, + 718 °C (1325 °F), force cooled to 621 °C (1150 °F), 18 h, air cooled. Composition: Ni-37Fe-16Cr-2.9Nb-1.8Ti. UNS N09706

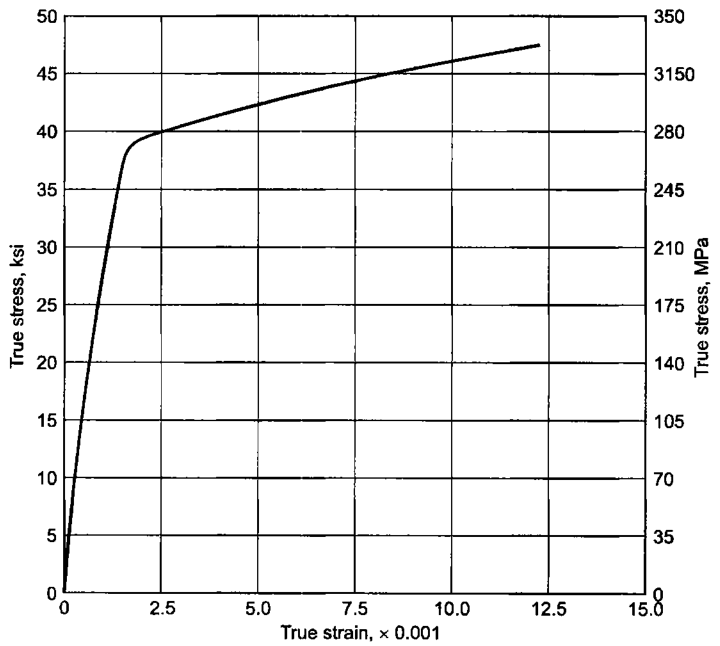
Source: O.L. Deel and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," Technical Report AFM6-TR-72-196, Vol II, Sept 1972, p 113, 127. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 4110, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



Ni.117 Inconel 706 nickel alloy bar, compressive stress-strain curves at room and elevated temperature

Test direction: transverse. 152.4 mm (6 in.) square bar pressed into 50.8 × 152.4 mm (2 × 6 in.) bar, treated at 982 °C (1800 °F), 2 h, air cooled, + 843 °C (1550 °F), 3 h, air cooled, + 718 °C (1325 °F), force cooled to 621 °C (1150 °F), 18 h, air cooled. Composition: Ni-37Fe-16Cr-2.9Nb-1.8Ti. UNS N09706

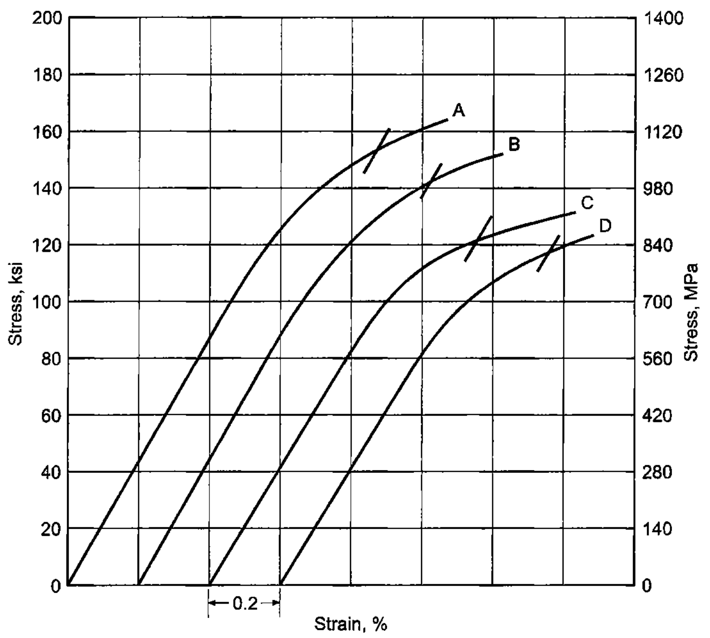
Source: O.L. Deel and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," Technical Report AFM6-TR-72-196, Vol II, Sept 1972, p 113, 128. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 4110, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



Ni.118 Inconel 706 annealed nickel alloy 51 mm (2 in.) diam rod, hot rolled, engineering stress-strain curve

Test direction: longitudinal. 0.2% yield strength = 280 MPa (40.6 ksi); ultimate tensile strength = 722 MPa (104.7 ksi); elongation = 51.3%; reduction in area = 71.5%. Composition: Ni-37Fe-16Cr-2.9Nb-1.8Ti. UNS N09706

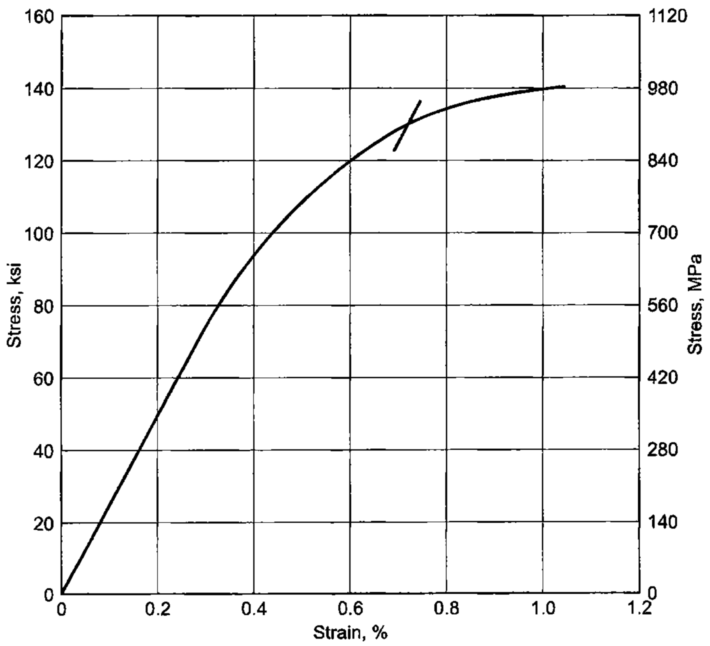
Courtesy of Special Metals Corporation



Ni.119 Incoloy 909 nickel alloy bar, tensile stress-strain curves at room temperature with effect of various heat treatments

Test direction: longitudinal. Bar diameter = 123.825 mm (4.875 in.). Heat treatment: A: 982 °C (1800 °F), 1 h, air cooled, + 718 °C (1325 °F), 8 h, force cooled to 621 °C (1150 °F), held 8 h, air cooled. B: 982 °C (1800 °F), 1 h, air cooled, + 718 °C (1325 °F), 4 h, force cooled to 621 °C (1150 °F, held 4 h, air cooled. C: 1038 °C (1900 °F), 1 h, air cooled, + 774 °C (1425 °F), 8 h, force cooled to 621 °C (1150 °F), held 8 h, air cooled. D: 1038 °C (1900 °F), 1 h, air cooled, + 774 °C (1425 °F), 8 h, force cooled to 621 °C (1150 °F), held 4 h, air cooled. Composition: Ni-42Fe-13Co-4.7Nb-1.5Ti. UNS N19909

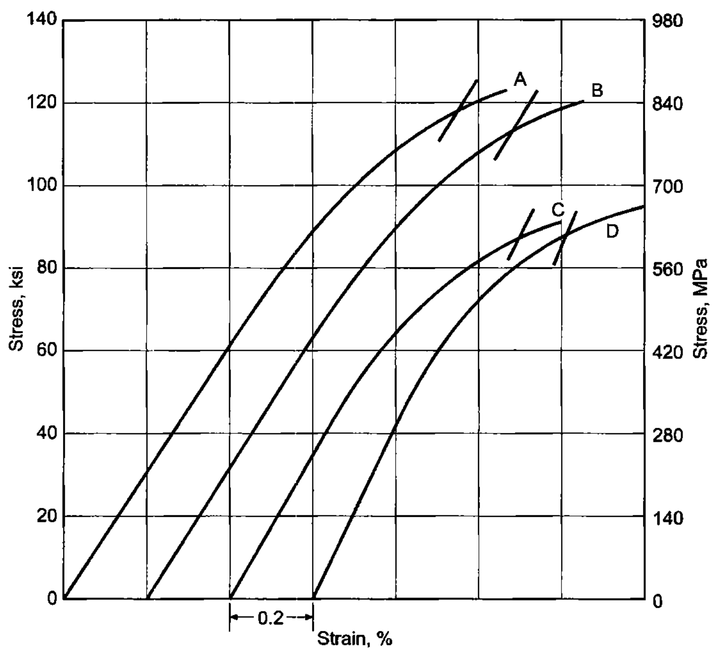
Source: Private communication from D.H. Yates, INCO Alloys International, 19 Oct 1989. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4219, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 8



Ni.120 Incoloy 909 nickel alloy bar, tensile stress-strain curve at 538 °C (1000 °F)

Test direction: longitudinal. Bar diameter = 123.825 mm (4.875 in.). Heat treatment: 982 °C (1800 °F), 1 h, air cooled, + 718 °C (1325 °F), 8 h, force cooled to 621 °C (1150 °F), held 8 h, air cooled. Composition: Ni-42Fe-13Co-4.7Nb-1.5Ti. UNS N19909

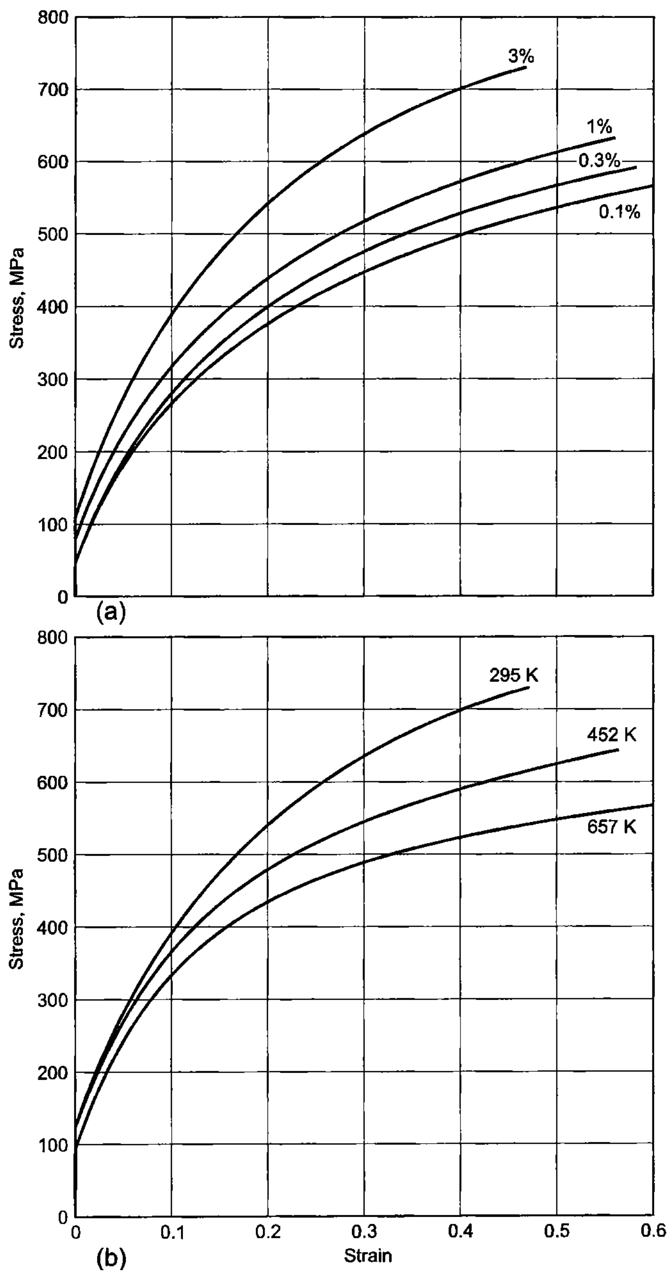
Source: Private communication from D.H. Yates, INCO Alloys International, 19 Oct 1989. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4219, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 9



Ni.121 Incoloy 909 nickel alloy bar, tensile stress-strain curves at 649 °C (1200 °F) with effect of various heat treatments

Test direction: longitudinal. Bar diameter = 123.825 mm (4.875 in.). Heat treatment: A: 982 °C (1800 °F), 1 h, air cooled, + 718 °C (1325 °F), 8 h, force cooled to 621 °C (1150 °F), held 8 h, air cooled. B: 982 °C (1800 °F), 1 h, air cooled, + 718 °C (1325 °F), 4 h, force cooled to 621 °C (1150 °F, held 4 h, air cooled. C: 1038 °C (1900 °F), 1 h, air cooled, + 774 °C (1425 °F), 8 h, force cooled to 621 °C (1150 °F), held 8 h, air cooled. D: 1038 °C (1900 °F), 1 h, air cooled, + 774 °C (1425 °F), 8 h, force cooled to 621 °C (1150 °F), held 4 h, air cooled. A: yield strength = 823 MPa (119.3 ksi); ultimate tensile strength = 1028 MPa (149.1 ksi); elongation (in 4*D*) = 19%; reduction in area = 38%. B: yield strength = 778 MPa (112.9 ksi); ultimate tensile strength = 990 MPa (143.6 ksi); elongation (in 4*D*) = 18%; reduction in area = 37%. C: yield strength = 594 MPa (86.1 ksi); ultimate tensile strength = 871 MPa (126.3 ksi); elongation (in 4*D*) = 23%; reduction in area = 44%. D: yield strength = 607 MPa (88.0 ksi); ultimate tensile strength = 916 MPa (132.9 ksi); elongation (in 4*D*) = 19%; reduction in area = 30%. Composition: Ni-42Fe-13Co-4.7Nb-1.5Ti.
UNS N19909

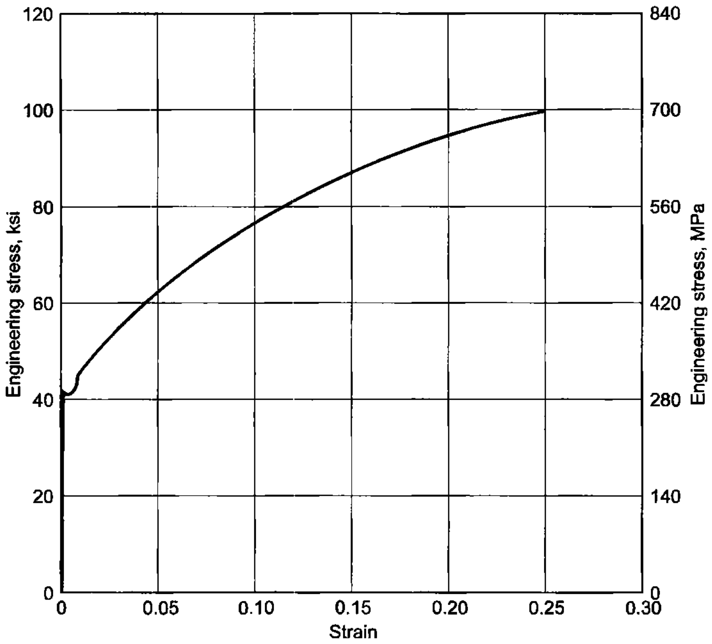
Source: Private communication from D.H. Yates, INCO Alloys International, 19 Oct 1989. As published in *Aerospace Structural Metals Handbook*, Vol 5, Code 4219, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 9



Ni.122 Nickel-molybdenum alloy, true compressive stress-strain curves for various alloys and temperatures

Strain rate = ~3 × 10^{-4}/s, d = ~75 × 10^{-6} m. (a) Temperature = ~295 K, composition as indicated; curves diverge monotonically. (b) Ni-3% Mo at various temperatures, curves coincide at low strains but diverge in the dynamic recovery range.

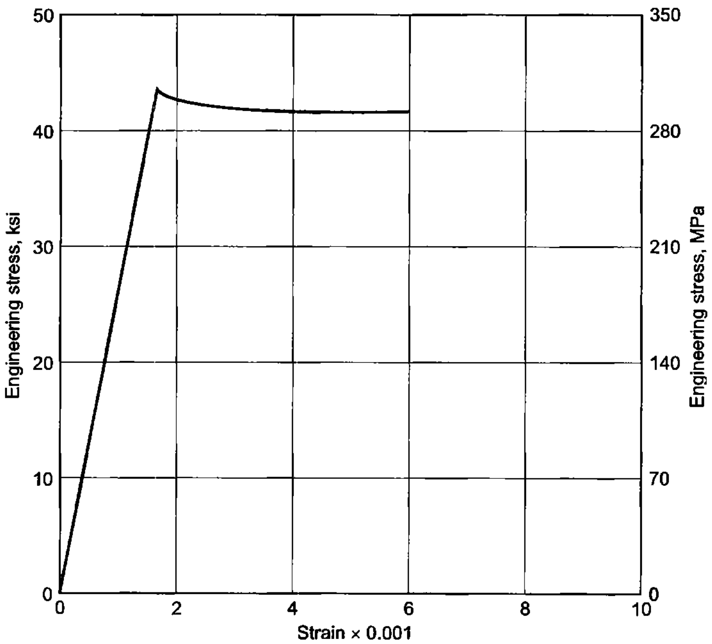
Source: George Krauss, Ed., *Deformation, Processing, and Structure,* papers presented at ASM Materials Science Seminar (St. Louis, MO), 23 Oct 1982, American Society for Metals, 1984, p 100–101



Ni.123 Incoloy 825 annealed nickel alloy sheet, engineering stress-strain curve (full range)

Test direction: longitudinal. Sheet thickness = 1.168 mm (0.046 in.). 0.2% yield strength = 294 MPa (42.7 ksi); ultimate tensile strength = 703 MPa (101.9 ksi); elongation = 39.4%. Composition: 42Ni-21.5Cr-bal Fe. UNS N08825

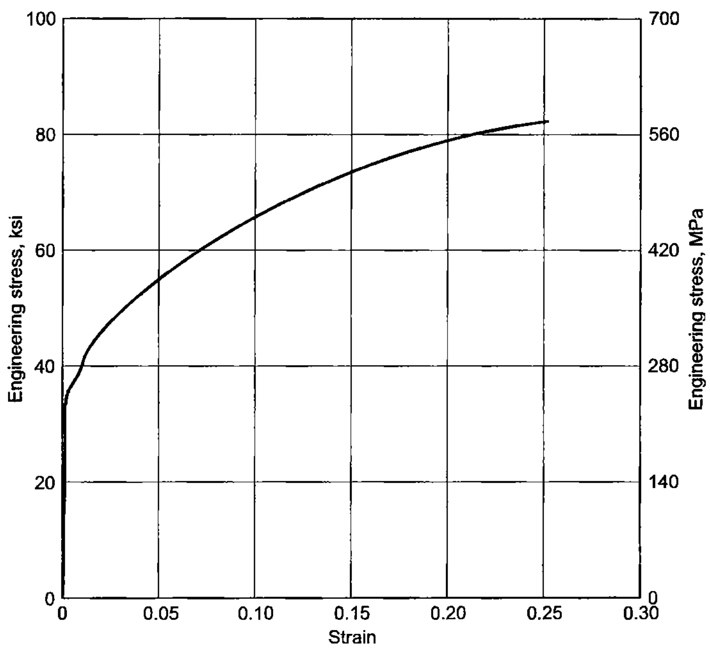
Courtesy of Special Metals Corporation



Ni.124 Incoloy 825 annealed nickel alloy sheet, engineering stress-strain curve (expanded range)

Test direction: longitudinal. Sheet thickness = 1.168 mm (0.046 in.). 0.2% yield strength = 289 MPa (41.9 ksi); ultimate tensile strength = 687 MPa (99.6 ksi); elongation = 37.7%. Composition: 42Ni-21.5Cr-bal Fe. UNS N08825

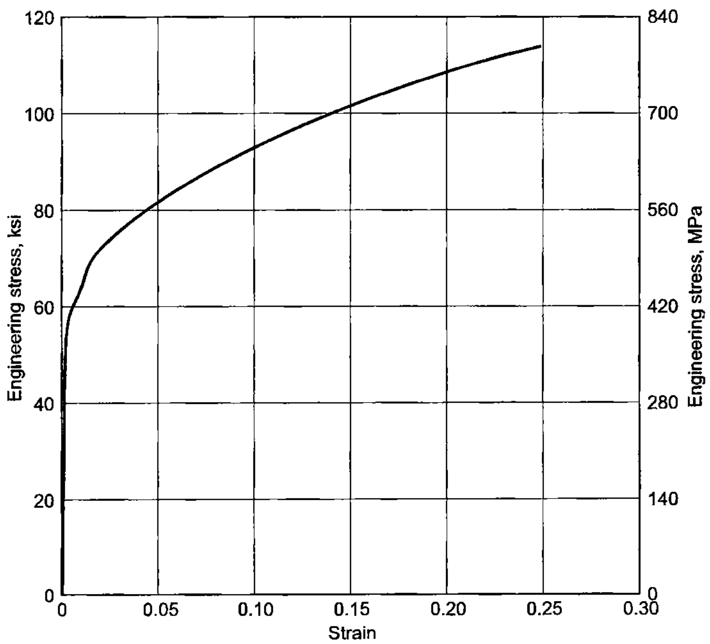
Courtesy of Special Metals Corporation



Ni.125 Incoloy 330 annealed nickel alloy sheet, engineering stress-strain curve (full range)

Test direction: longitudinal. Sheet thickness = 2.946 mm (0.116 in.). 0.2% yield strength = 247 MPa (35.8 ksi); ultimate tensile strength = 587 MPa (85.2 ksi); elongation = 43.5%. Composition: 44Fe-35.5Ni-18.5Cr. UNS N08330

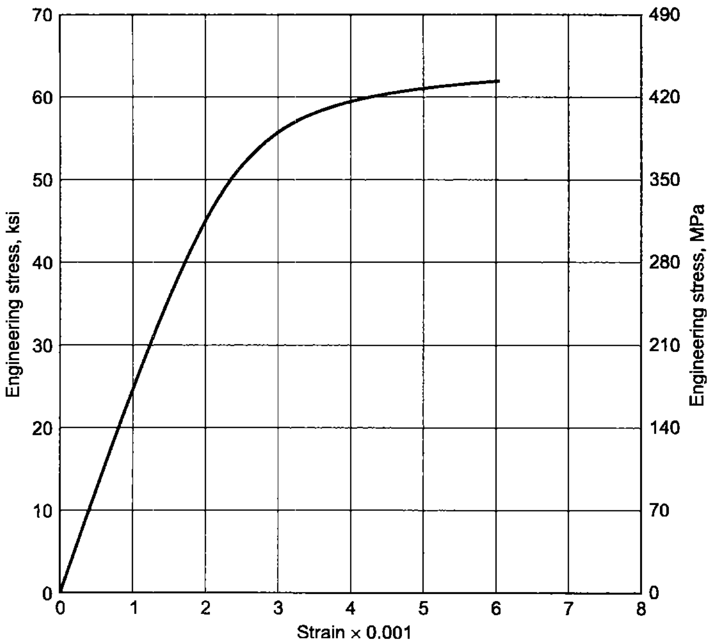
Courtesy of Special Metals Corporation



Ni.126 Incoloy 25-6 annealed nickel alloy sheet, engineering stress-strain curve (full range)

Test direction: longitudinal. Sheet thickness = 0.889 mm (0.035 in.). 0.2% yield strength = 413 MPa (59.9 ksi); ultimate tensile strength = 785 MPa (113.9 ksi); elongation = 41.5%. Composition: 45.5Fe-25Ni-20Cr-6.5Mo. UNS N08926

Courtesy of Special Metals Corporation

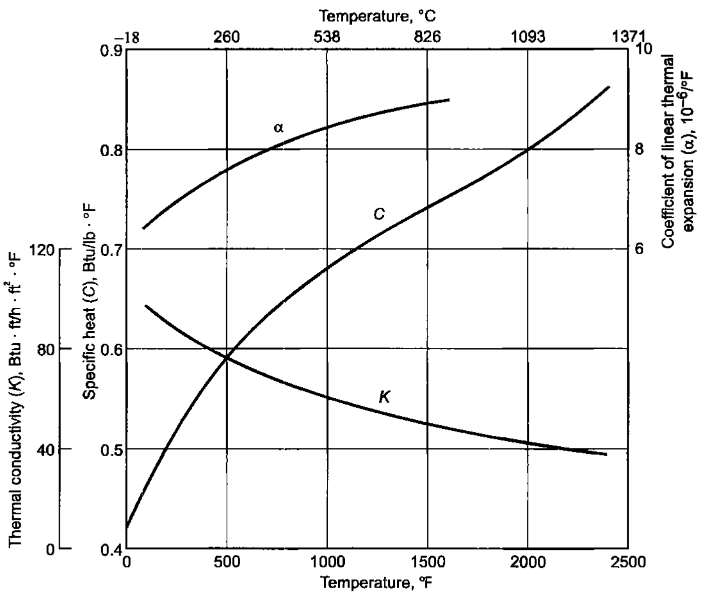


Ni.127 Incoloy 25-6 annealed nickel alloy sheet, engineering stress-strain curve (expanded range)

Test direction: longitudinal. Sheet thickness = 0.889 mm (0.035 in.). 0.2% yield strength = 413 MPa (59.9 ksi); ultimate tensile strength = 785 MPa (113.9 ksi); elongation = 41.5%. Composition: 45.5Fe-25Ni-20Cr-6.5Mo. UNS N08926

Courtesy of Special Metals Corporation

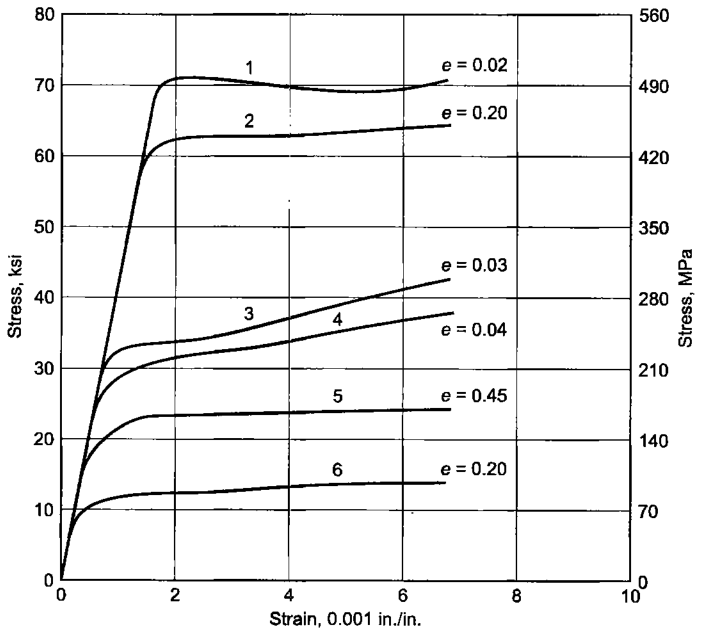
Reactive and Refractory Metals (RM)



RM.001 Be-2%BeO beryllium all forms, effect of temperature on physical properties

The coefficient of thermal expansion, α, is between 21 °C (70 °F) and the indicated temperature. The thermal conductivity, *K*, is at the indicated temperature. The specific heat, *C*, is at the indicated temperature.

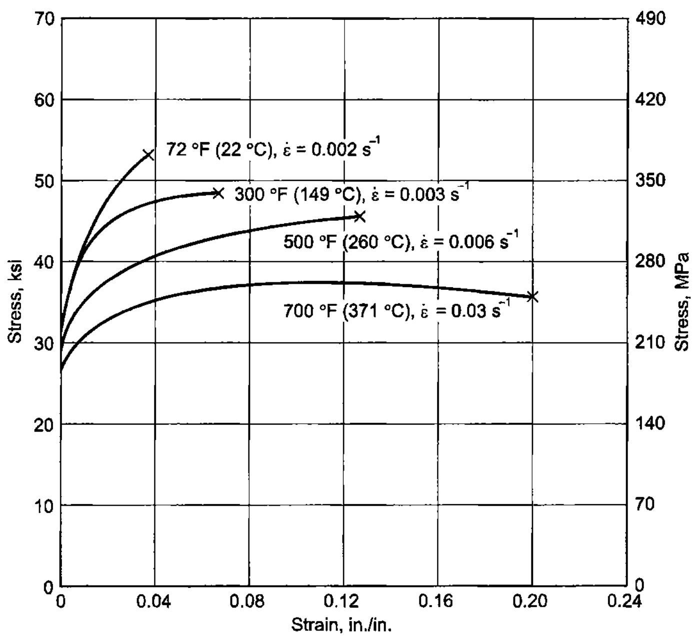
Source: *MIL-HDBK-5H*, Dec 1998, p 7–5



RM.002 Various grades of beryllium, various forms, tensile stress-strain curves

(1) I400 hot-pressed block. Ultimate tensile strength: longitudinal (L), 450 MPa (66 ksi); transverse (T), 550 MPa (80 ksi). Typical compressive and tensile yield strength: L, 430 MPa (62 ksi); T, 450 MPa (65 ksi). (2) SR200 sheet. Ultimate tensile strength (L and T), 540 MPa (79 ksi). Tensile and compressive yield strength (L and T), 400 MPa (58 ksi). (3) S200E hot-pressed block. Ultimate tensile strength: L, 340 MPa (50 ksi); T, 390 MPa (56 ksi). Tensile and compressive yield strength: L, 260 MPa (38 ksi); T, 270 MPa (39 ksi). (4) I70 brake grade. Ultimate tensile strength: L, 340 MPa (50 ksi); T, 360 MPa (53 ksi). Tensile and compressive yield strength (L and T), 220 MPa (32 ksi). (5) BG 170 brake grade at 371 °C (700 °F). (6) BG 170 brake grade at 649 °C (1200 °F). The elongation, *e*, is listed for each by the material curve. All values are typical. Guaranteed values are lower.

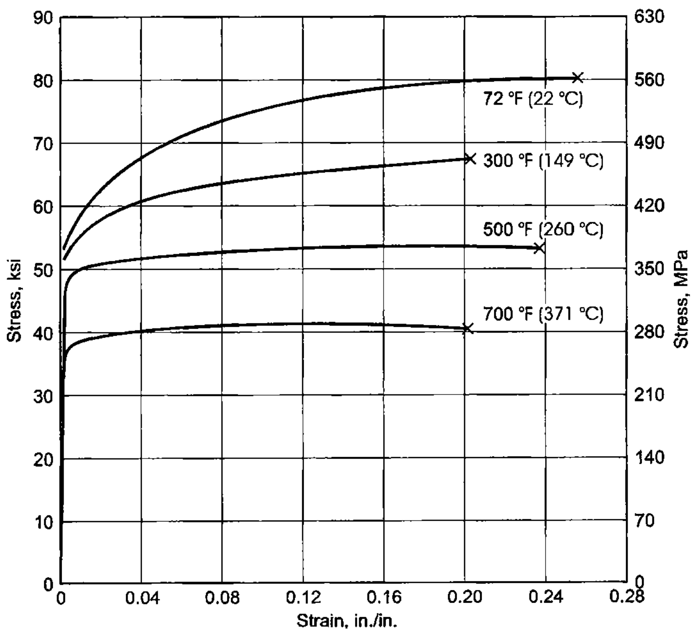
Source: Brush Wellman unpublished data and specification data. As published in Vol 5, Code 5101, *Aerospace Structural Metals Handbook*, CINDAS/USAF CRDA Handbook Operation, Purdue University, 1995, p 9 and 12



RM.003 S200E beryllium block, tensile stress-strain curves

Tested at various temperatures and strain rates, $\dot{\varepsilon}$. Hot-pressed block with 20 μm grain size. Tested in the transverse direction. X indicates fracture.

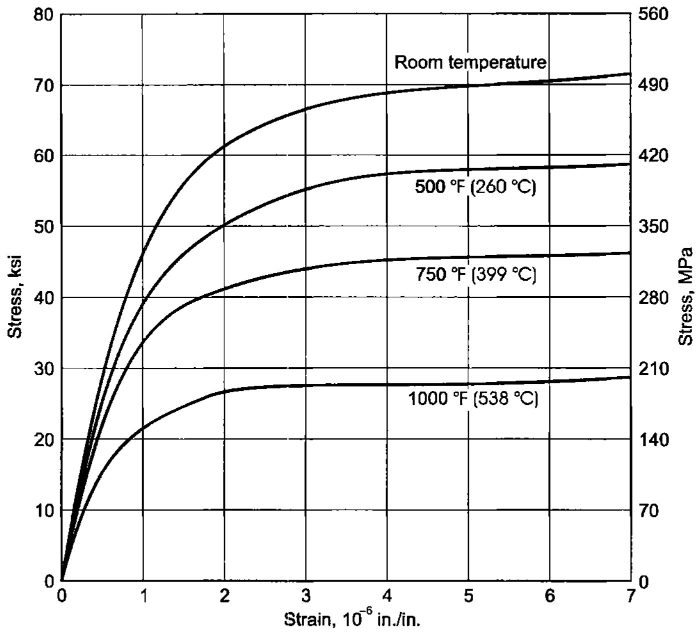
Source: F.L. Schierloh and S.G. Babcock, "Tensile Properties of Beryllium at High Strain Rates and Temperatures," AFML-TR-69-273, General Motors Tech Center, Oct 1969. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 5101, CINDAS/USAF CRDA Handbook Operation, Purdue University, 1995, p 12



RM.004 SR200 beryllium sheet, tensile stress-strain curves

Tested at various temperatures and a strain rate of 0.005 s^{-1} for 1.5 mm (0.060 in.) sheet with 13 μm grain size. X indicates fracture.

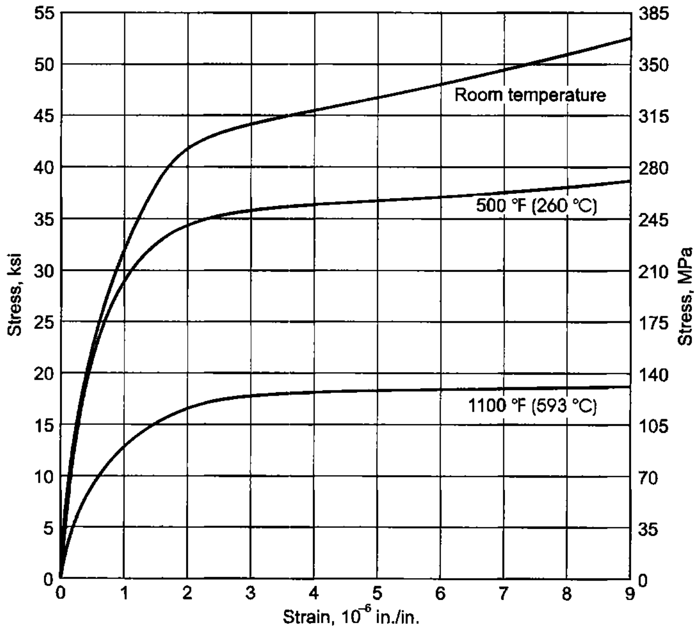
Source: F.L. Schierloh and S.G. Babcock, "Tensile Properties of Beryllium at High Strain Rates and Temperatures," AFML-TR-69-273, General Motors Tech Center, 1969. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 5101, CINDAS/USAF CRDA Handbook Operation, Purdue University, 1995, p 12



RM.005 S200E beryllium sheet, tensile stress-strain curves

Tested at various temperatures for cross-rolled sheet. At room temperature for 0.5–6.35 mm (0.021–0.25 in.) sheet: ultimate tensile strength (min), 483 MPa (70.0 ksi); 0.2% offset yield strength (min), 345 MPa (50.0 ksi)

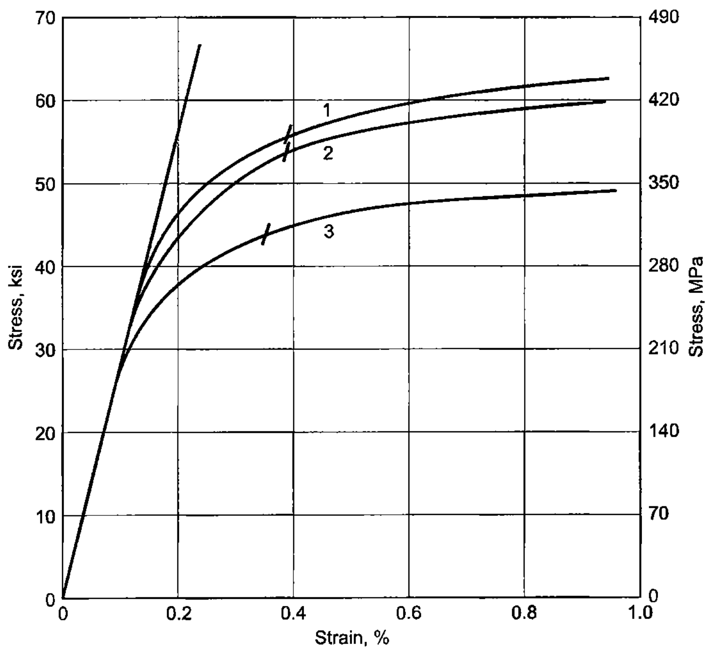
Source: "Designing with Beryllium," Brush Wellman, Inc., Cleveland, OH. As published in *Aerospace Structural Metals Handbook*, Vol 5, Code 5101, CINDAS/USAF CRDA Handbook Operation, Purdue University, 1995, p 8, 9



RM.006 S200E beryllium block, tensile stress-strain curves

Tested at various temperatures for hot-pressed block. At room temperature: typical minimum ultimate tensile strength, 280 MPa (40 ksi); typical minimum tensile yield strength, 210 MPa (30 ksi)

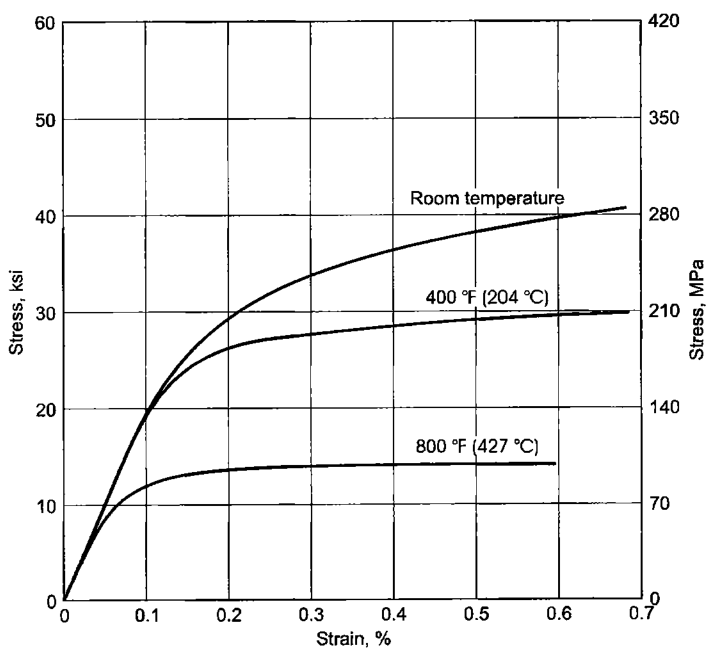
Source: "Designing with Beryllium," Brush Wellman, Inc., Cleveland, OH. As published in *Aerospace Structural Metals Handbook*, Vol 5, Code 5101, CINDAS/USAF CRDA Handbook Operation, Purdue University, 1995, p 8, 9



RM.007 Be-38Al, Lockalloy beryllium sheet, tensile stress-strain curves

Sheet thickness: 1.47–2.47 mm (0.058–0.108 in.) sheet. Young's modulus, 193 GPa (28 × 10^6 psi). Curve 1 is for sheet in as-rolled condition with longitudinal, L, specimen. Curve 2 is for as-rolled condition with transverse, T, specimen. Curve 3 is annealed, and applies to both L and T.

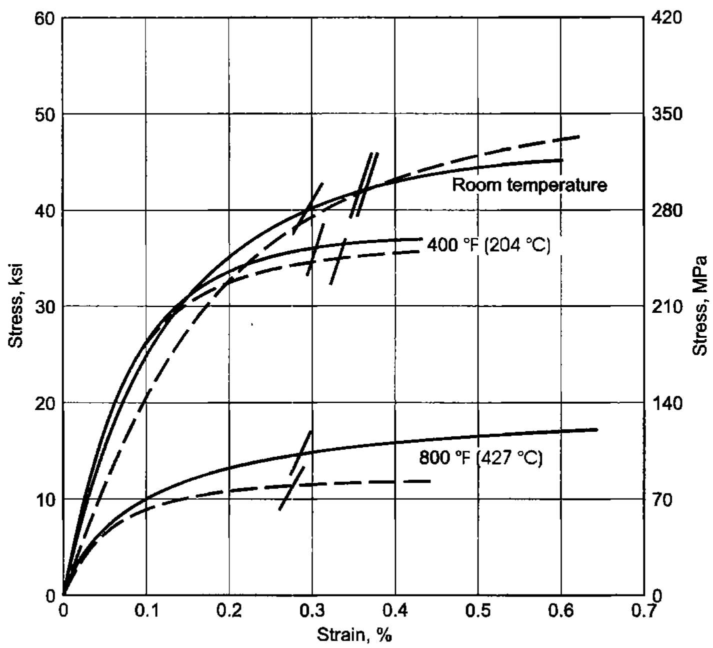
Source: R.W. Fenn, Jr., D.D. Crooks, W.C. Coons, and E.E. Underwood, "Properties and Behavior of Beryllium-Aluminum Alloys," Lockheed Missiles & Space Company, Oct 1964. As published in *Aerospace Structural Metals Handbook*, Vol 5, Code 5102, CINDAS/USAF CRDA Handbook Operation, Purdue University, 1995, p 4



RM.008 Be-38Al, Lockalloy beryllium sheet, compression stress-strain curves

Tested at various temperatures and at a strain rate of ~0.13 mm/min (~0.005 in./min) for 1.5 mm (0.060 in.) annealed sheet, in both longitudinal and transverse directions

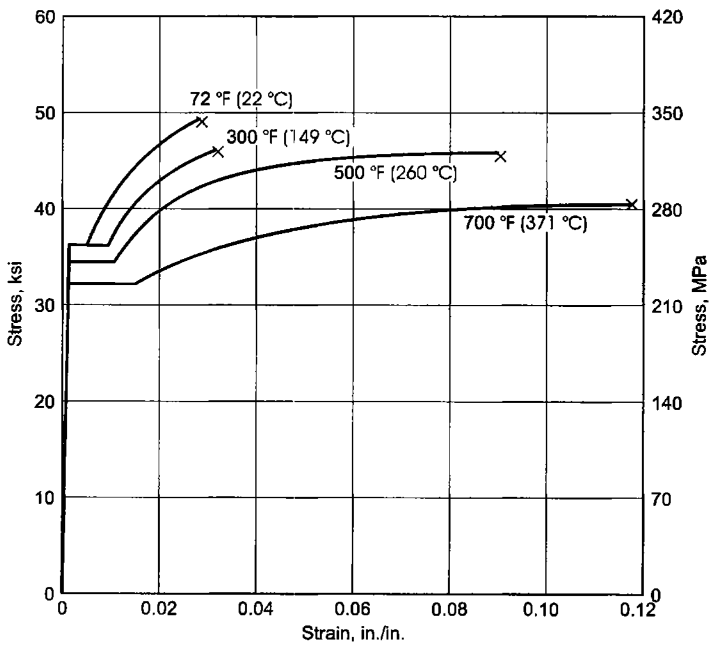
Source: R.W. Fenn, Jr., D.D. Crooks, G.E. Watts, and A.S. Neiman, A Mechanical Property Evaluation of Be-38% Al Alloy from –320 to 800 F, *Met. Eng. Q.*, Nov 1965. As published in *Aerospace Structural Metals Handbook*, Vol 5, Code 5102, CINDAS/USAF CRDA Handbook Operation, Purdue University, 1995, p 7



RM.009 Be-38Al, Lockalloy beryllium extrusion, compression stress-strain curves

Tested at various temperatures and at a strain rate of approximately 0.13 mm/min (0.005 in./min) for annealed extrusion. Solid line is longitudinal, broken line is transverse direction.

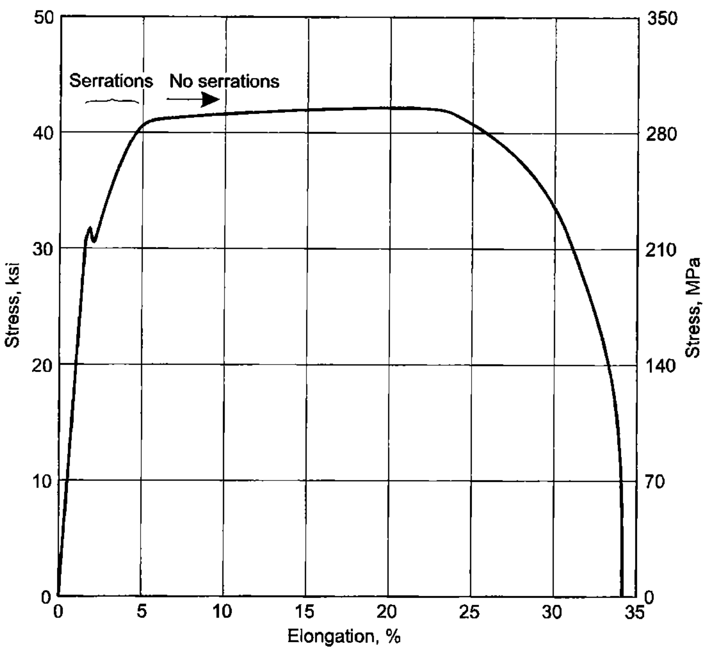
Source: R.W. Fenn, Jr., D.D. Crooks, G.E. Watts, and A.S. Neiman, A Mechanical Property Evaluation of Be-38% Al Alloy from −320 to 800 F, *Met. Eng. Q.*, Nov 1965. As published in *Aerospace Structural Metals Handbook*, Vol 5, Code 5102, CINDAS/USAF CRDA Handbook Operation, Purdue University, 1995, p 7



RM.010 N50 beryllium block, tensile stress-strain curves

Tested at various temperatures and strain rate of 0.002 s^{-1}. Hot-pressed block with 40 μm grain size. Tested in the transverse direction. X indicates fracture.

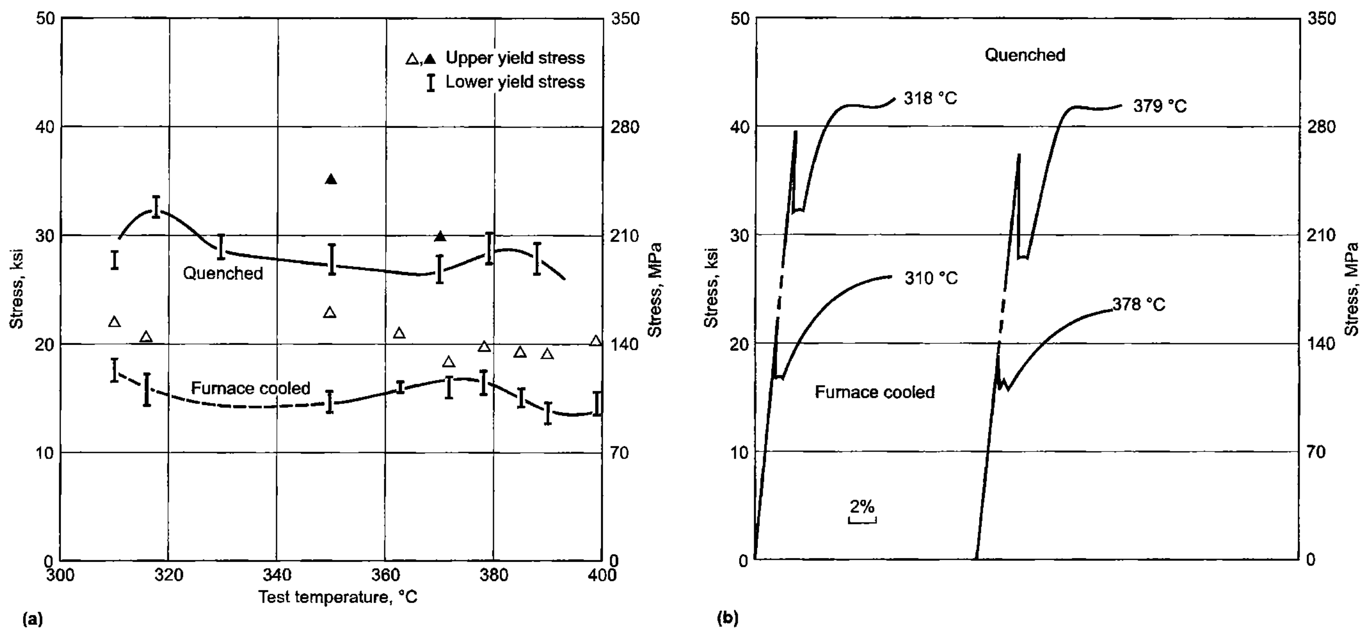
Source: F.L. Schierloh and S.G. Babcock, "Tensile Properties of Beryllium at High Strain Rates and Temperatures," General Motors Tech Center, Oct 1969. As published in *Aerospace Structural Metals Handbook*, Vol 5, Code 5101, CINDAS/USAF CRDA Handbook Operation, Purdue University, 1995, p 12



RM.011 Worked chromium rod, quenched medium-grain size chromium, stress-strain curve

Tested at 340 °C. The chromium displayed an average rate of work hardening of 27.6 MPa (4000 psi)/percent strain between 0 and 3% strain, compared with a rate of 3.5 MPa (500 psi) between 3 and 20% strain.

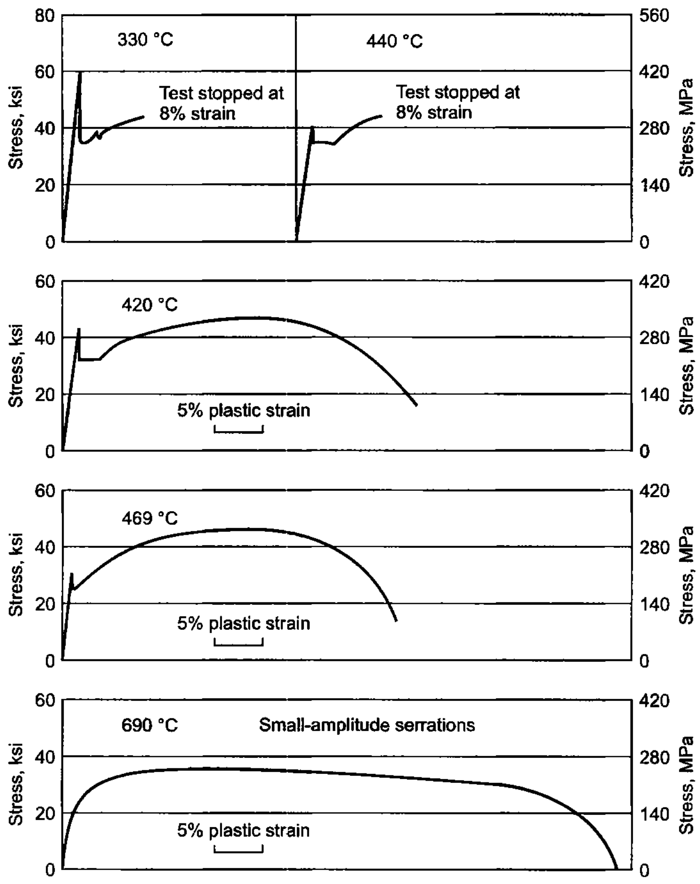
Source: A Gilbert, C.N. Reid, and G.T. Hahn, Tensile Properties of Chromium and Chromium-Rhenium Alloys, *High Temperature Refractory Metals*, R.W. Fountain, J. Malt, and L.S. Richardson, Ed., based on a symposium, 16–20 Feb 1964, sponsored by the High Temperature Metals Committee Extractive Metallurgy Division) and the Refractory Metals Committee (Institute of Metals Division) of the Metallurgical Society of the American Institute of Mining, Metallurgical, and Petroleum Engineers, Gordon and Breach Science Publishers, 1966, p 200



RM.012 Worked chromium rod, quenched and furnace cooled medium-grain size chromium, effect of quenching on yield properties

(a) Yield stress versus temperature. (b) Effect of cooling rate on the shape of stress-strain curves. The quenched specimens were all strained 8% in the strain-aging range and, compared with the furnace-cooled samples, had higher upper and lower yield stress values and markedly different stress-strain curves that showed an unusually high rate of work hardening. After about 3% strain, the rate of work hardening decreased substantially.

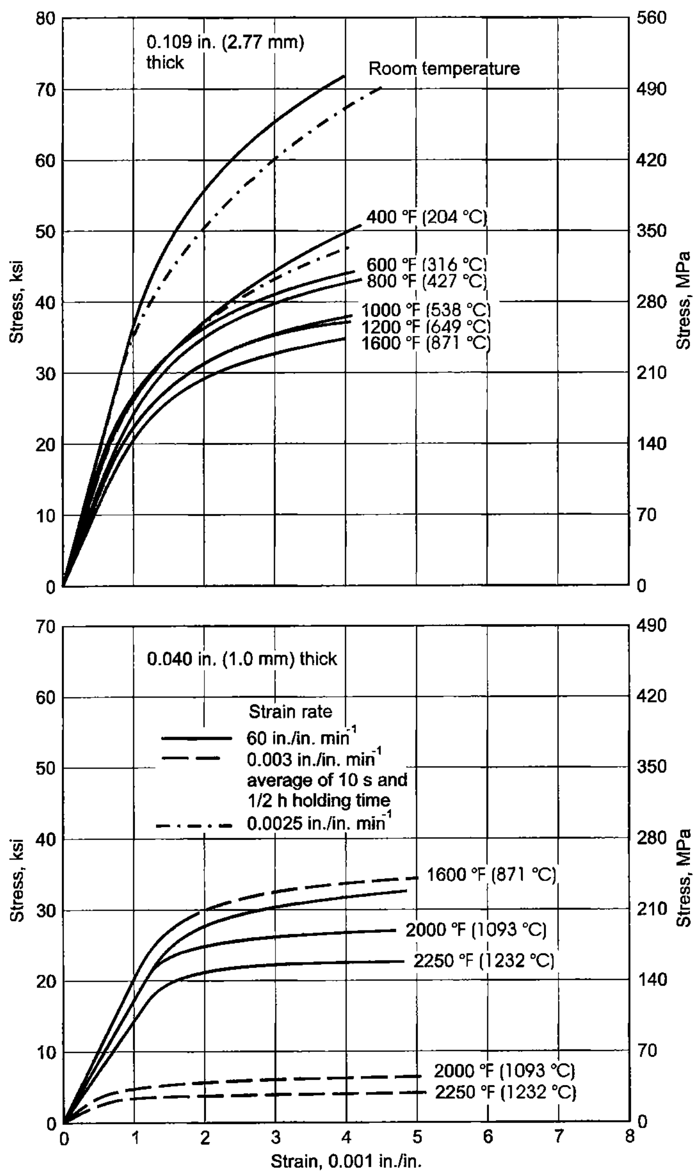
Source: A Gilbert, C.N. Reid, and G.T. Hahn, Tensile Properties of Chromium and Chromium-Rhenium Alloys, *High Temperature Refractory Metals*, R.W. Fountain, J. Malt, and L.S. Richardson, Ed., based on a symposium, 16–20 Feb 1964, sponsored by the High Temperature Metals Committee Extractive Metallurgy Division) and the Refractory Metals Committee (Institute of Metals Division) of the Metallurgical Society of the American Institute of Mining, Metallurgical, and Petroleum Engineers, Gordon and Breach Science Publishers, 1966, p 199



RM.013 Chromium-rhenium alloy worked rod, stress-strain curves at various temperatures

Cr-1 at.% Rh alloy specimens

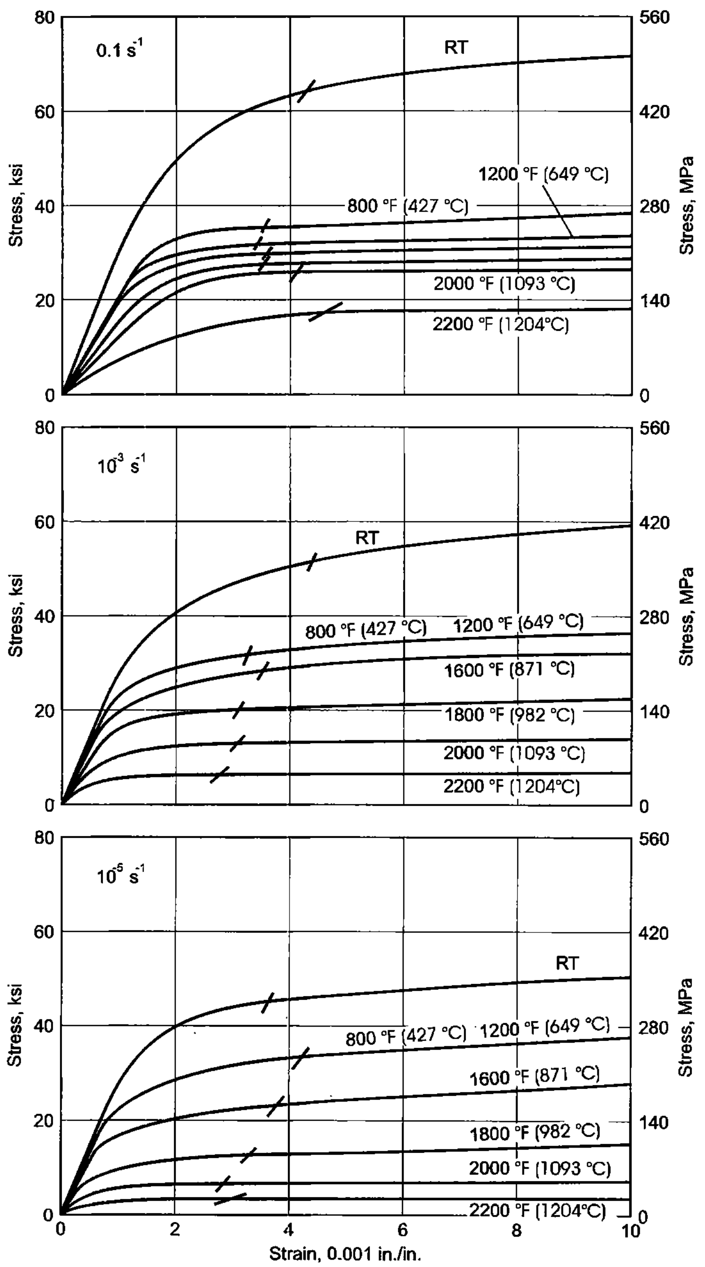
Source: A Gilbert, C.N. Reid, and G.T. Hahn, Tensile Properties of Chromium and Chromium-Rhenium Alloys, *High Temperature Refractory Metals,* R.W. Fountain, J. Malt, and L.S. Richardson, Ed., based on a symposium, 16–20 Feb 1964, sponsored by the High Temperature Metals Committee Extractive Metallurgy Division) and the Refractory Metals Committee (Institute of Metals Division) of the Metallurgical Society of the American Institute of Mining, Metallurgical, and Petroleum Engineers, Gordon and Breach Science Publishers, 1966, p 203



RM.014 L-605 (UNS R30605) cobalt sheet, tensile stress-strain curves for thicknesses as indicated at room and elevated temperatures and various strain rates

The 2.77 mm (0.109 in.) sheet was solution treated at 1200 °C (2200 °F) and rapid air cooled. The 1.0 mm (0.040 in.) sheet was solution treated at 1200 °C (2200 °F) and air cooled. Composition: Co-20Cr-15W-10Ni

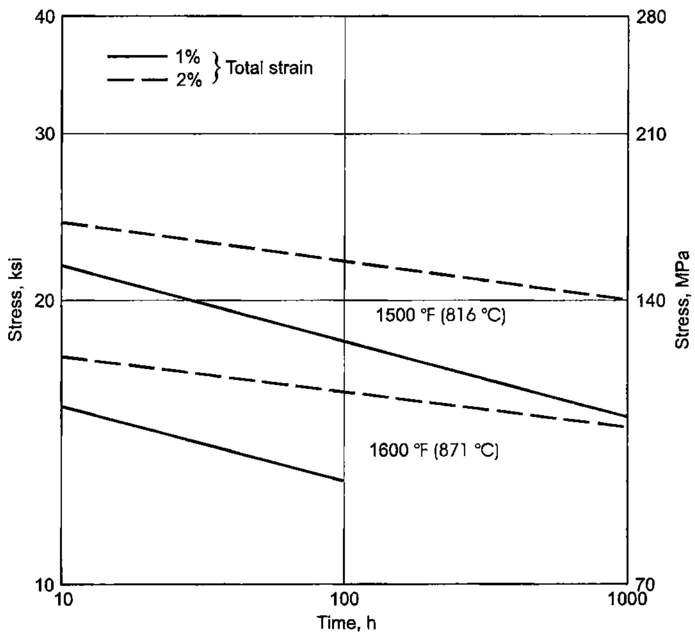
Source: For 0.109 in. sheet, Haynes Stellite Company, "Haynes Alloy No. 25," March 1959; for 0.040 in., sheet, W.P. Roe and J.R. Kattus, "Tensile Properties of Aircraft Structural Metals at Various Rate of Loading after Rapid Heating," TR-55-199, Part III, Wright Air Development Center, Sept 1957. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4302, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 22



RM.015 L-605 (UNS R30605) cobalt sheet, compressive stress-strain curves at room and elevated temperatures and strain rates

Sheet thickness: 1.6 mm (0.063 in.). Solution heat treated at 1232 °C (2250 °F) and rapid air cooled. RT, room temperature. Other test specimens were resistance heated to the indicated temperatures. Composition: Co-20Cr-15W-10Ni

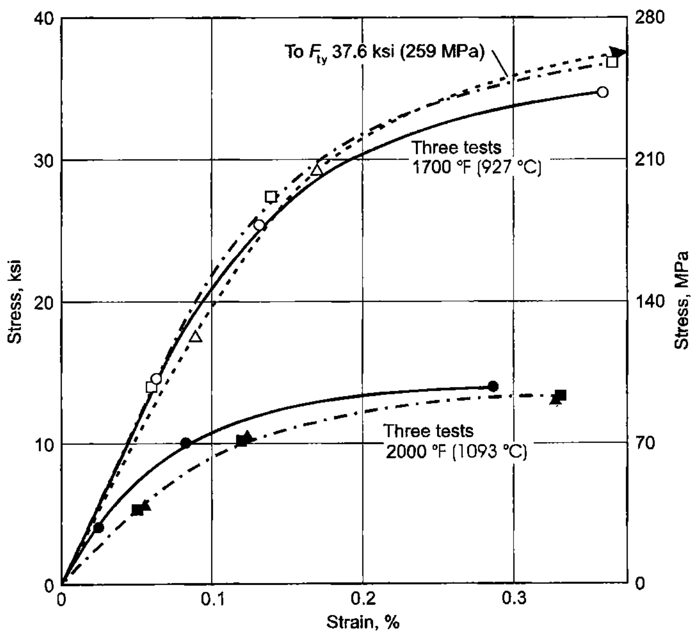
Source: P.R. Dioguardo and R.D. Lloyd, "Investigation of the Effects of Rapid Properties of Compressive and Column Members," ASD-TR 61-499, The Marquardt Corp., Jan 1962. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4302, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 21



RM.016 X-40 cobalt investment casting, as cast, total strain curves

Tested at 816 and 871 °C (1500 and 1600 °F). Total strain of 1 and 2% as indicated. Composition: Co-25Cr-10Ni-7.5W

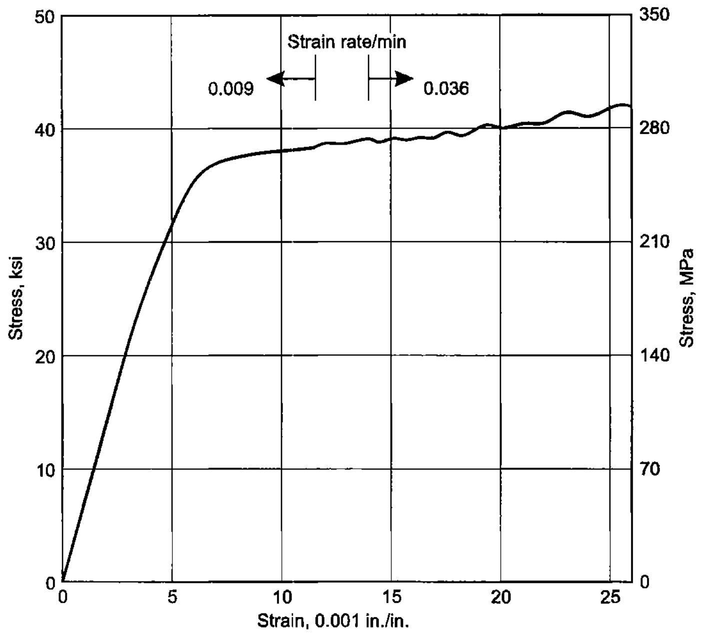
Source: Haynes Stellite Company, "Haynes Stellite Alloy No. 31," April 1958. As published in *Aerospace Structural Metals Handbook*, Vol 5, Code 4305, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 26



RM.017 WI-52 cobalt stress-strain curves

Tested at 927 and 1093 °C (1700 and 2000 °F). Pratt Whitney Aircraft 653 coated with PWA 45, chromized at 1052 °C (1925 °F), time unspecified. Individual tests are plotted. F_{ty}, tensile yield strength. Composition: Co-21Cr-11W-2Fe-1.75(Ta + Nb)

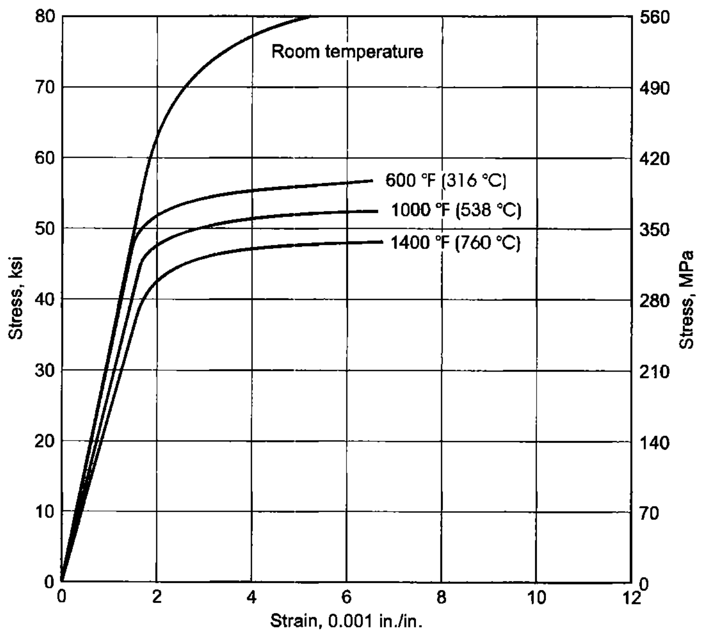
Source: Personal communication from Pratt & Whitney Aircraft. As published in *Aerospace Structural Metals Handbook*, Vol 5, Code 4308, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 10



RM.018 Haynes Alloy No. 188 (UNS R30188) stress-strain curve

Tested at 871 °C (1600 °F). Note the change in strain rate over the range of strain. Composition: Co-22Cr-22Ni-14W-0.08La-low C

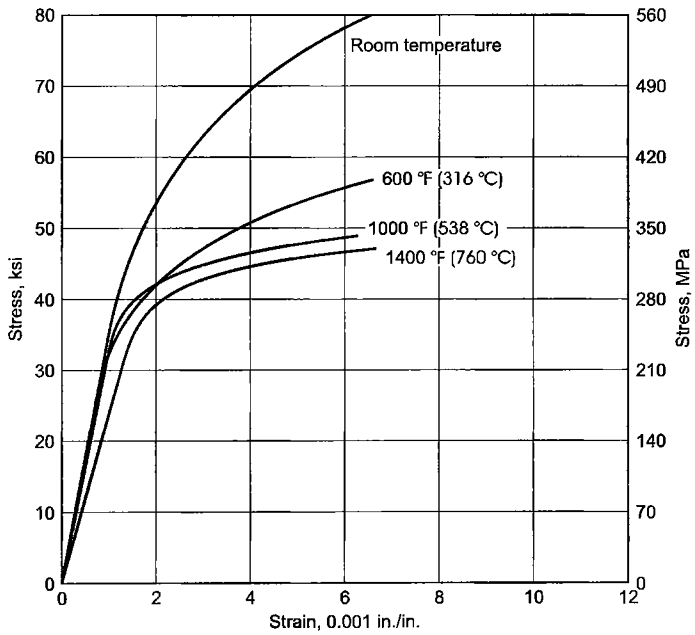
Source: W.T. Ebihara and R.B. Herchenroeder, "Mechanical and Physical Properties of Haynes Developmental Alloy No. 188," Report No. 7626, Kokomo Laboratory, Union Carbide Corp., 16 July 1969. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4310, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 24



RM.019 Haynes Alloy No. 188 (UNS R30188) cobalt sheet, mill annealed, stress-strain curves

Tested in longitudinal direction. Typical for sheet thickness: 1.73 mm (0.068 in.). Temperature effects on the stress-strain properties are indicated. Strain rate in the elastic region was 0.005 min^{-1}. After yielding to fracture, the strain rate was 0.1 min^{-1} head speed. Composition: Co-22Cr-22Ni-14W-0.08La-low C

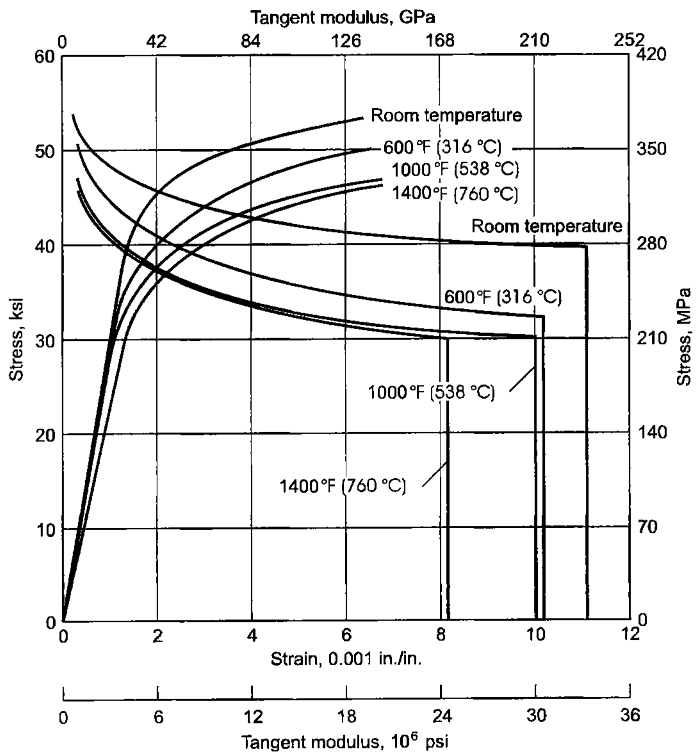
Source: O.L. Deel and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," Technical Report AFML-TR-71-249, Battelle Columbus Laboratories, Air Force Materials Laboratory, Contract No. F33615-70-C-1070, Dec 1971. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4310, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 24



RM.020 Haynes Alloy No. 188 (UNS R30188) cobalt sheet, mill annealed, stress-strain curves

Tested in transverse direction. Typical for sheet thickness: 2.0 mm (0.078 in.). Temperature effects on the stress-strain properties are indicated. In the elastic region the strain rate was 0.005 min^{-1}. After yielding to fracture, the strain rate was 0.1 min^{-1} head speed. Composition: Co-22Cr-22Ni-14W-0.08La-low C

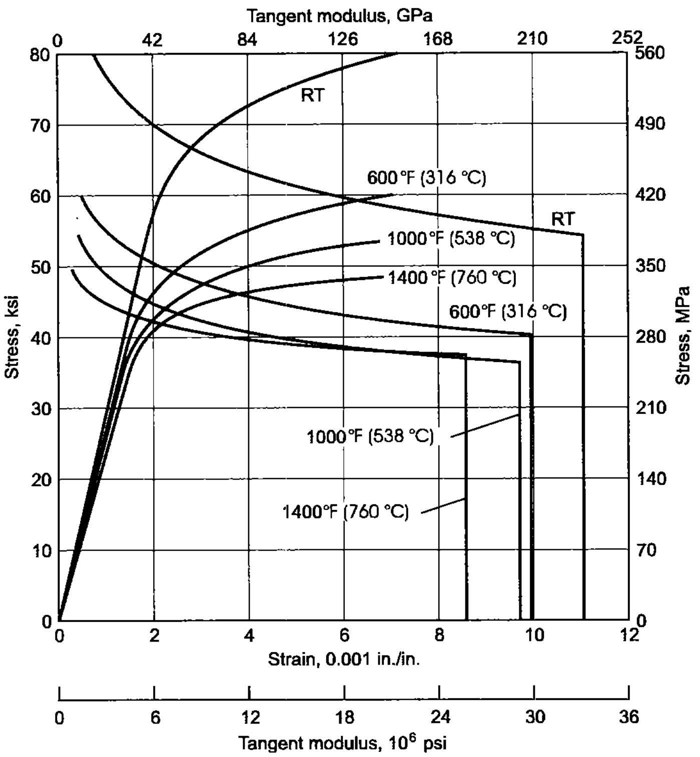
Source: O.L. Deel and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," Technical Report AFML-TR-71-249, Battelle Columbus Laboratories, Air Force Materials Laboratory, Contract No. F33615-70-C-1070, Dec 1971. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4310, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 25



RM.021 Haynes Alloy No. 188 (UNS R30188) cobalt sheet, mill annealed, compressive stress-strain and tangent modulus curves

Tested in the longitudinal direction. Typical for sheet thickness: 2.0 mm (0.078 in.). Temperature effects on the mechanical properties are indicated. The strain rate was 0.005 min^{-1}. RT, room temperature. Composition: Co-22Cr-22Ni-14W-0.08La-low C

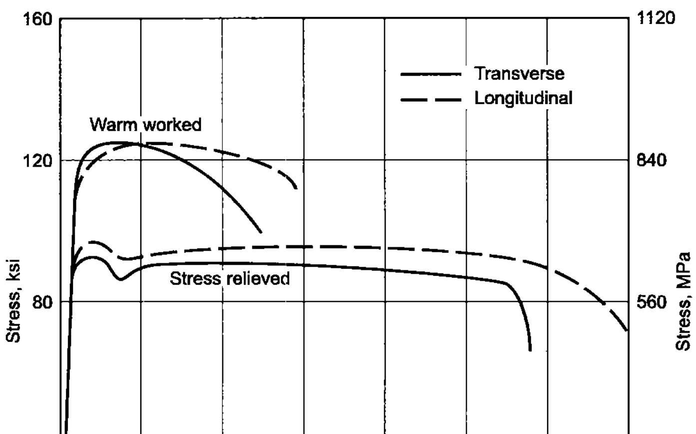
Source: O.L. Deel and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," Technical Report AFML-TR-71-249, Battelle Columbus Laboratories, Air Force Materials Laboratory, Contract No. F33615-70-C-1070, Dec 1971. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4310, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 29



RM.022 Haynes Alloy No. 188 (UNS R30188) cobalt sheet, mill annealed, compressive stress-strain and tangent modulus curves

Tested in the transverse direction. Typical for sheet thickness: 2.0 mm (0.078 in.). Temperature effects on the mechanical properties are indicated. The strain rate was 0.005 min^{-1}. RT, room temperature. Composition: Co-22Cr-22Ni-14W-0.08La-low C

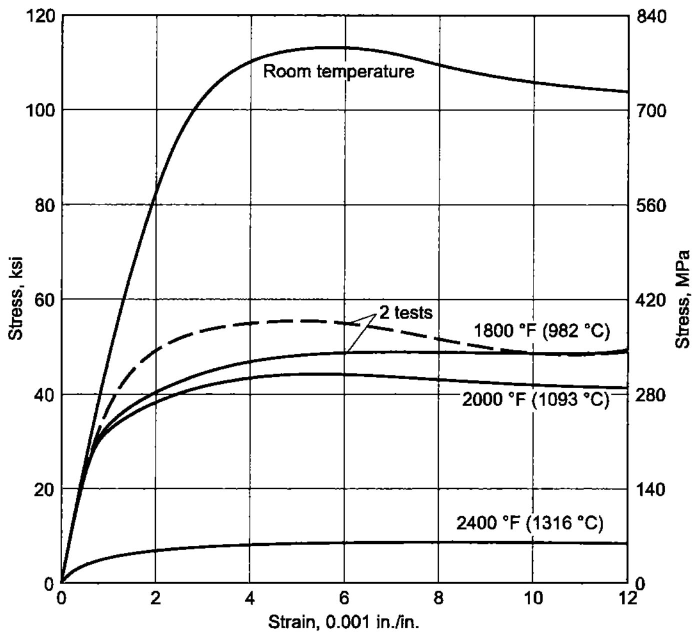
Source: O.L. Deel and H. Mindlin, "Engineering Data on New Aerospace Structural Materials," Technical Report AFML-TR-71-249, Battelle Columbus Laboratories, Air Force Materials Laboratory, Contract No. F33615-70-C-1070, Dec 1971. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 4310, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 29



RM.023 Commercially pure molybdenum sheet, tensile stress-strain curves

Curves given for arc cast sheet, 0.76–1.0 mm (0.030–0.040 in.) thick, warm worked and stress relieved. Stress relieved 982 °C (1800 °F) for 2 h. Tested in longitudinal and transverse direction at a strain rate of 0.025/min

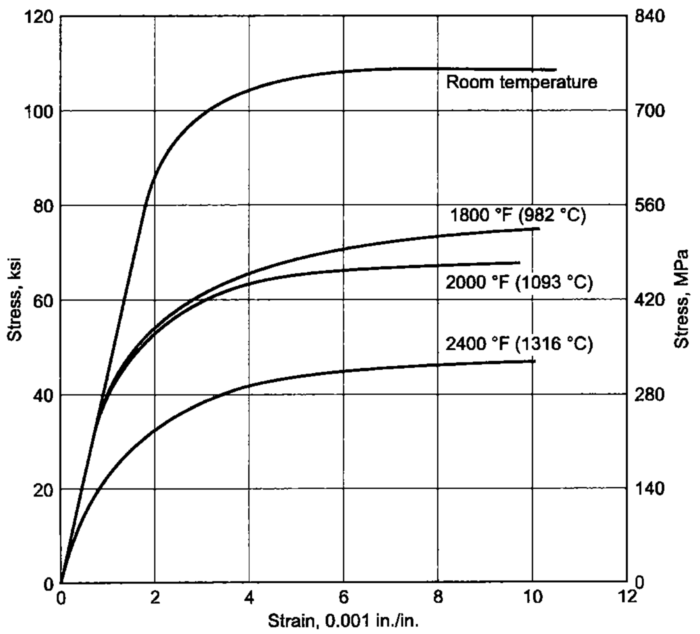
Source: "Molybdenum Metal," Climax Molybdenum Co., 1960. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 5301, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 6



RM.024 Commercially pure-0.03 C molybdenum bar, tensile stress-strain curves at room and elevated temperatures

16 mm (5/8 in.) thick bar stress relieved at 982 °C (1800 °F) for 1 h. Tested at a strain rate of 0.005/min

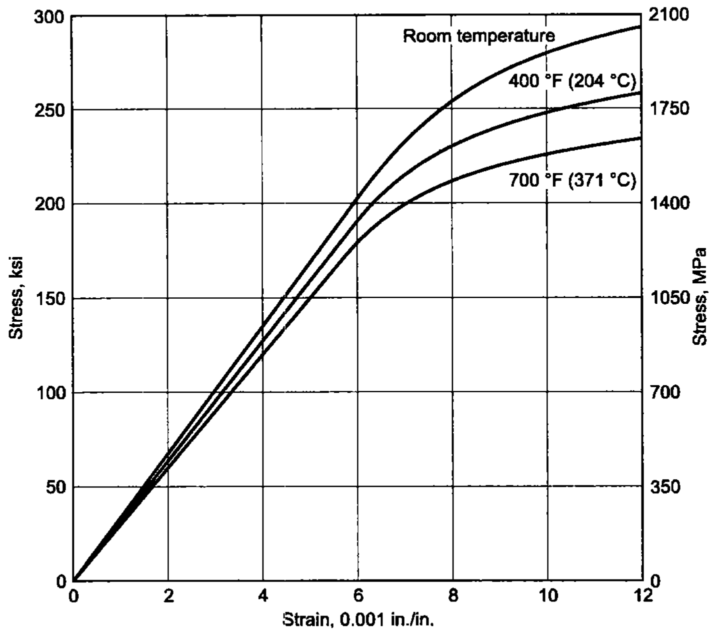
Source: R.Q. Barr and M. Semchyshen, "Stress Strain Curves for Wrought Molybdenum and Three Molybdenum Base Alloys," Climax Molybdenum Co., Dec 1959. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 5301, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 8



RM.025 TZM molybdenum alloy rolled rounds, tensile stress-strain curves at room and elevated temperatures

Round diam: 16–17.5 mm (5/8–11/16 in.). Stress relief unspecified. Tested at a strain rate of 0.005/min. Composition: Mo-0.5Ti-0.08Zr

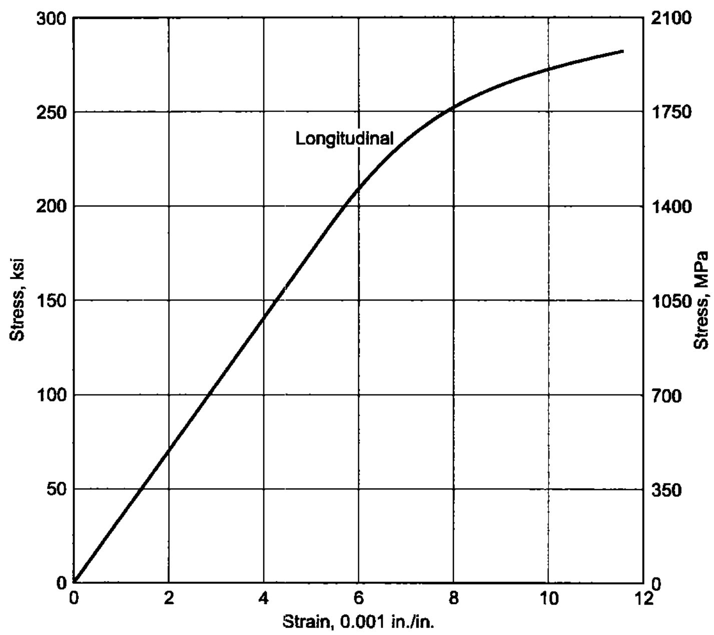
Source: J.A. Houck, "Physical and Mechanical Properties of Commercial Molybdenum Base Alloys," DMIC Rep. 140, 1960. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 5303, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 9



RM.026 MP35N multiphase alloy bar, tensile stress-strain curves at room and elevated temperatures

Typical curves for specimen (UNS R30035) cold worked and aged 538–649 °C (1000–1200 °F) for 4–4.5 h and air cooled. Test direction: longitudinal. Exposed to elevated temperatures for 0.5 h. Ultimate tensile strength, S basis for diam up to 44.45 mm (1.750 in.), 1793 MPa (260 ksi). RT, room temperature. Ramberg-Osgood parameters: *n*(RT) = 13, *n*(400 F) = 14, *n*(700 F) = 15. Composition: Co-35Ni-20Cr-9.75Mo

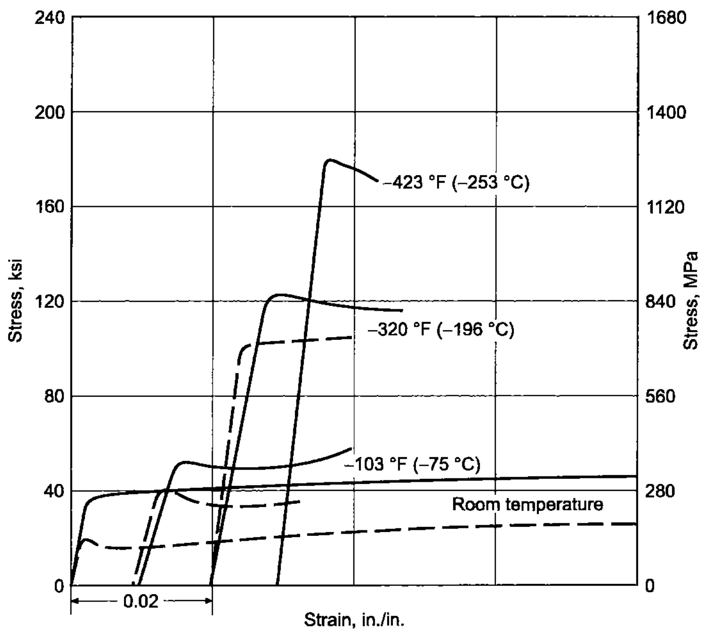
Source: *MIL-HDBK-5H,* Dec 1998, p 7–25



RM.027 MP159 multiphase alloy bar, tensile stress-strain curve at room temperature

Typical curves for specimen (UNS R30159) cold worked and aged 649 to 677 ± 14 °C (1200 to 1250 ± 25 °F) for 4–4.5 h and air cooled. Bar thickness: ≤13.462 mm (≤0.530 in.). Test direction: longitudinal. Ultimate tensile strength, S basis for 20.3–44.45 mm (0.801–1.750 in.) diam, 1793 MPa (260 ksi). Ramberg-Osgood parameters: *n*(room temperature) = 13. Composition: 36Co-19Cr-9Fe-7Mo-Ni(bal)

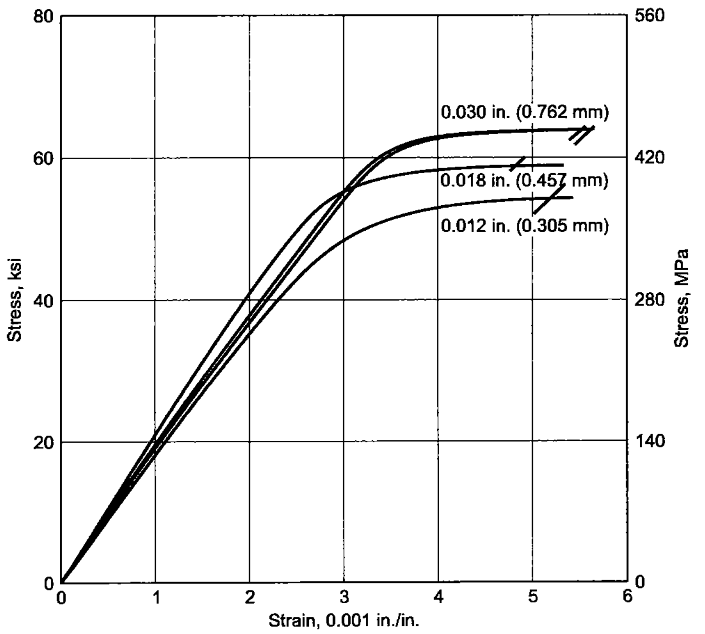
Source: *MIL-HDBK-5H,* Dec 1998, p 7–30



RM.028 Commercially pure niobium bar, tensile stress-strain curves at room and low temperatures

Solid line curves for wrought bar stress relieved at 750 °C (1382 °F) for 1 h. Dashed line curves for bar recrystallized at 1100 °C (2012 °F) for 15 min

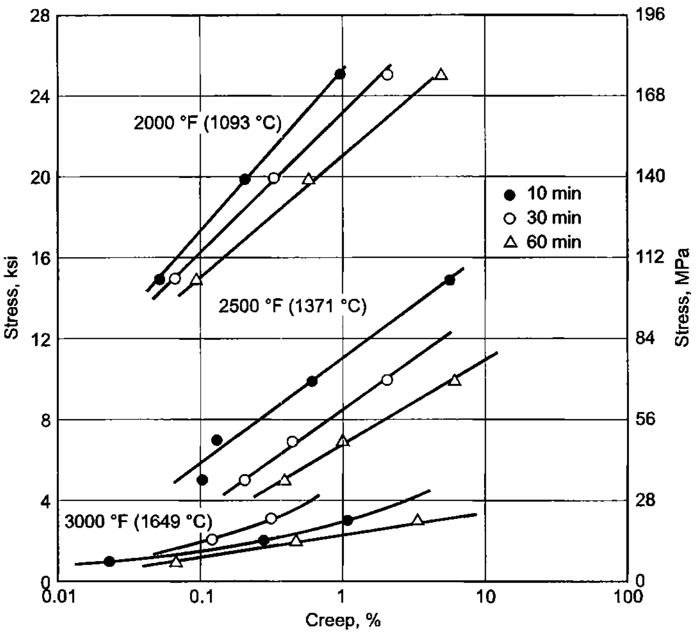
Source: A.G. Imgram, F.C. Holden, H.R. Ogden, and R.I. Jaffee, "Notch Sensitivity of Refractory Metals," WADD Tech. Rep. 60-278, Sept 1960. As published in *Aerospace Structural Metals Handbook*, Vol 5, Code 5201, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 5



RM.029 Nb752 niobium alloy sheet, tensile stress-strain curves at room temperature for several thicknesses

Sheet mill annealed. Sheet thickness: 0.30–0.76 mm (0.012–0.030 in.). Composition: Nb-10W-2.5Zr

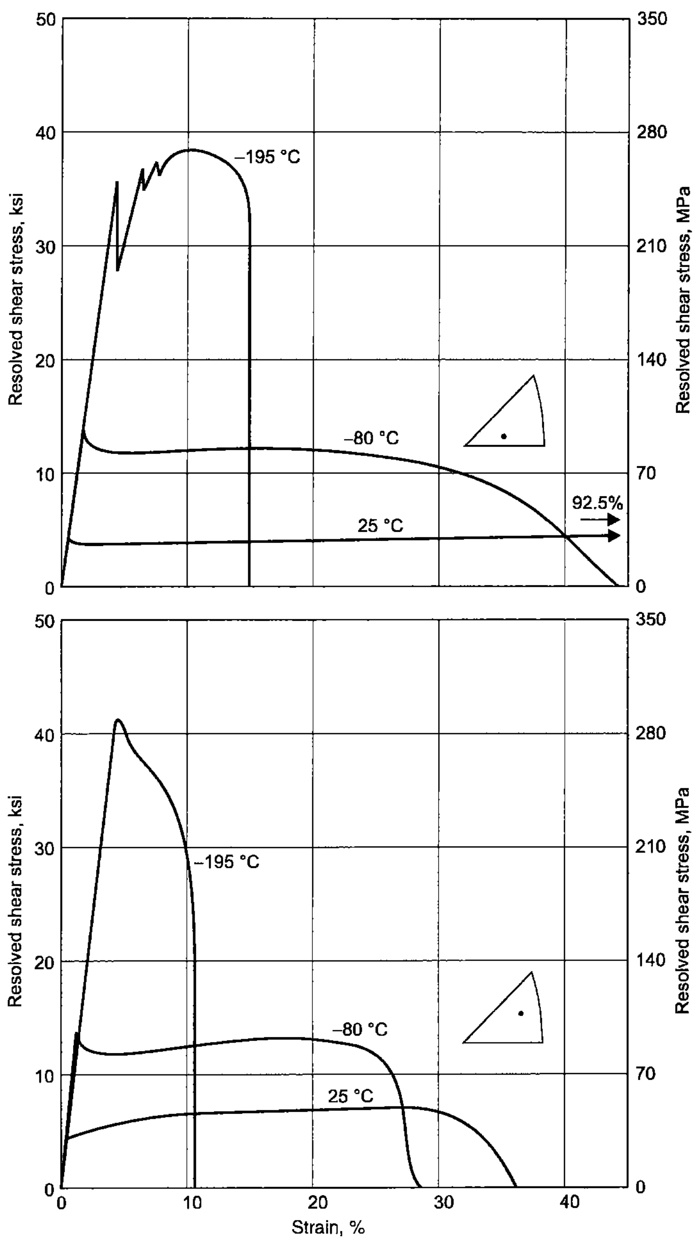
Source: J.P. O'Connor, "Evaluation of Cb-10W-2.5Zr (Cb-752) Columbium Alloy," Rep. A-742, Ser. No. 1, McDonnell Aircraft Corp., June 1964. As published in *Aerospace Structural Metals Handbook*, Vol 5, Code 5209, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 10



RM.030 Nb752 niobium alloy, isochronous stress-strain curves for several temperatures

Composition: Nb-10W-2.5Zr

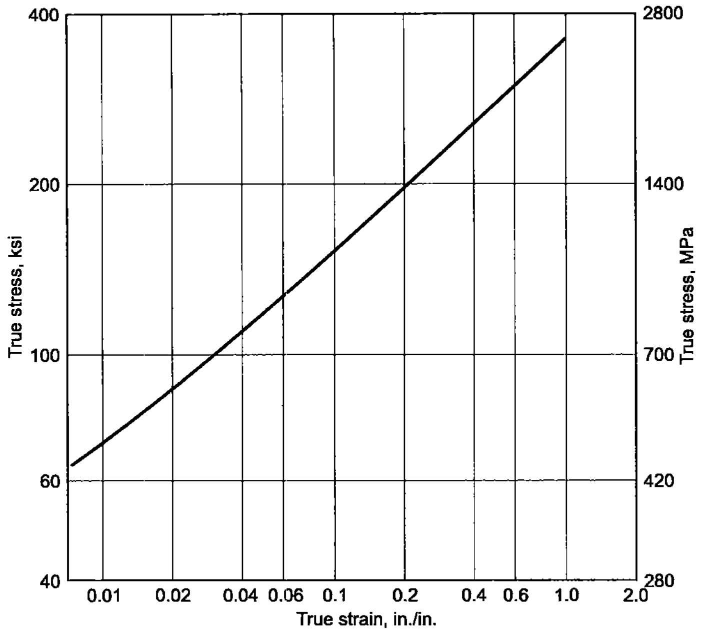
Source: E.J. Beck and F.R. Schwartzberg, "Determination of Mechanical and Thermophysical Properties of Refractory Metals," AFML-TR-65-247, July 1965. As published in *Aerospace Structural Metals Handbook*, Vol 5, Code 5209, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 13



RM.031 E8ZR niobium alloy rod, zone-refined, resolved shear stress-strain after one pass (top) and three passes (bottom)

The resolved shear stress as a function of engineering strain for the one- and three-pass electron beam zone-refined niobium is shown. Their orientations are shown in the unit triangles with each curve.

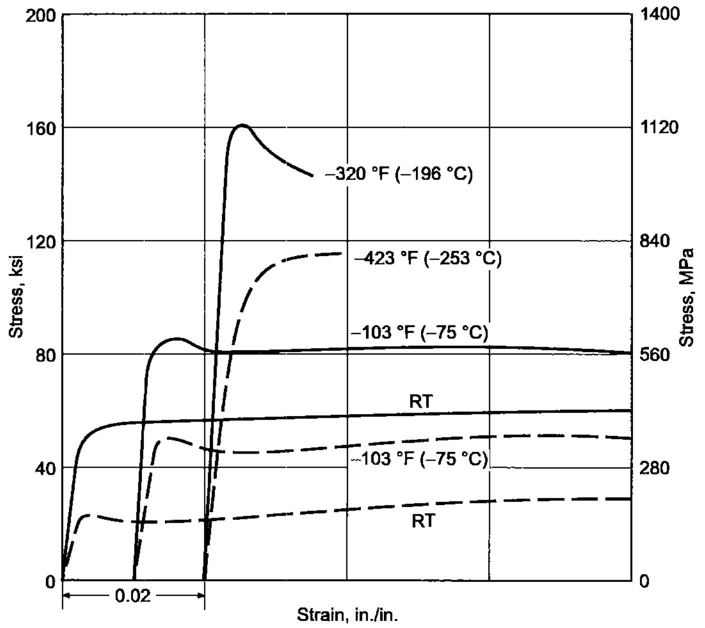
Source: M.K. Thomas, E.S. Jenkins, and J.F. Erthal, Mechanical Properties of Zone Refined Columbium and Tantalum, *High Temperature Refractory Metals,* 16–20, Feb 1964, Metallurgical Society of American Institute of Mining, Metallurgical, and Petroleum Engineers, Gordon and Breach Science Publishers, 1966, p 460



RM.032 Rhenium sheet, wire, and rod, average true stress-strain curve

Room-temperature properties for 0.254 mm (0.01 in.) sheet (S), 12.7 mm (0.5 in.) wire (W), and 3.175 mm (0.125 in.) rod (R), all in annealed condition. Yield strength (0.2%): S, 930 MPa (135 ksi); R', 317 MPa (46 ksi). Ultimate tensile strength: S, 1160 MPa (168 ksi); W, 1170 MPa (170 ksi); R, 1130 MPa (164 ksi)

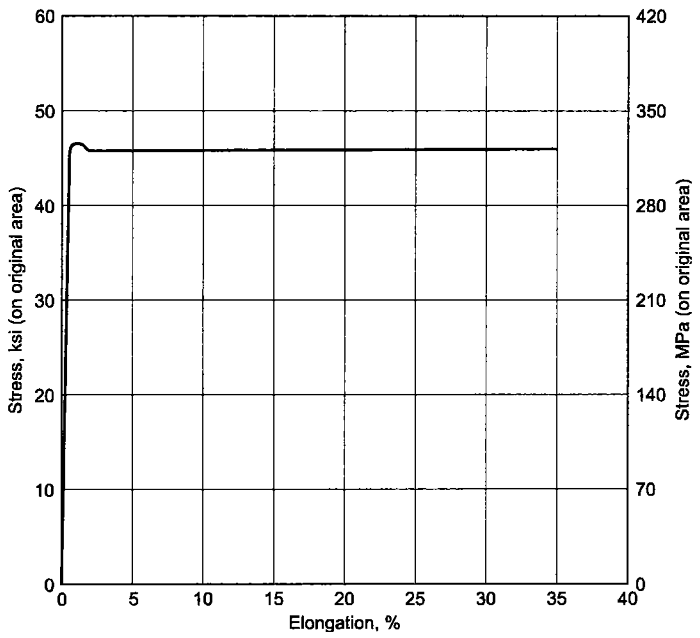
Source: B.W. Gonser, Ed., papers presented at symposium on rhenium, 3–4 May 1960 (Chicago, IL), Electrothermics and Metallurgical Division of the Electrochemical Society, Elsevier Publishing Co., 1962, p 34



RM.033 Commercially pure tantalum wrought bar, stress-strain curves at room and low temperatures

RT, room temperature. Solid lines for wrought bar stress relieved at 750 °C (1382 °F) for 1 h. Dashed lines for wrought bar, recrystallized at 1200 °C (2192 °F) for 3 h

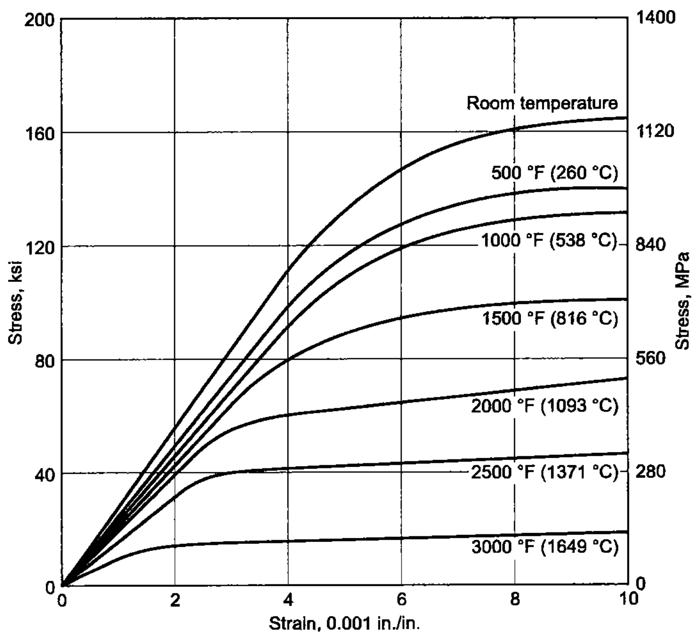
Source: A.G. Imgram, F.C. Holden, H.R. Ogden, and R.I. Jaffee, "Notch Sensitivity of Refractory Metals," WADD Tech. Rep. 60-278, 1960. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 5401, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 4



RM.034 Commercially pure recrystallized tantalum foil, tensile stress-strain curve

Foil thickness: 0.076 mm (0.0003 in.). Curve is similar to other body-centered cubic metals, showing the typical yield point. Yield drop observed in all specimens, with average being 21 MPa (3 ksi).

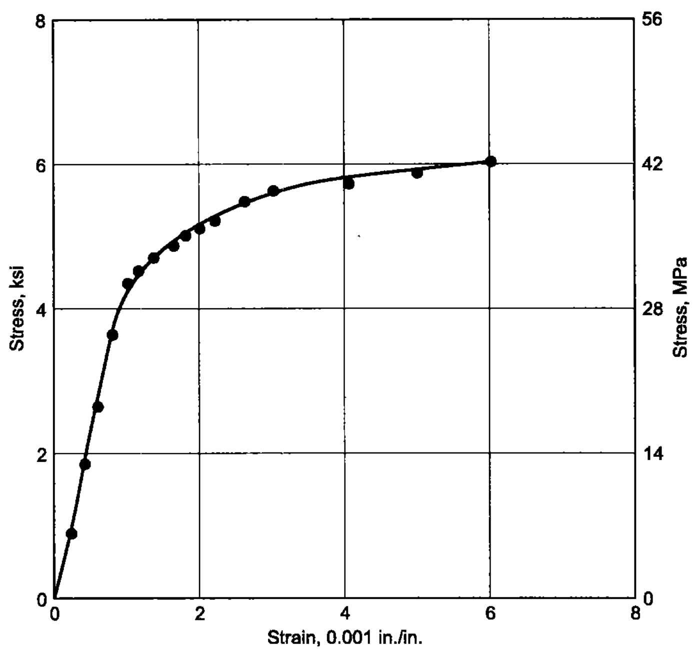
Source: R.P. Jewett and E.D. Weisert, Dislocation Morphology of Tantalum deformed in Tension, *High Temperature Refractory Metals,* based on a symposium, 16-20 Feb 1964, Metallurgical Society of American Institute of Mining, Metallurgical, and Petroleum Engineers, Gordon and Breach Science Publishers, 1966, p 163



RM.035 Ta-10W tantalum alloy sheet, arc cast, as-rolled, tensile stress-strain curves at room and elevated temperatures

1 mm (0.040 in.) sheet, as-rolled, 96% reduction, tested in argon at a strain rate of 0.001/s

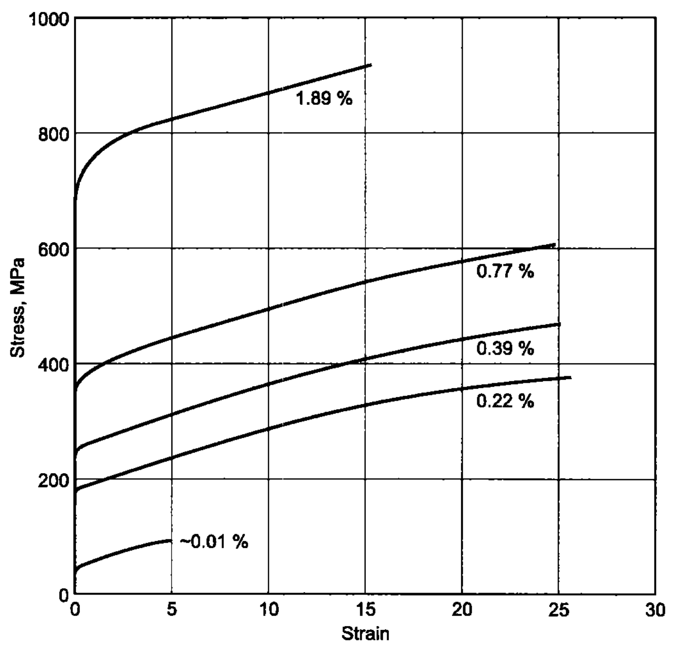
Source: A.S. Rabensteine, "Tensile and Creep Rupture Properties of Tantalum-10% Tungsten Alloy Sheet," PR 281-1Q-2, AF 33(657)-8706, The Marquardt Corp., Sept 1963. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 5402, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 6



RM.036 Ta-10W tantalum alloy, tensile stress-strain curve at 1704 °C (3100 °F)

Form and condition of material not given for curve. At 1704 °C (3100 °F): ultimate tensile strength, 109.3 MPa (15.85 ksi); tensile yield strength, 74.81 MPa (10.85 ksi), elongation, 22%

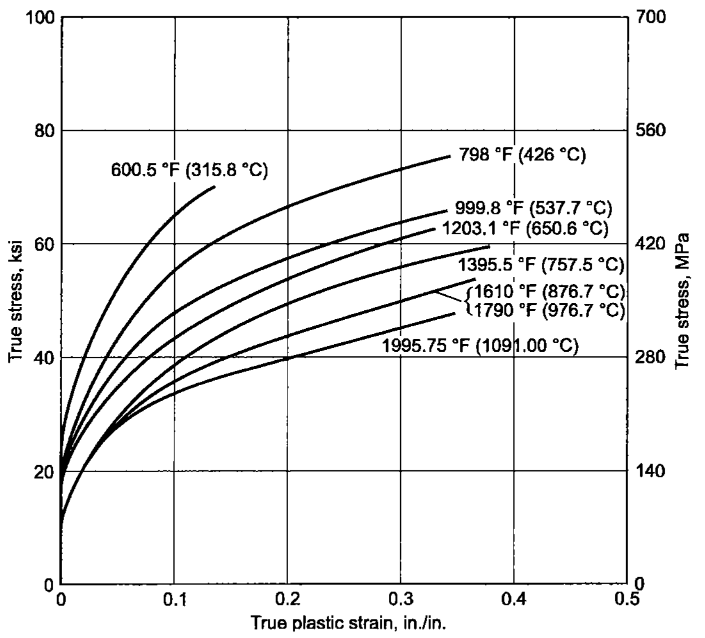
Source: P.E. Moorhead, "Tensile and Creep Properties of Columbium, Tantalum and Titanium Alloys at Elevated Temperatures," BLR-62-26, Bell Aerosystems Co., Dec 1962. As published in *Aerospace Structural Metals Handbook,* Vol 5, Code 5402, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 6



RM.037 Thorium-carbon alloy, tensile stress-strain curves for various alloys

Alloys with grain size approximately 18 μm, tested at 78 K, at a strain rate of 0.0007/s

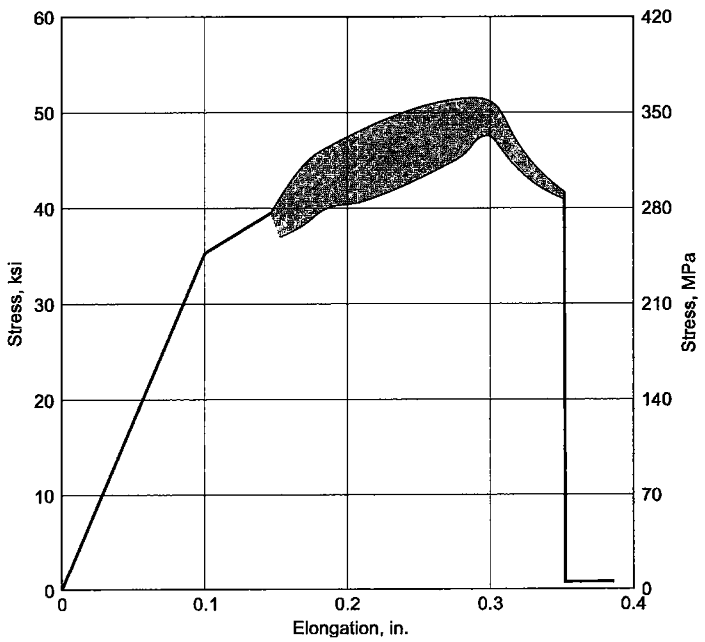
Source: G. Krauss, Ed., *Deformation, Processing, and Structure,* papers presented at ASM Materials Science Seminar, 23 Oct 1982 (St. Louis, MO), American Society for Metals, 1984, p 95



RM.038 Commercially pure tungsten rod, true tensile stress-strain curves at elevated temperatures

Recrystallized swaged rods

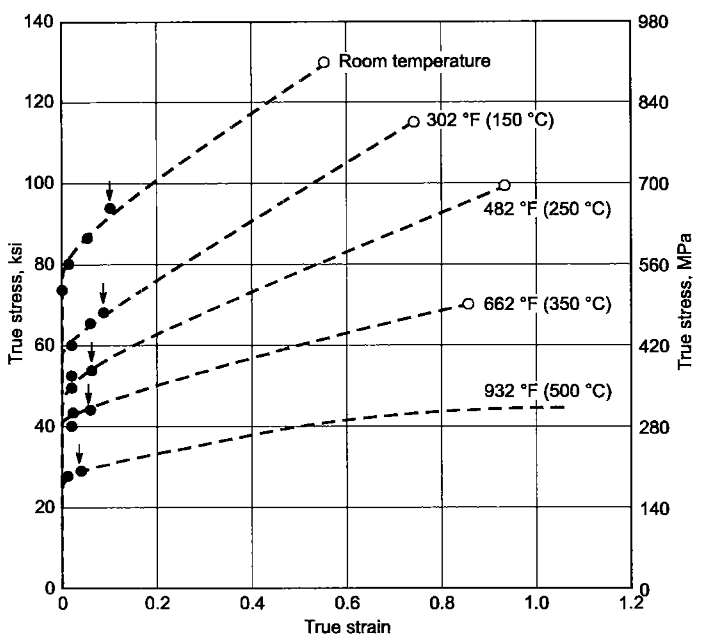
Source: J.W. Pugh, "Tensile and Creep Properties of Tungsten at Elevated Temperatures," ASTM Preprint No. 71, 1957. As published in *Aerospace Structural Metals Handbook*, Vol 5, Code 5501, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995



RM.039 W-Hf-C tungsten alloy rod, tensile stress elongation curve

Rod recrystallized at 2200 °C (4000 °F) 1 h and tested at 1370 °C (2500 °F). Composition: W-0.35Hf-0.025C

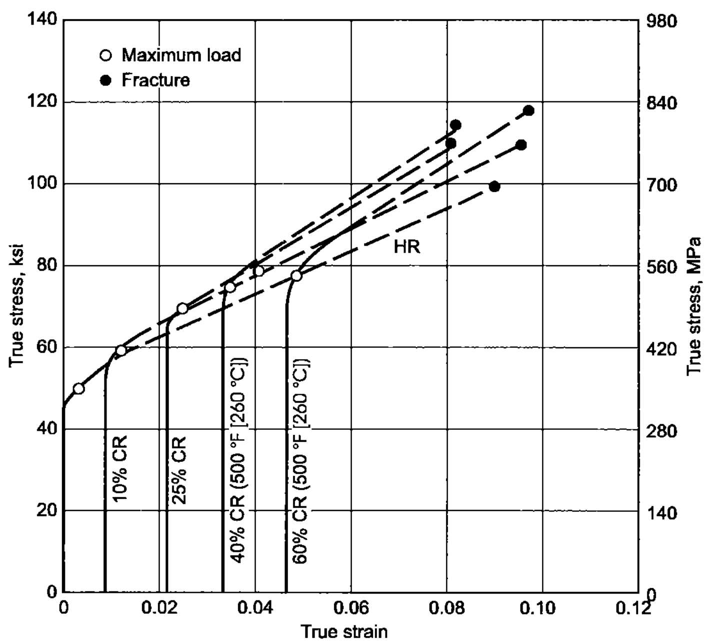
Source: L.S. Rubenstein, "Effect of Composition and Heat Treatment on High Temperature Strength of Arc Melted Tungsten-Hafnium-Carbon Alloys," TN D-4379, NASA Lewis Research Center, 1963. As published in *Aerospace Structural Metals Handbook*, Vol 5, Code 5502, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 4



RM.040 Zr-1.5Sn zirconium alloy, true tensile stress-strain curves at room and elevated temperatures

1.52 mm (0.060 in.) thick sheet hot rolled at 843 °C (1550 °F). Zircaloy 2 composition: Zr-1.5Sn. Nominal ultimate tensile strengths are indicated on curves by arrows.

Source: F. Forscher, "Effects of Cold Work on the Mechanical Properties of Zircaloy-2," Westinghouse Atomic Power Division, 1957. As published in *Aerospace Structural Metals Handbook*, Vol 5, Code 5701, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 5

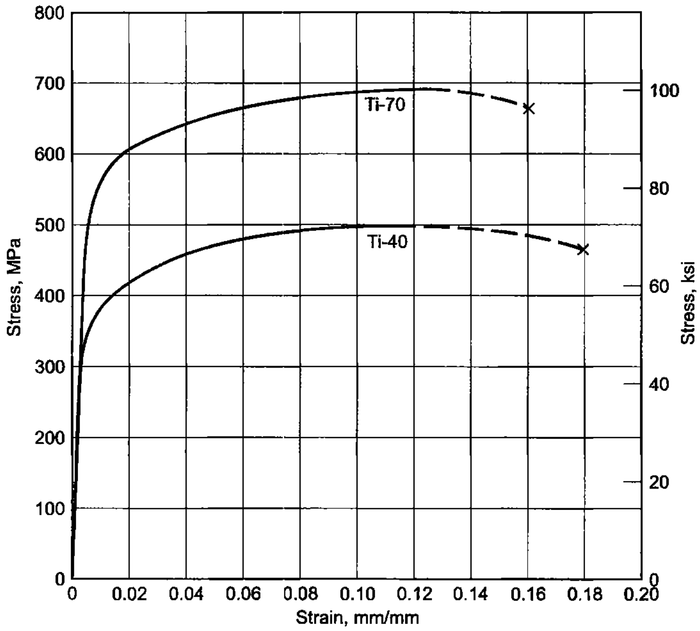


RM.041 Zr-1.5Sn zirconium alloy, true tensile stress-strain curves for various conditions

Sheet thickness: 1.52 mm (0.060 in.). Test direction: longitudinal. Tested at 250 °C (482 °F). HR, sheet hot rolled at 843 °C (1550 °F). Other curves for cold rolled (CR) conditions as indicated. Zircaloy 2 Composition: Zr-1.5Sn

Source: F. Forscher, "Effects of Cold Work on the Mechanical Properties of Zircaloy-2," Westinghouse Atomic Power Division, 1957. As published in *Aerospace Structural Metals Handbook*, Vol 5, Code 5701, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 5

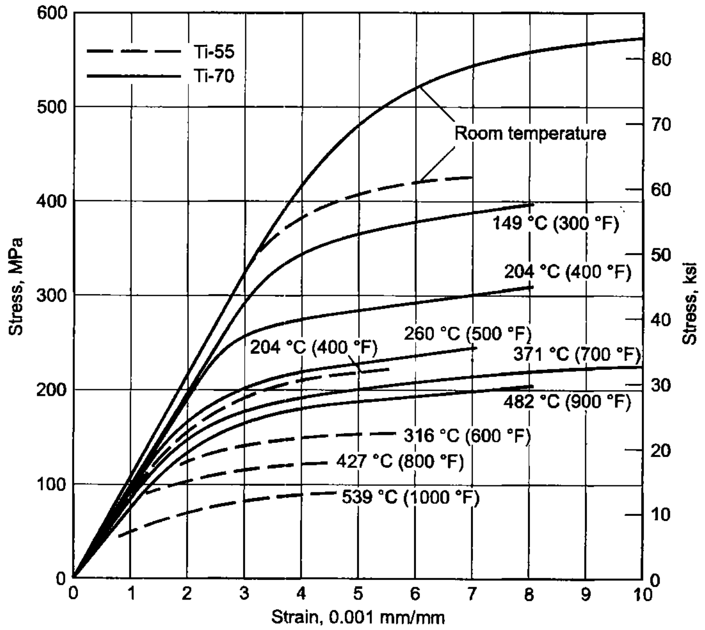
Titanium (Ti)



Ti.001 Commercially pure titanium (CP-Ti) sheet, typical tensile stress-strain curves (full range) at room temperature

Yield strength = 275 and 480 MPa (40 and 70 ksi). Ti-40 is UNS R50400; Ti-70 is UNS R50700.

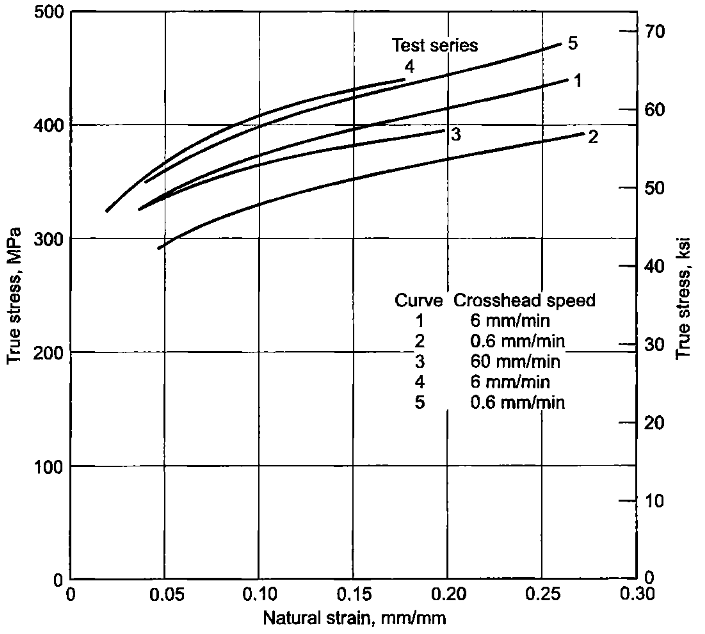
Source: Data consistent with *MIL-HDBK 5H,* 1998 p 5–13, 5–14. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *ASM Material Properties Handbook: Titanium Alloys*, ASM International, 1994, p 239



Ti.002 Commercially pure Ti-55 and Ti-70 titanium sheet, stress-strain curves at room and elevated temperatures

Ti-55 (UNS R50550): 1.6 mm (0.064 in.) thick, ½–100 h exposure. Ti-70 (UNS R50700): 0.6 mm (0.025 in.) thick

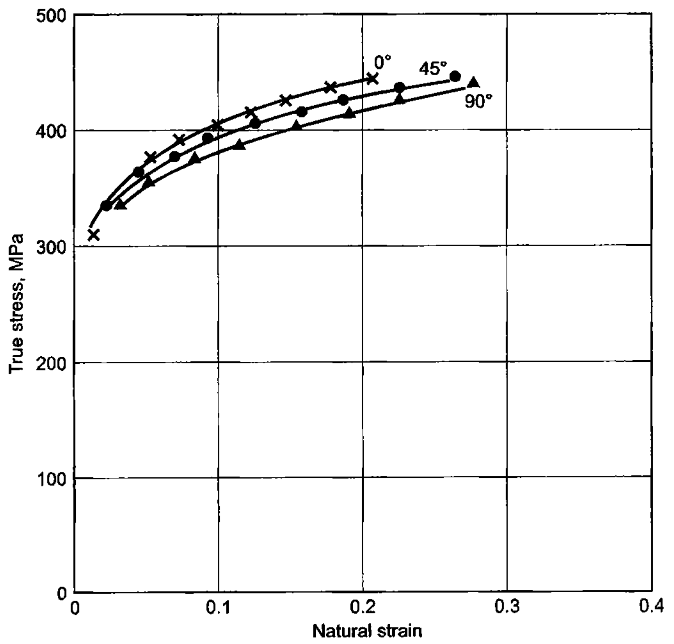
Source: Ti-70 data from E.J. King and H.M. Lundstrom, "Short-Time High-Temperature Data of Titanium Sheet RC-70," Bell Aircraft Corp., 1955. Ti-55 data from D.D. Doerr, "Determination of Physical Properties of Nonferrous Structural Sheet Materials at Elevated Temperatures," AFTR 6517 Part 1, Supplement 1, Feb 1953. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3701, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 5



Ti.003 Commercially pure titanium (CP-Ti) sheet, effect of crosshead speed on tensile stress-strain curves

Sheet thickness = 0.81 mm. Test direction: longitudinal. Tests for 1–3 conducted in air at 20 ± 1 °C; tests for 4 and 5 conducted in water at 20 ± 0.5 °C. Composition analysis: 0.009 C, 0.055–0.058 O_2, 0.002 H_2, 0.002Fe, 0.007 N

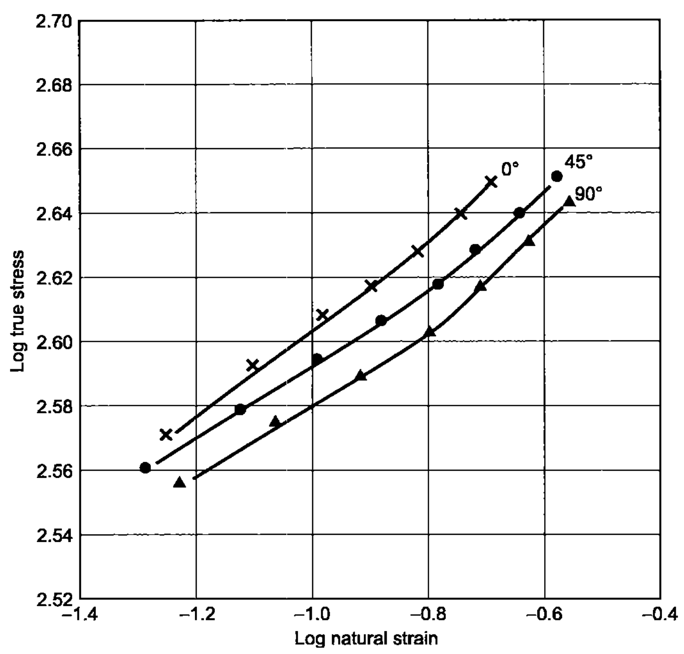
Source: P. Kvist, Material Properties of Commercially Pure Titanium Sheet, *Titanium '80 Science and Technology*, TMS, 1980, p 1124



Ti.004 Commercially pure titanium (CP-Ti) sheet, effect of orientation to rolling direction on tensile stress-strain curves

Sheet thickness = 0.81 mm. Curves from series 4 tests. 6 mm/min conducted in water at 20 ± 0.5 °C. Composition analysis: 0.009 C, 0.055–0.058 O_2, 0.002 H_2, 0.002 Fe, 0.007 N

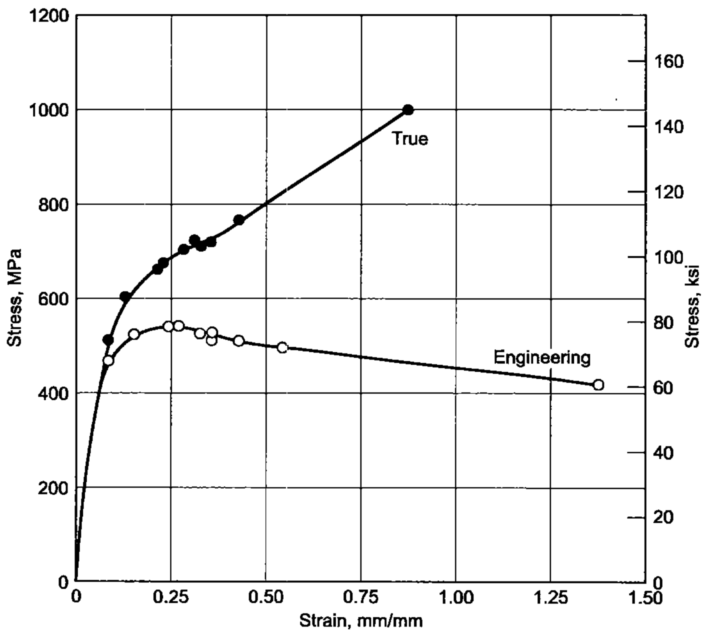
Source: P. Kvist, Material Properties of Commercially Pure Titanium Sheet, *Titanium '80 Science and Technology*, TMS, 1980, p 1124



Ti.005 Commercially pure titanium (CP-Ti) sheet, effect of orientation to rolling direction on log tensile stress-strain curves

Sheet thickness = 0.81 mm. Curves from series 4 tests. 6 mm/min conducted in water at 20 ± 0.5 °C. Log curves yield strain hardening *n* values for strains greater than and less than 0.15: *n*(0°, where strain is <0.15) = 0.14, *n*(0°, where strain is >0.15) = 0.17; *n*(45°, where strain is <0.15) = 0.11, *n*(45°, where strain is >0.15) =; *n*(90 °, where strain is <0.15) = 0.11, *n*(90°, where strain is >0.15) = 0.18. Composition analysis: 0.009 C, 0.055–0.058 O_2, 0.002 H_2, 0.002 Fe, 0.007 N

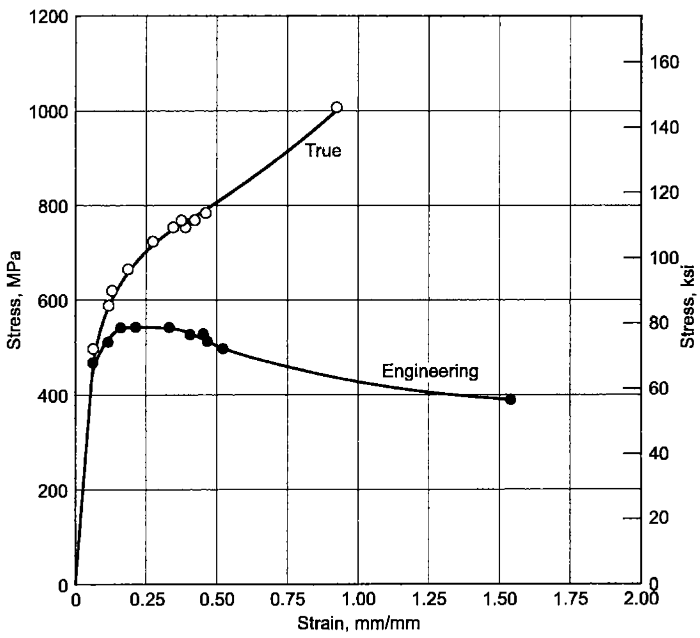
Source: P. Kvist, Material Properties of Commercially Pure Titanium Sheet, *Titanium '80 Science and Technology*, TMS, 1980, p 1124



Ti.006 Commercially pure grade 2 titanium textured sheet, true and engineering stress-strain curves

Test direction: longitudinal. UNS R50400

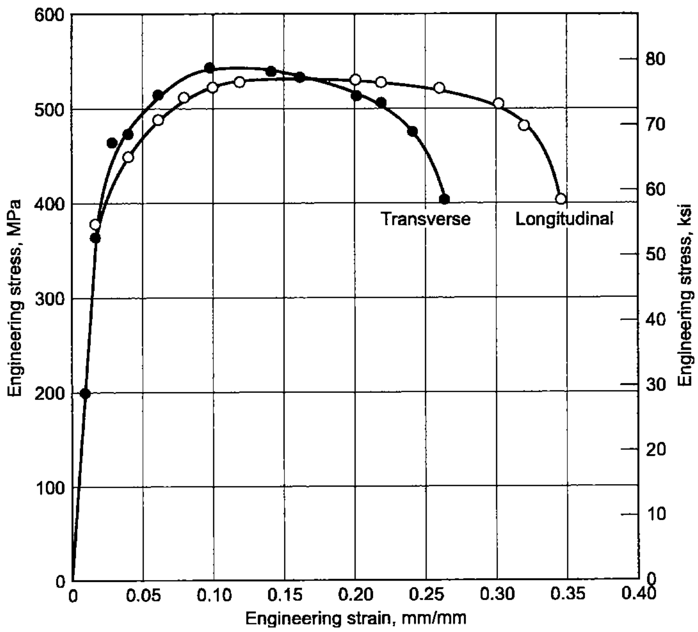
Source: L. Murugesh et al., *J. Mater. Shap. Technol.*, Vol 7 (No. 2), 1989, p 86. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 240



Ti.007 Commercially pure grade 2 titanium textured sheet, true and engineering stress-strain curves

Test direction: transverse. UNS R50400

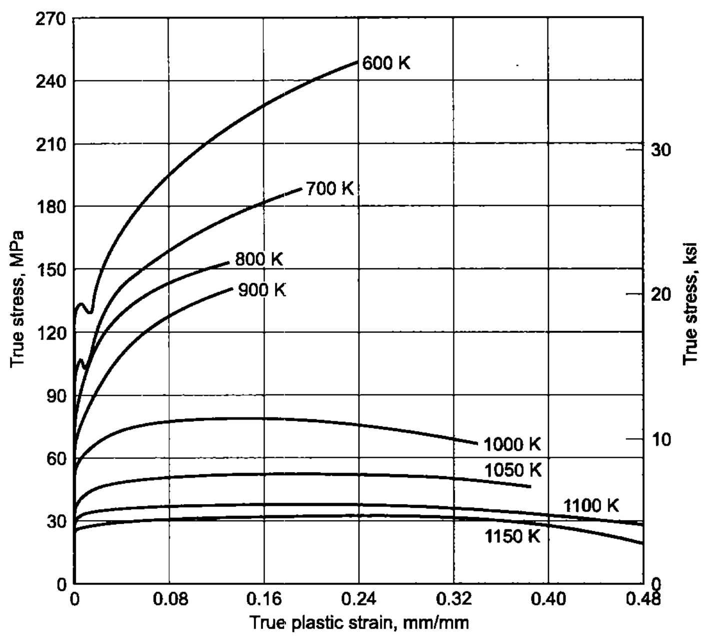
Source: L. Murugesh et al., *J. Mater. Shap. Technol.*, Vol 7 (No. 2), 1989, p 86. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 240



Ti.008 Commercially pure grade 2 titanium sheet, engineering stress-strain curves

Test direction: longitudinal and transverse. UNS R50400

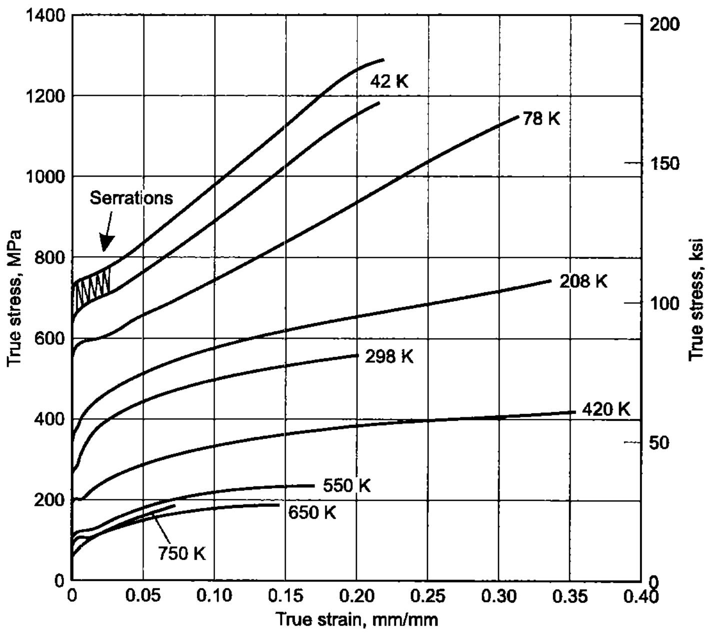
Source: L. Murugesh et al., *J. Mater. Shap. Technol.*, Vol 7 (No. 2), 1989, p 86. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 240



Ti.009 Grade 2 equivalent titanium, true stress-strain curves at elevated temperatures

Strain rate: 0.033/s. Composition: commercially pure with 0.49 at.% O_{eq}

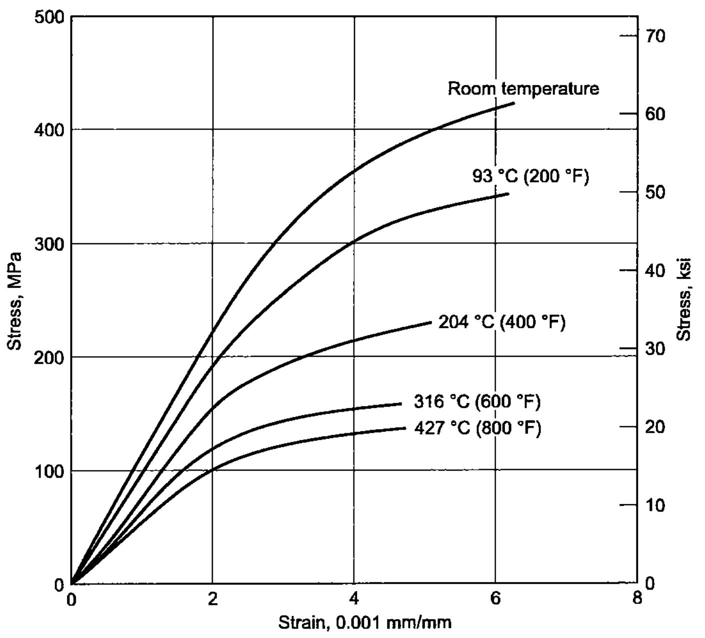
Source: Metall. Trans. A, Vol 14, Dec 1983, p 2810. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 241



Ti.010 Grade 2 equivalent titanium, true stress-strain curves at various temperatures

Strain rate: 0.00036/s. Composition: commercially pure with 0.5 at.% O_{eq}. Grain size: 22 μm

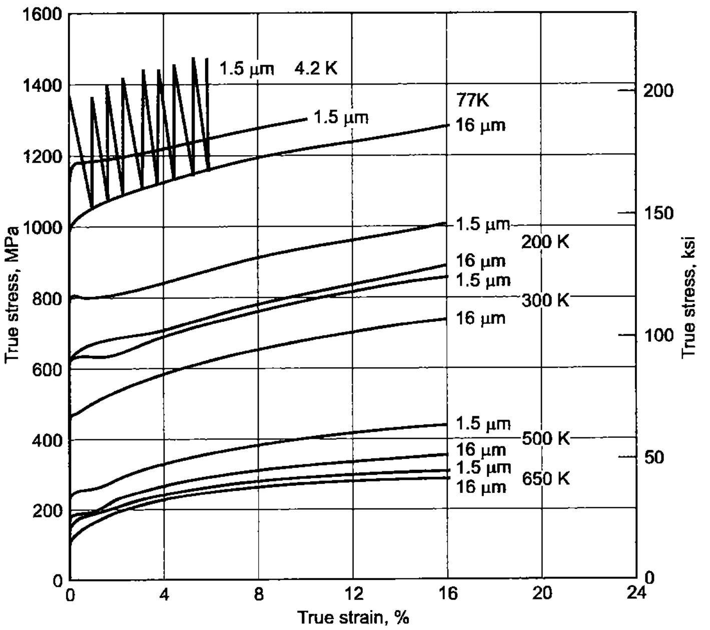
Source: Metall. Trans. A, Vol 14, Dec 1983, p 2546. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 241



Ti.011 Commercially pure grade 3 annealed titanium sheet, typical compressive stress-strain curves at room and elevated temperatures

Annealed at 705 °C (1300 °F), air cooled. UNS R50550. Chemical composition: Ti-0.02C-0.20Fe-0.005H-0.01N-0.20O

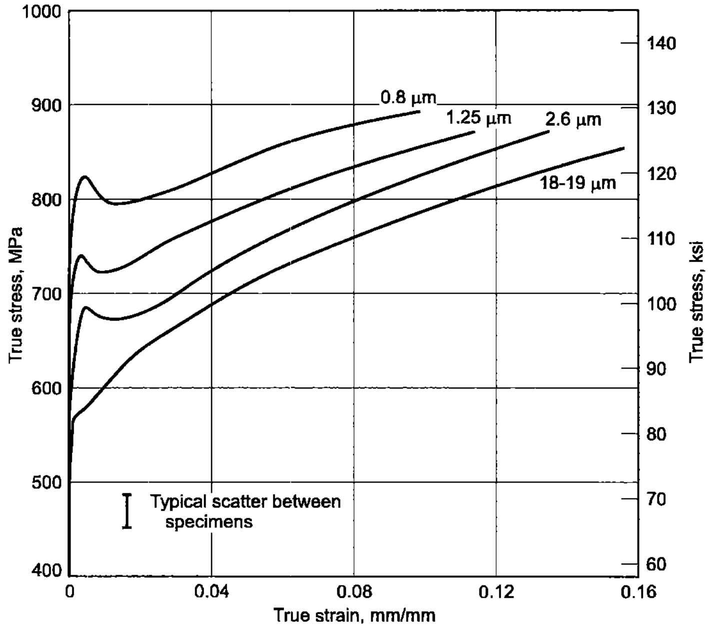
Source: Crucible Data Sheet, Crucible Specialty Metals. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 241



Ti.012 Commercially pure grade 4 titanium, effect of grain size on true stress-strain curves at various temperatures

Strain rate: 0.00033/s. UNS R50700. Composition: ~1 at.% O_{eq}

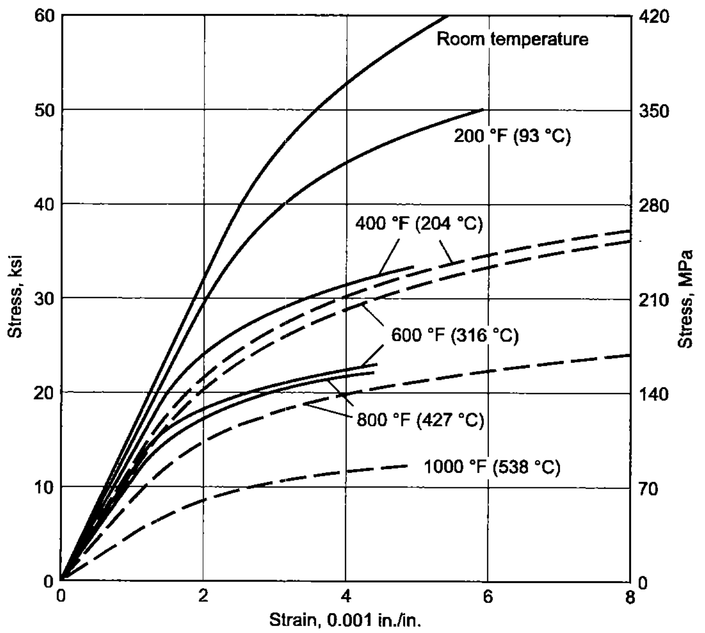
Source: Acta Metall., Vol 21, Aug 1973, p 1117–1129. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 241



Ti.013 Commercially pure grade 4 titanium, effect of grain size on true stress-strain curves at room temperature

Strain rate: ~0.0003/s. UNS R50700

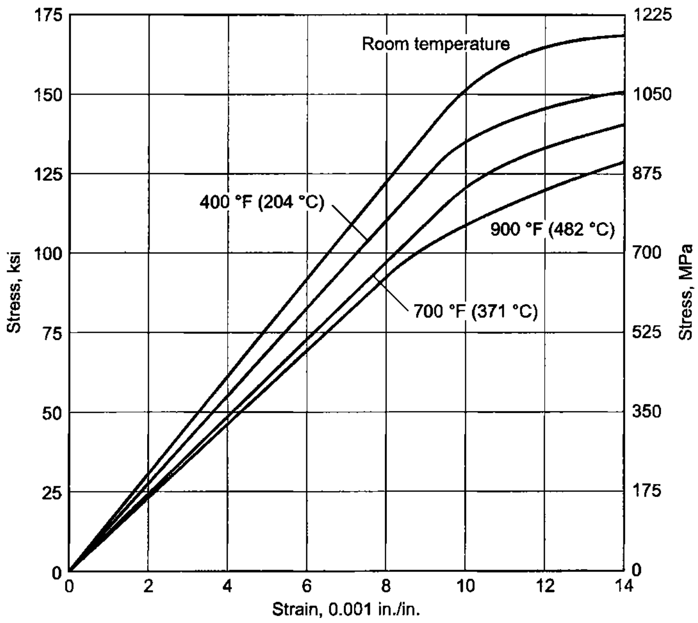
Source: H. Conrad and R. Jones, *The Science, Technology and Application of Titanium*, R.I. Jaffe and N.E. Promisel, Ed., Pergamon Press, p 489–501. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 239



Ti.014 Commercially pure titanium (Ti-55) sheet, compressive stress-strain curves for room and elevated temperatures

Solid line: 100 h exposure. Dashed line: ½–100 h exposure. UNS R50550

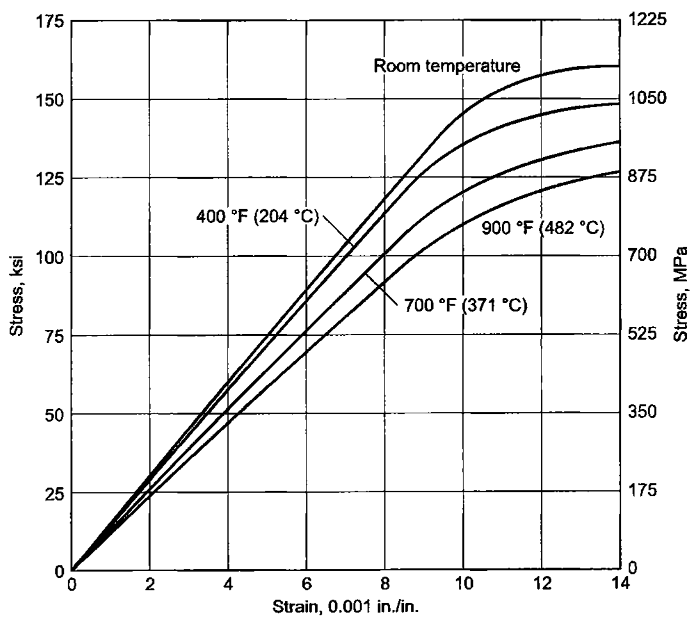
Source: Data for 0.5–100 h exposure from D.E. Miller, "Determination of the Tensile, Compressive and Bearing Properties of Ferrous and Nonferrous Structural Sheet Materials at Elevated Temperatures," AFTR Part 5, 1957. Data for 100 h exposure from TML Memo, 1958. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3701, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 7



Ti.015 Ti-3Al-8V-6Cr-4Mo-4Zr titanium alloy billet, tensile stress-strain curves for room and elevated temperatures

Test direction: longitudinal. 152 mm (6 in.) square billet solution heat treated for 15 min at 815 °C (1500 °F), air cooled, 12 h, 565 °C (1050 °F), air cooled. UNS R58640

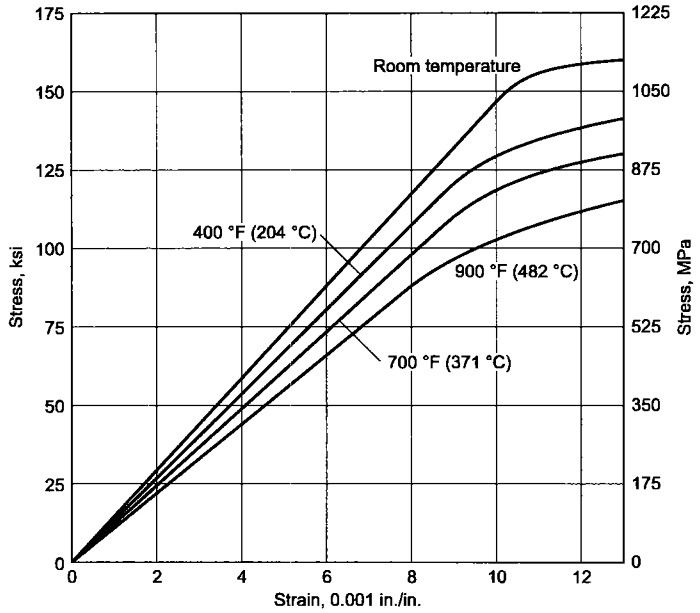
Source: O.L. Deel and H. Mindlin, "Engineering Data on New and Emerging Structural Materials," AFML-TR-70-252, Batelle-Columbus Laboratories. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3723, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 10



Ti.016 Ti-3Al-8V-6Cr-4Mo-4Zr titanium alloy billet, tensile stress-strain curves for room and elevated temperatures

Test direction: transverse. 152 mm (6 in.) square billet solution heat treated for 15 min at 815 °C (1500 °F), air cooled, 12 h, 565 °C (1050 °F), air cooled. UNS R58640

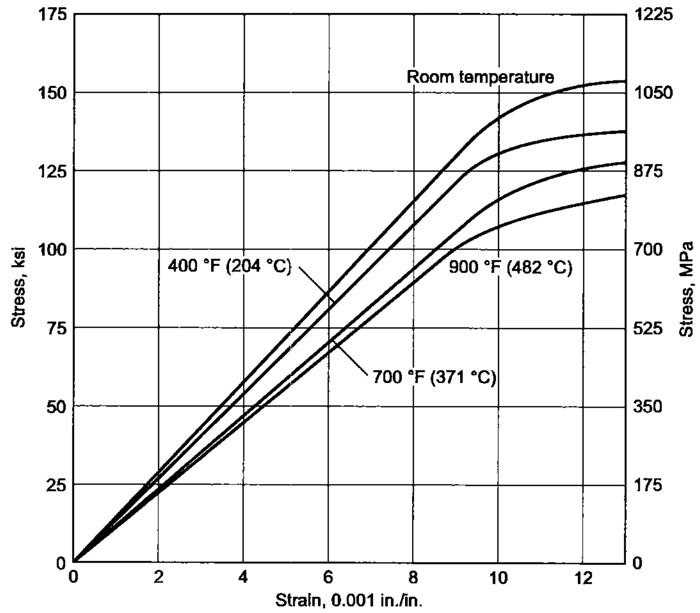
Source: O.L. Deel and H. Mindlin, "Engineering Data on New and Emerging Structural Materials," AFML-TR-70-252, Batelle-Columbus Laboratories. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3723, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 11



Ti.017 Ti-3Al-8V-6Cr-4Mo-4Zr titanium alloy billet, compressive stress-strain curves for room and elevated temperatures

Test direction: longitudinal. 152 mm (6 in.) square billet solution heat treated for 15 min at 815 °C (1500 °F), air cooled, 12 h, 565 °C (1050 °F), air cooled. UNS R58640

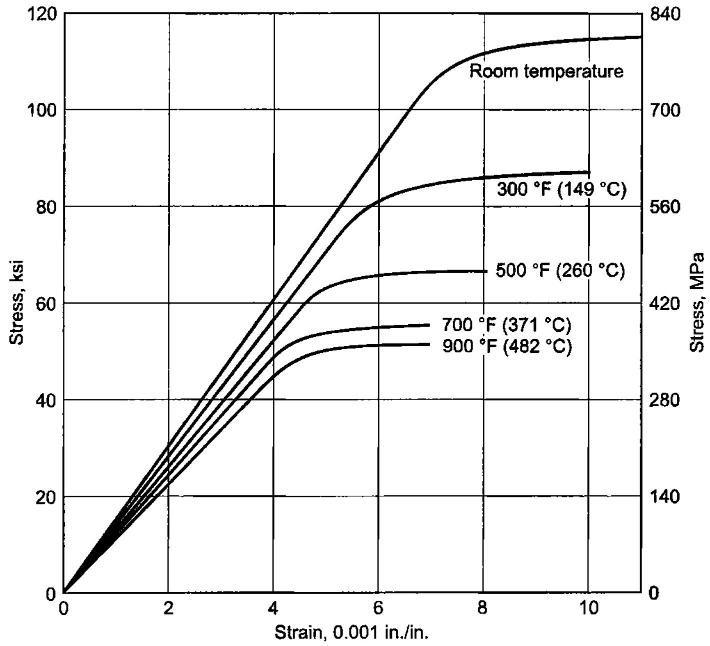
Source: O.L. Deel and H. Mindlin, "Engineering Data on New and Emerging Structural Materials," AFML-TR-70-252, Batelle-Columbus Laboratories. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3723, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



Ti.018 Ti-3Al-8V-6Cr-4Mo-4Zr titanium alloy billet, compressive stress-strain curves for room and elevated temperatures

Test direction: transverse. 152 mm (6 in.) square billet solution heat treated for 15 min at 815 °C (1500 °F), air cooled, 12 h, 565 °C (1050 °F), air cooled. UNS R58640

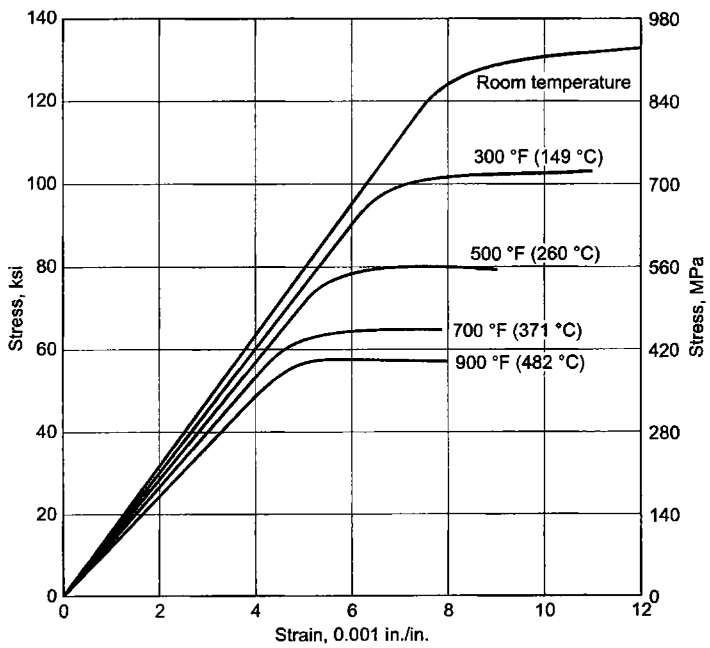
Source: O.L. Deel and H. Mindlin, "Engineering Data on New and Emerging Structural Materials," AFML-TR-70-252, Batelle-Columbus Laboratories. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3723, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



Ti.019 Ti-5Al-2.5Sn annealed titanium alloy sheet, bar, and forging, tensile stress-strain curves at room and elevated temperatures

90% probability tension. UNS R54520/R54521.

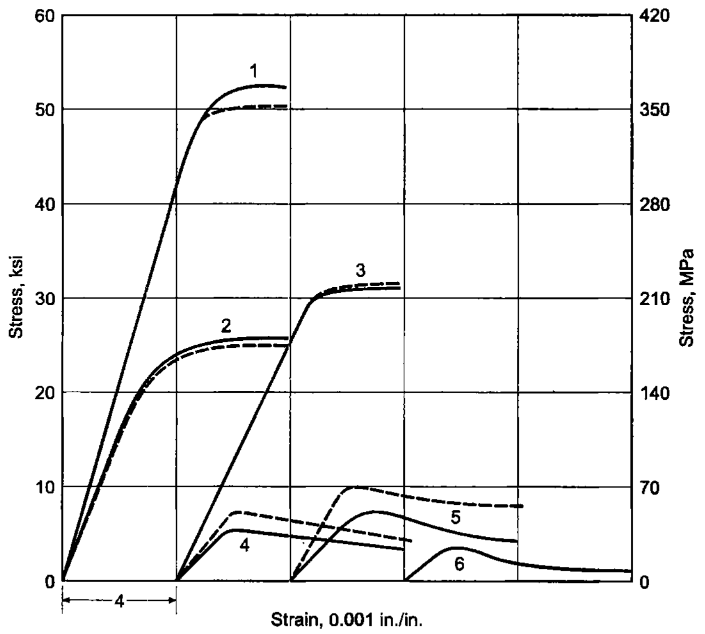
Source: "Compilation of Available Information on Ti-5Al-2.5Sn Alloy," TML Memo, Batelle Memorial Institute, 1957. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3706, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 5



Ti.020 Ti-5Al-2.5Sn annealed titanium alloy sheet, bar, and forging, compressive stress-strain at room and elevated temperatures

90% probability compression. UNS R54520/R54521

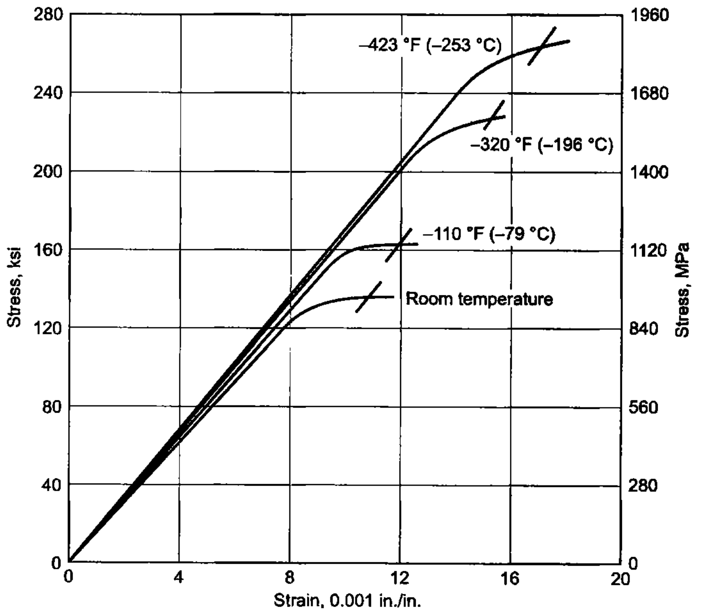
Source: "Compilation of Available Information on Ti-5Al-2.5Sn Alloy," TML Memo, Batelle Memorial Institute, 1957. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3706, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 8



Ti.021 Ti-5Al-2.5Sn annealed titanium alloy sheet, effect of test temperature, holding time, and strain rate on tensile properties

Holding time: solid line, 10 s; dashed line, 30 min. Strain rates at temperature: curve 1, 649 °C (1200 °F), 60 in./in./min; curve 2, 649 °C (1200 °F), 0.003 in./in./min; curve 3, 871 °C (1600 °F), 60 in./in./min; curve 4, 871 °C (1600 °F), 0.003 in./in./min; curve 5, 1288 °C (2350 °F), 60 in./in./min; curve 6, 1521 °C (2770 °F), 60 in./in./min. UNS R54520/R54521

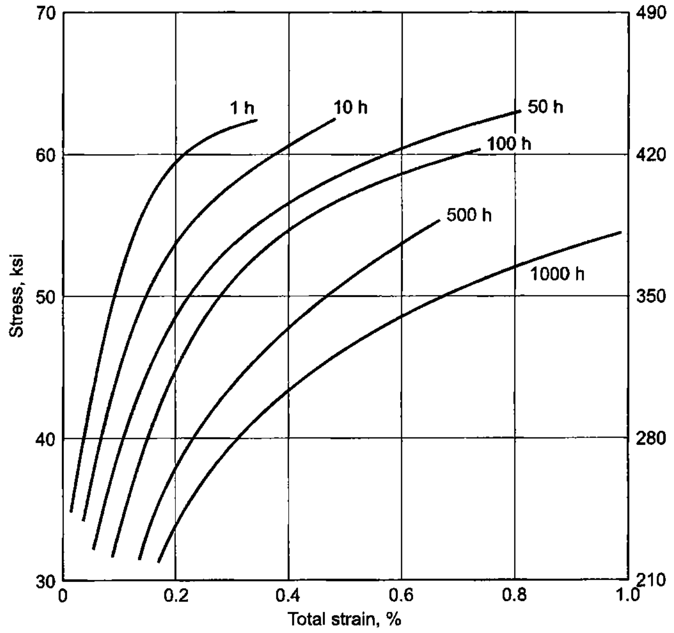
Source: J.D. Morrison and R.J. Kattus, "Tensile Properties of Aircraft-Structural Metals at Various Rates of Loading after Rapid Heating," WADC TR 55-199, 1956. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3706, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 6



Ti.022 Ti-5Al-2.5Sn annealed titanium alloy sheet, tensile stress-strain curves for room and low temperatures

UNS R54520/R54521

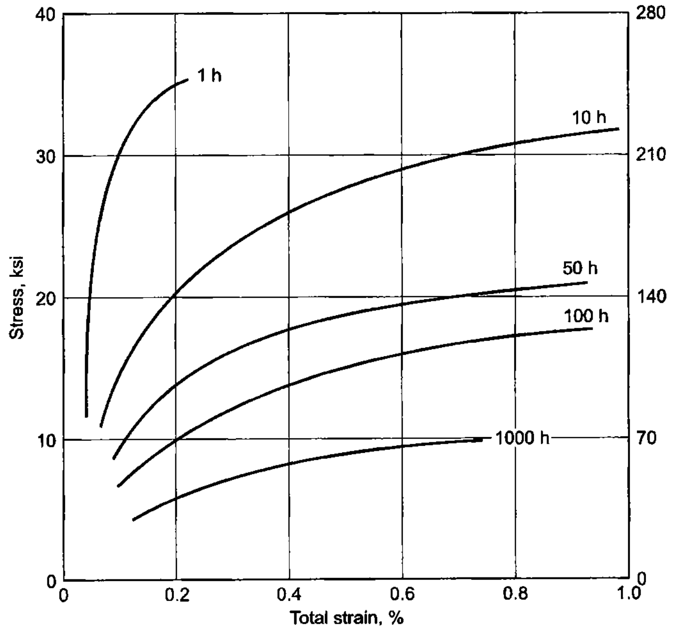
Source: R.L. McGee, J.E. Campbell, R.L. Carlson, and G.K. Manning, "The Mechanical Properties of Certain Aircraft Structural Metals at Very Low Temperatures," WADC TR 58-386, June 1958. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3706, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 6



Ti.023 Ti-5Al-2.5Sn annealed titanium alloy sheet, isochronous tensile stress-strain curves at 427 °C (800 °F)

Test direction: longitudinal. Sheet thickness = 1.6 mm (0.064 in.). Results are the average of two heats. UNS R54520/R54521

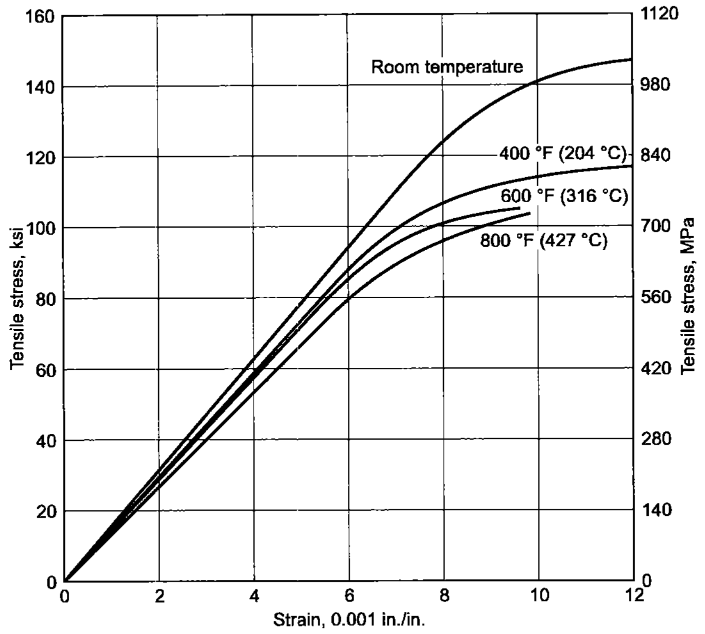
Source: J.O. Hatchet and E.L. Horne, "Tensile and Creep Properties of A110-AT Titanium Sheet Material at Elevated Temperatures," ASD TDR 62-524, July 1962. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3706, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



Ti.024 Ti-5Al-2.5Sn annealed titanium alloy sheet, isochronous stress-strain curves at 538 °C (1000 °F)

Test direction: longitudinal. Sheet thickness = 1.6 mm (0.064 in.). Results are the average of two heats. UNS R54520/R54521

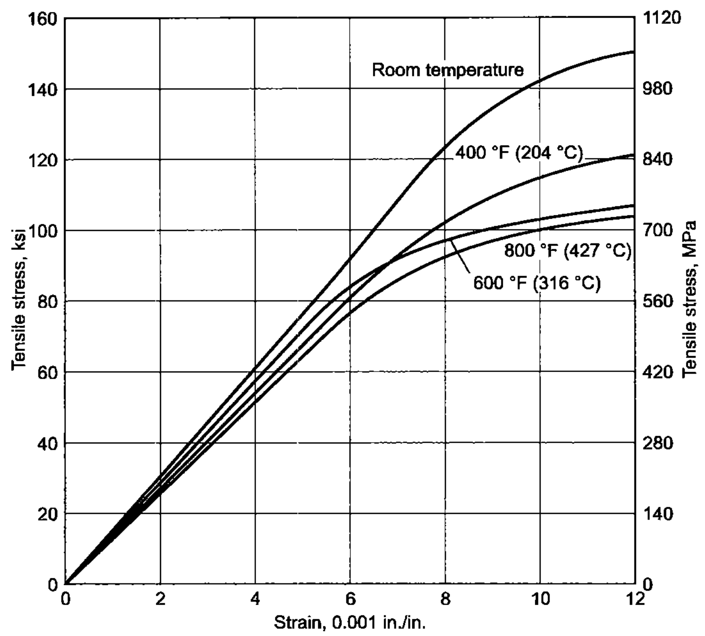
Source: J.O. Hatchet and E.L. Horne, "Tensile and Creep Properties of A110-AT Titanium Sheet Material at Elevated Temperatures," ASD TDR 62-524, 1962. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3706, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



Ti.025 Ti-6Al-2Sn-2Zr-2Mo-2Cr-0.25Si titanium alloy billet, tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal. α-β finished forged and duplex annealed billet 102 × 152 mm (4 × 6 in.). Billet treated at 952 °C (1745 °F), 1 h, air cooled + 900 °C (1650 °F), water quenched, 538 °C (1000 °F), 8 h

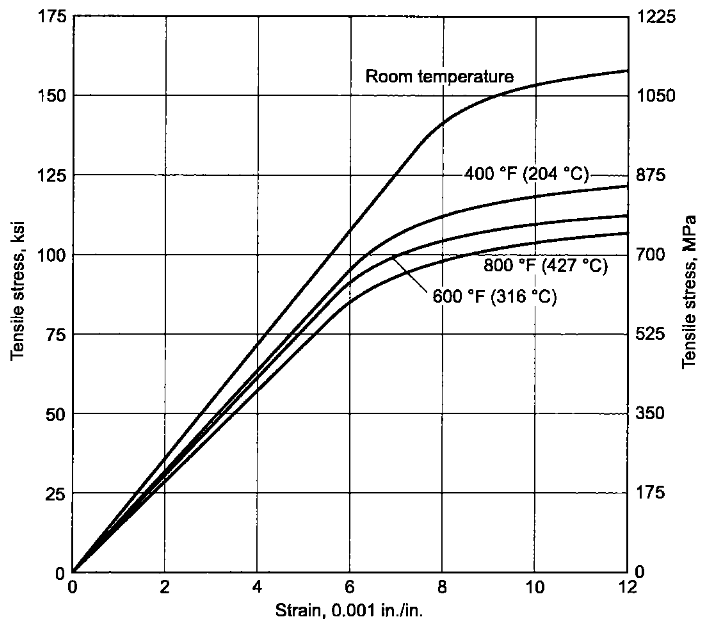
Source: O.L. Deel, P.E. Ruff, and H. Mindlin, "Engineering Data on New Aerospace Materials," AFML-TR-75-97, Batelle-Columbus Laboratories, June 1975. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3717, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 23



Ti.026 Ti-6Al-2Sn-2Zr-2Mo-2Cr-0.25Si titanium alloy billet, tensile stress-strain curves at room and elevated temperatures

Test direction: transverse. α-β finished forged and duplex annealed billet 102 × 152 mm (4 × 6 in.). Billet treated at 952 °C (1745 °F), 1 h, air cooled + 900 °C (1650 °F), water quenched, 538 °C (1000 °F), 8 h

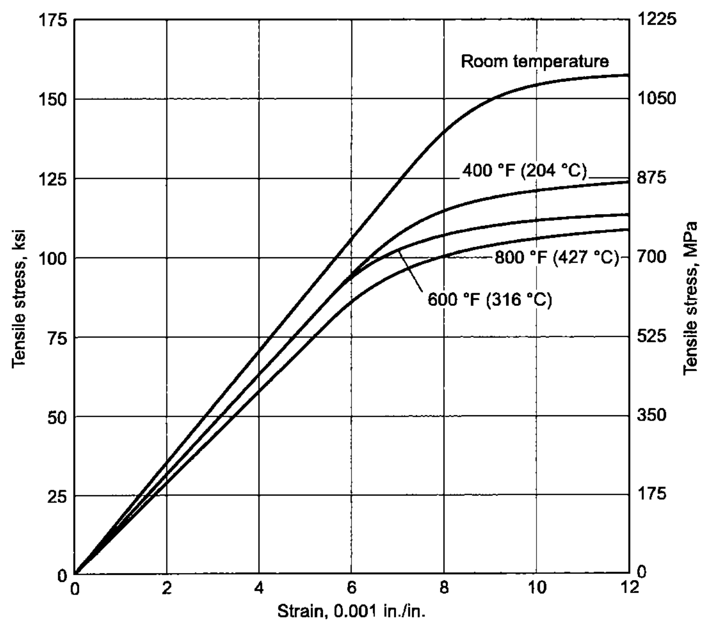
Source: O.L. Deel, P.E. Ruff, and H. Mindlin, "Engineering Data on New Aerospace Materials," AFML-TR-75-97, Batelle-Columbus Laboratories, June 1975. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3717, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 23



Ti.027 Ti-6Al-2Sn-2Zr-2Mo-2Cr-0.25Si titanium alloy plate, tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Plate thickness = 38 mm (1½ in.). Conventionally processed plate: 949 °C (1740 °F), 1 h, air cooled + 538 °C (1000 °F), 8 h

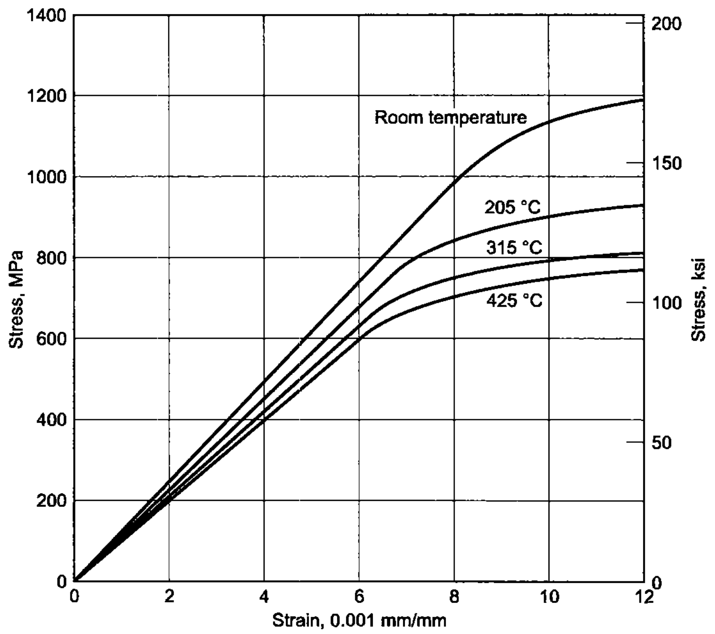
Source: O.L. Deel, P.E. Ruff, and H. Mindlin, "Engineering Data on New Aerospace Materials," AFML-TR-75-97, Batelle-Columbus Laboratories, June 1975. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3717, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 23



Ti.028 Ti-6Al-2Sn-2Zr-2Mo-2Cr-0.25Si titanium alloy plate, tensile stress-strain curves at room and elevated temperatures

Test direction: transverse. Plate thickness = 38 mm (1½ in.). Conventionally processed plate: 949 °C (1740 °F), 1 h, air cooled + 538 °C (1000 °F), 8 h

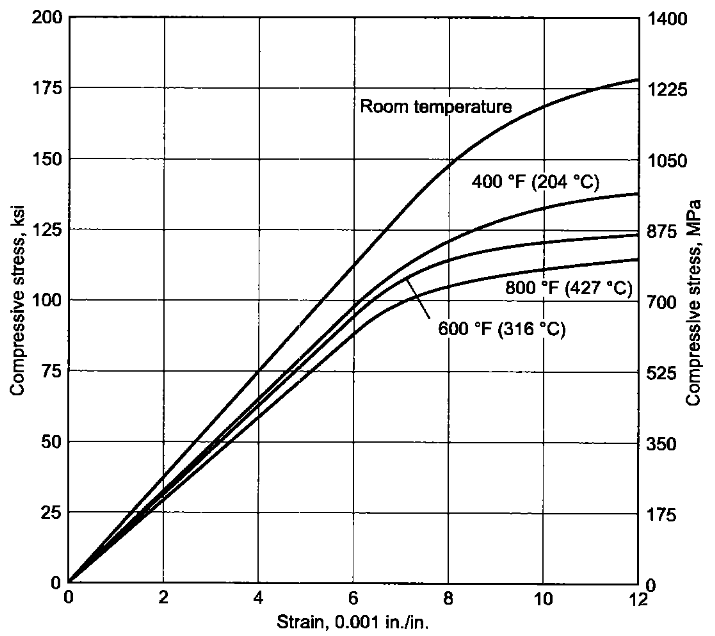
Source: O.L. Deel, P.E. Ruff, and H. Mindlin, "Engineering Data on New Aerospace Materials," AFML-TR-75-97, Batelle-Columbus Laboratories, June 1975. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3717, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 23



Ti.029 Ti-6Al-2Sn-2Zr-2Mo-2Cr-0.25Si solution treated annealed titanium alloy plate, compressive stress-strain curves at room and elevated temperatures

Test direction: longitudinal

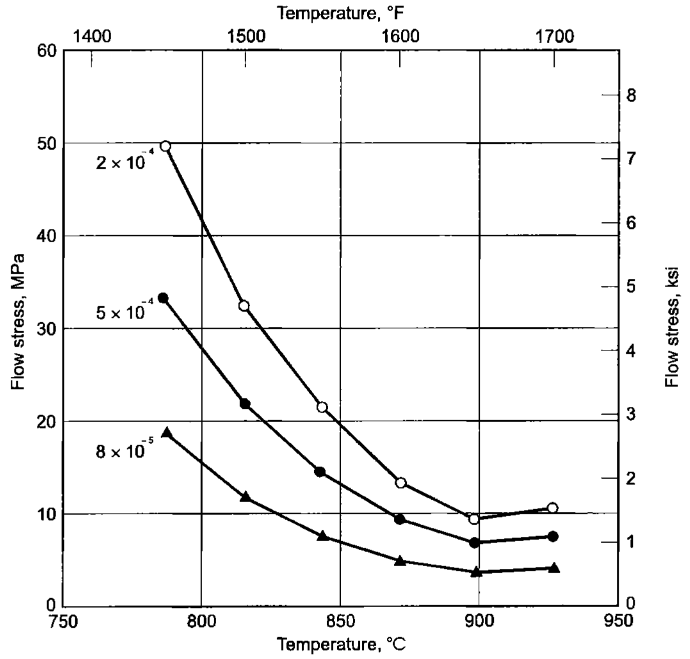
Source: O.L. Deel, P.E. Ruff, and H. Mindlin, "Engineering Data on New Aerospace Materials," AFML-TR-73-114, Batelle-Columbus Laboratories, June 1973. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 727



Ti.030 Ti-6Al-2Sn-2Zr-2Mo-2Cr-0.25Si titanium alloy plate, compressive stress-strain curves at room and elevated temperatures

Test direction: transverse. Plate thickness = 38 mm (1½ in.). Conventionally processed plate: 949 °C (1740 °F), 1 h, air cooled + 538 °C (1000 °F), 8 h

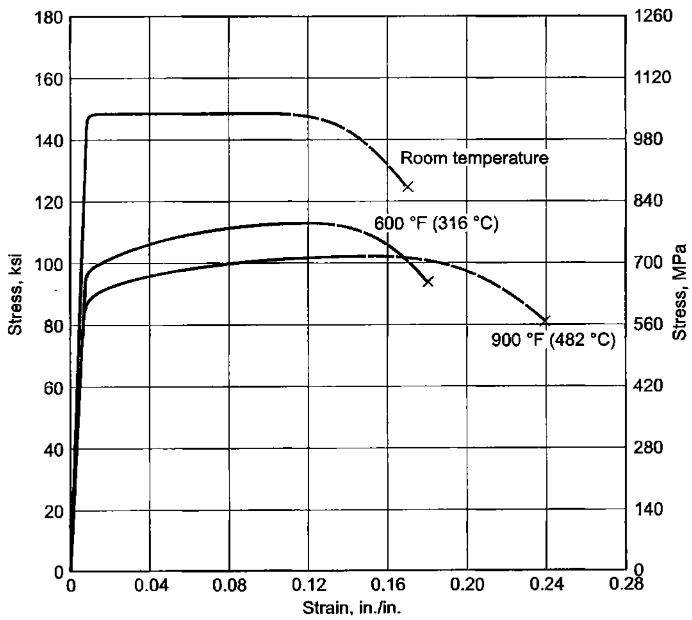
Source: O.L. Deel, P.F. Ruff, and H. Mindlin, "Engineering Data on New Aerospace Materials," AFML-TR-75-97, Batelle-Columbus Laboratories, June 1975. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3717, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 25



Ti.031 Ti-6Al-2Sn-2Zr-2Mo-2Cr-0.25Si annealed titanium-alloy sheet, flow stress versus temperature

Sheet thickness = 2.5 mm (0.10 in.). As-annealed step-strain-rate tensile tests under argon at several strain rates

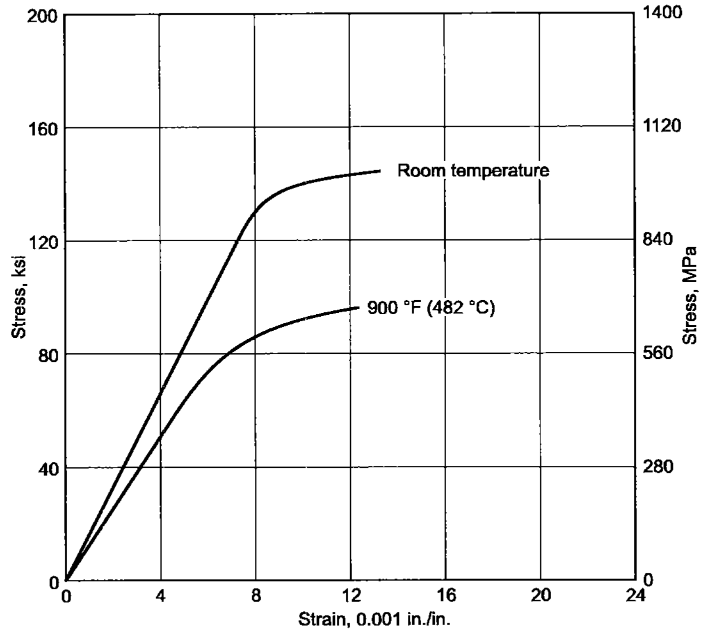
Source: RMI Titanium Co. unpublished data. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 727



Ti.032 Ti-6Al-2Sn-4Zr-2Mo duplex-annealed titanium sheet, typical tensile stress-strain curves (full range) at room and elevated temperatures

Test direction: longitudinal. 0.5 h exposure. UNS R54620

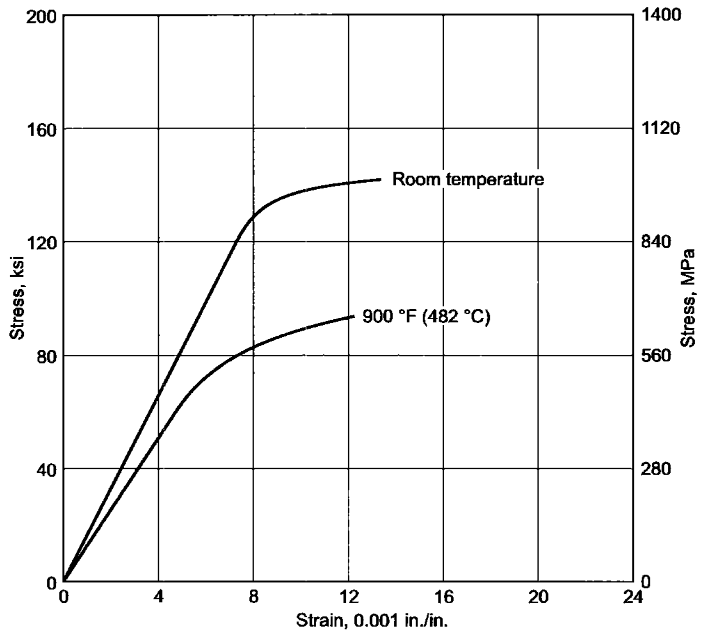
Source: *MIL-HDBK-5H*, Dec 1998, p 5–50



Ti.033 Ti-6Al-2Sn-4Zr-2Mo duplex- and triplex-annealed titanium alloy sheet, typical tensile stress-strain curves at room temperature and 482 °C (900 °F)

Test direction: longitudinal and transverse. Sheet thickness = 1.22–2.16 mm (0.048–0.085 in.). 0.5 h exposure. UNS R54620. Ramberg-Osgood parameters: *n*(room temperature) = 35; *n*(900 °F) = 12

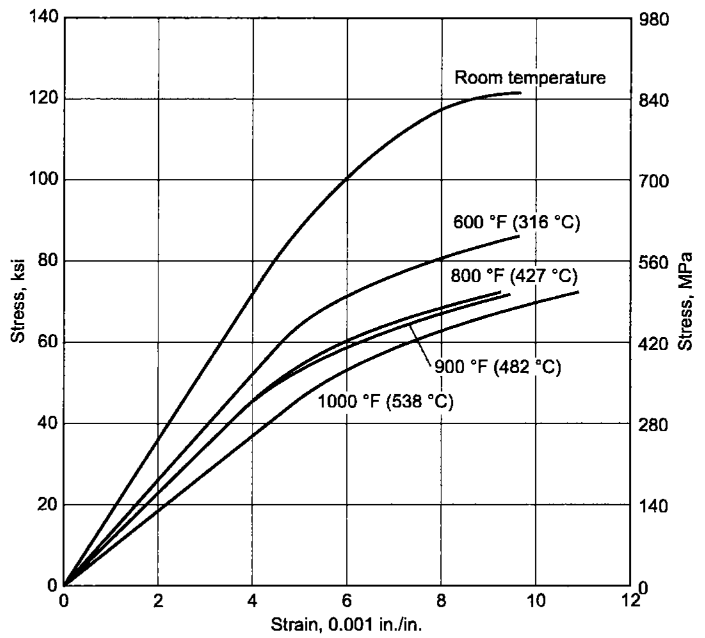
Source: *MIL-HDBK-5H*, Dec 1998, p 5–49



Ti.034 Ti-6Al-2Sn-4Zr-2Mo duplex-annealed titanium alloy bar, typical tensile stress-strain curves at room temperature and 482 °C (900 °F)

Test direction: longitudinal. Bar thickness = 28.575–31.75 mm (1.125–1.250 in.). 0.5 h exposure. UNS R54620. Ramberg-Osgood parameters: *n*(room temperature) = 34; *n*(900 °F) = 10

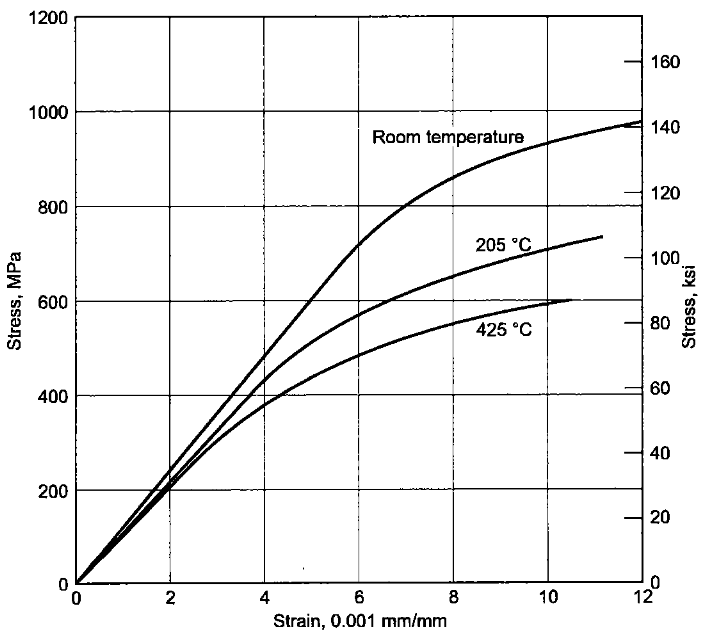
Source: *MIL-HDBK-5H*, Dec 1998, p 5–49



Ti.035 Ti-6Al-2Sn-4Zr-2Mo duplex-annealed titanium alloy bar, typical tensile stress-strain curves at room and elevated temperatures

Duplex annealed: 900 °C (1650 °F), 1 h, air cooled + 593 °C (1100 °F), 8 h, air cooled. UNS R54620

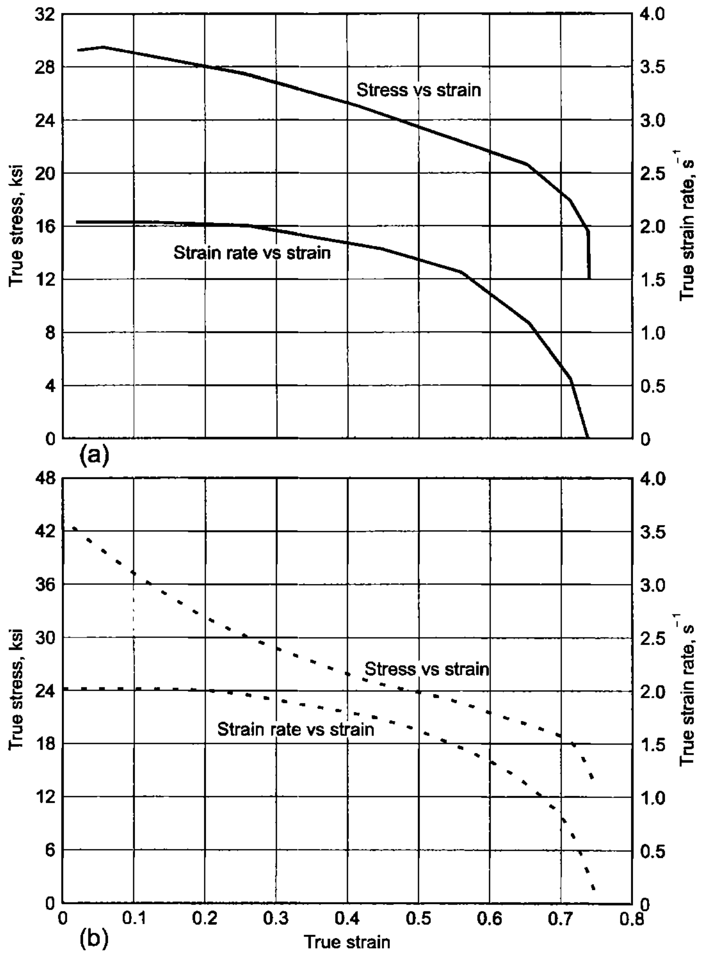
Source: "Metallurgical and Mechanical Properties of Titanium Alloy Ti-6Al-2Sn-4Zr-2Mo Sheet, Bar, and Forgings," TMCA, Sept 1966. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3718, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 67



Ti.036 Ti-6Al-2Sn-4Zr-2Mo titanium alloy tapered plate, compressive stress strain curves at room and elevated temperatures

Specimens were cast wedges (tapered plates) and were tested in the as-received as-cast condition. UNS R54620

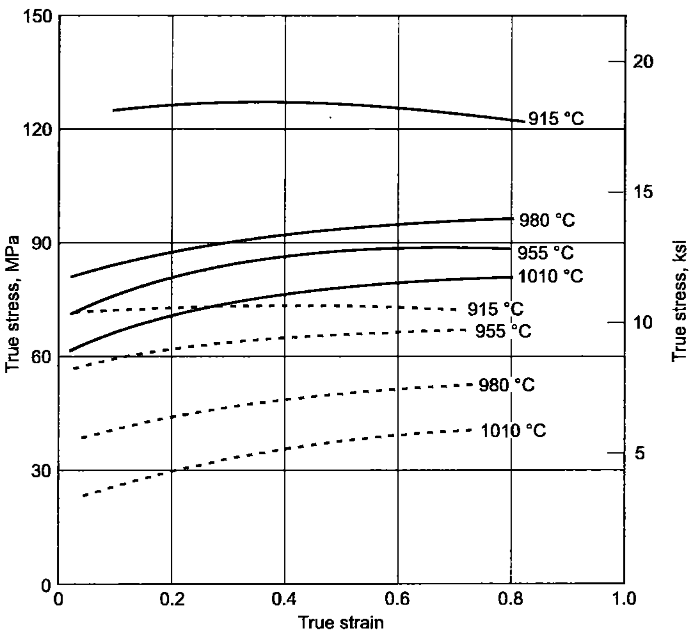
Source: O.L. Deel, "Engineering Data on New Aerospace Structural Materials," AFML-TR-77-198, Batelle-Columbus Laboratories, 1977, p 28. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 365



Ti.037 Ti-6Al-2Sn-4Zr-2Mo titanium alloy forging, true flow stress-strain and strain-strain rate curves

Tested at 915 °C for α + β (a) and β (b). For both, the stress decreases with strain (flow). UNS R54620

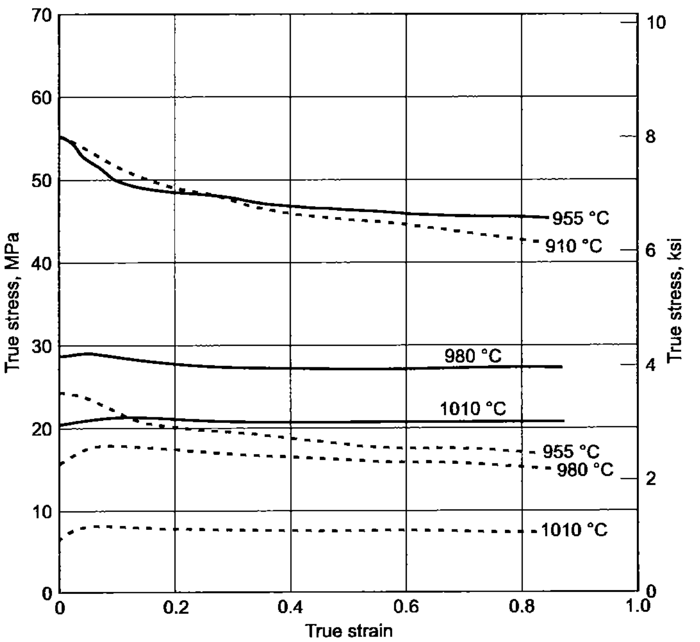
Source: S.L. Semiatin et al., in *Process Modeling Fundamentals and Applications to Metals*, American Society for Metals, 1980, p 387–408



Ti.038 Ti-6Al-2Sn-4Zr-2Mo titanium alloy, true stress-strain curves showing effects of temperature and strain rate

Strain rate: solid line, 10.0/s; dashed line, 1.0/s.
UNS R54620

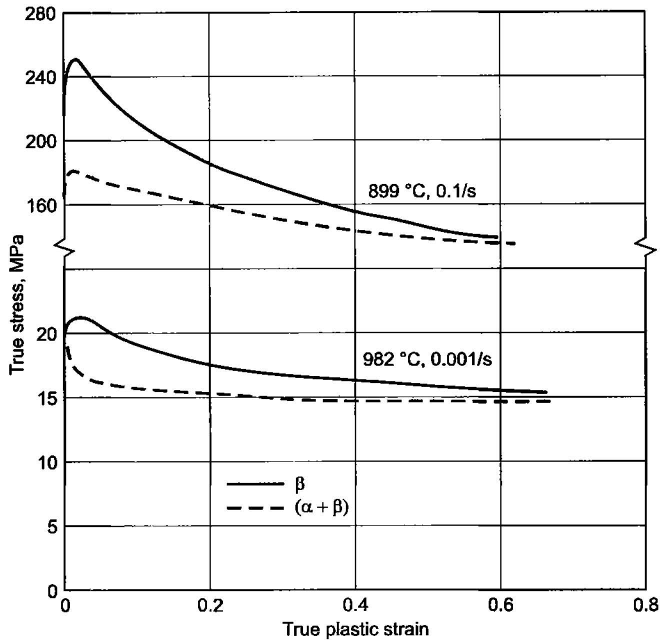
Source: G.D. Lahoti and T. Altan, AFML-TR-79-4156, Dec 1979. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 366



Ti.039 Ti-6Al-2Sn-4Zr-2Mo titanium alloy, true stress-strain curves showing effects of temperature and strain rate

Strain rate: solid line, 0.1/s; dashed line, 0.01/s.
UNS R54620

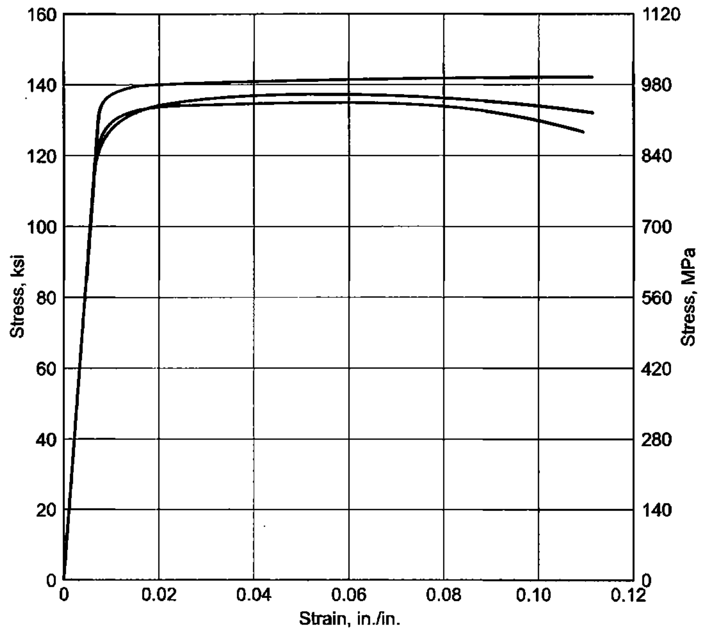
Source: G.D. Lahoti and T. Altan, "Research to Develop Process Models for Producing a Dual Property Titanium Alloy Compressor Disk," AFWAL-TR-80-4162, 1980. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 366



Ti.040 Ti-6Al-2Sn-4Zr-2Mo titanium alloy forging, true flow stress-strain curves

Flow stress of the α-β titanium alloy. The critical strains and temperatures for which the acicular α microstructure transformed to an equiaxed microstructure are shown. It is found that deformation to strains of the order of 1.0 at 900 °C (1650 °F), followed by heat treatment at 955 °C (1750 °F), produced the desired transformation. UNS R54620

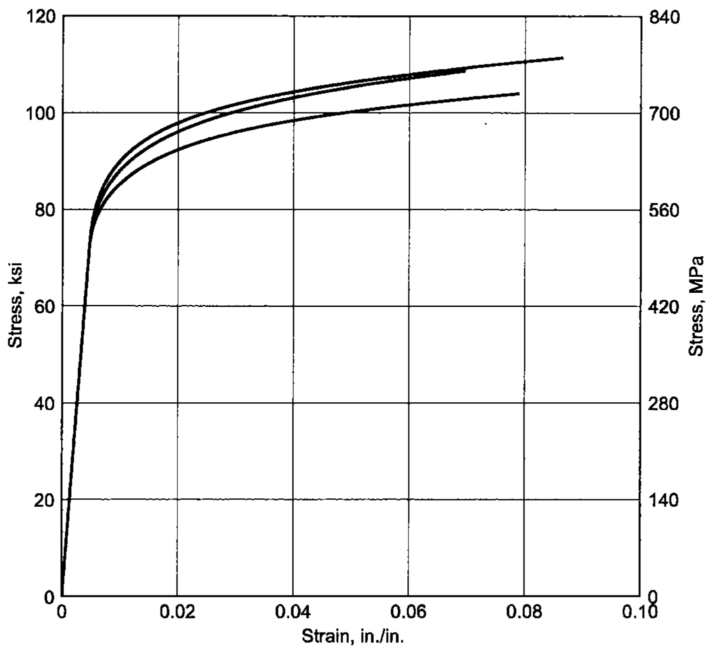
Source: T.G. Byrer, S.L. Semiatin, and D.C. Vollmer, Ed., *Forging Handbook*, Forging Industry Association of America, 1985, p 116



Ti.041 Ti-6Al-2Sn-4Zr-2Mo titanium alloy forged compressor discs, typical tensile stress-strain curves at room temperature

Duplex annealed 968 °C (1775 °F), 1 h, air cooled, 593 °C (1100 °F), 8 h, air cooled. UNS R54620

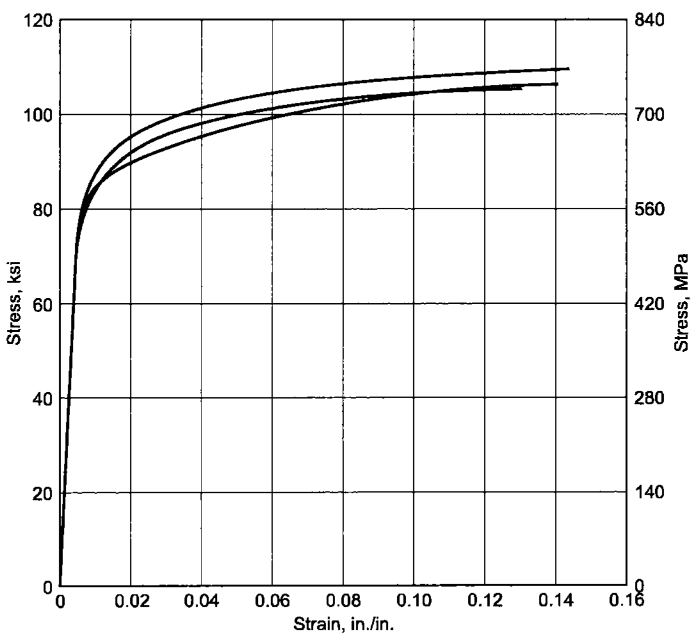
Source: G. Curbishley, "Mechanical Properties of Ti-6Al-6Sn-4Zr-2Mo Forgings," Garrett Corp. Airesearch Manufacturing Co., 1970. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3718, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 49



Ti.042 Ti-6Al-2Sn-4Zr-2Mo duplex-annealed titanium alloy forged compressor discs, tensile stress-strain curves at 316 °C (600 °F)

Duplex annealed 968 °C (1775 °F), 1 h, air cooled, 593 °C (1100 °F), 8 h, air cooled. UNS R54620

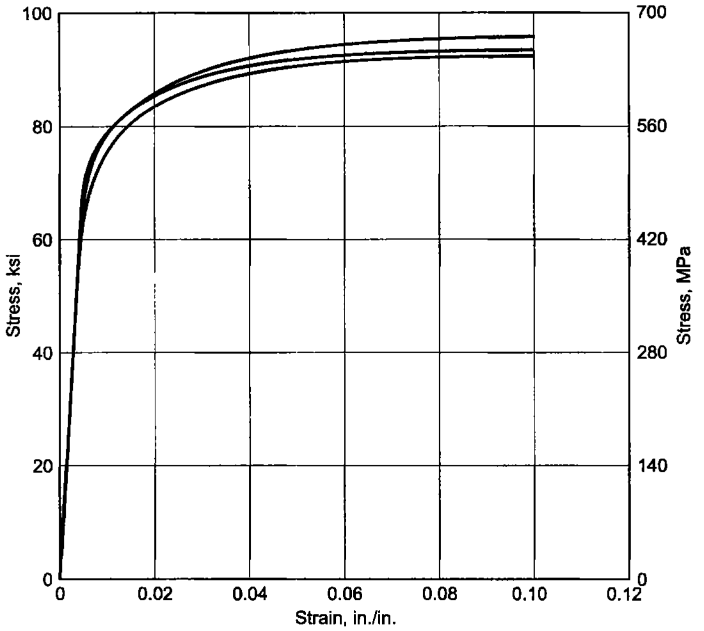
Source: G. Curbishley, "Mechanical Properties of Ti-6Al-6Sn-4Zr-2Mo Forgings," Garrett Corp. Airesearch Manufacturing Co., 1970. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3718, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 68



Ti.043 Ti-6Al-2Sn-4Zr-2Mo duplex-annealed titanium alloy forged compressor discs, tensile stress-strain curves at 427 °C (800 °F)

Duplex annealed 968 °C (1775 °F), 1 h, air cooled, 593 °C (1100 °F), 8 h, air cooled. UNS R54620

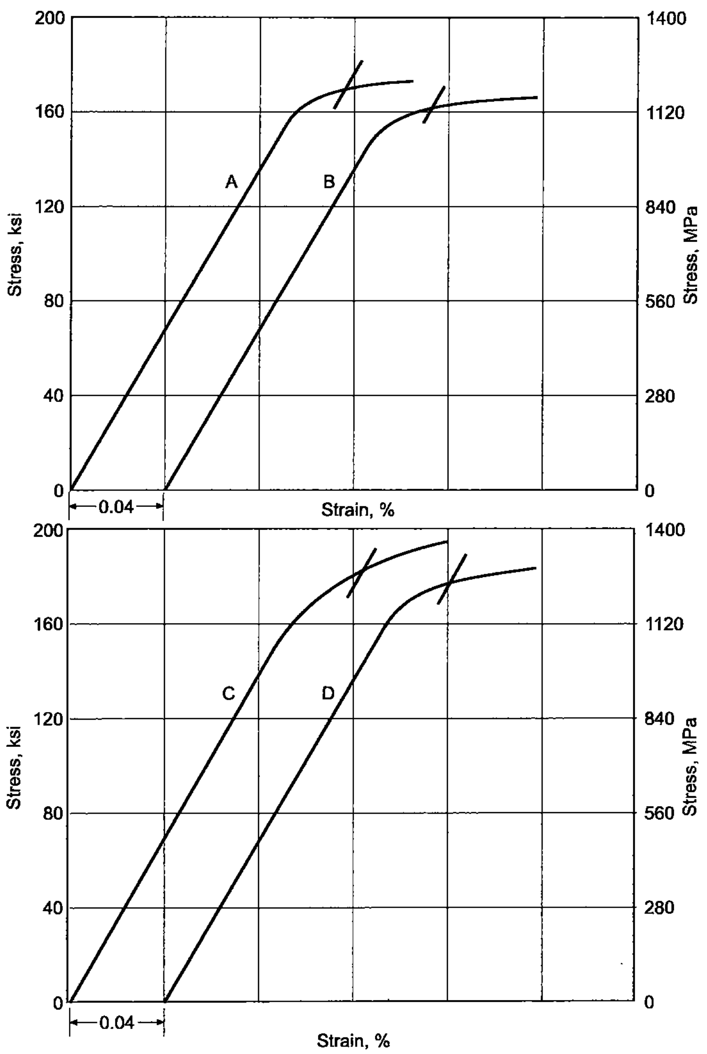
Source: G. Curbishley, "Mechanical Properties of Ti-6Al-6Sn-4Zr-2Mo Forgings," Garrett Corp. Airesearch Manufacturing Co., 1970. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3718, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 68



Ti.044 Ti-6Al-2Sn-4Zr-2Mo duplex-annealed titanium alloy forged compressor discs, tensile stress-strain curves at 538 °C (1000 °F)

Duplex annealed 968 °C (1775 °F), 1 h, air cooled, 593 °C (1100 °F), 8 h, air cooled. UNS R54620

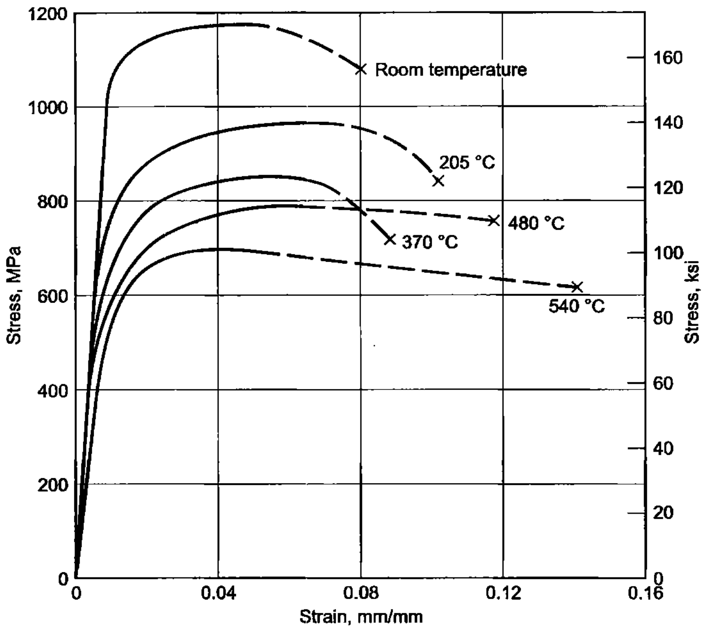
Source: G. Curbishley, "Mechanical Properties of Ti-6Al-6Sn-4Zr-2Mo Forgings," Garrett Corp. Airesearch Manufacturing Co., 1970. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3718, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 68



Ti.045 Ti-6Al-2Sn-4Zr-6Mo duplex-annealed titanium alloy forging, duplicate stress-strain curves for two different duplex-annealing treatments

Test specimens 6.3 mm (0.25 in.) diam × 25.4 mm (1 in.) gage. Duplex anneal for curves A and B: 904 °C (1660 °F), 1 h, air cooled + 593 °C (1100 °F), 8 h, air cooled. Duplex annealing for curves C and D: 910 °C (1670 °F), 1 h, fast air cooled + 593 °C (1100 °F), 8 h, air cooled. Curve A: ultimate tensile strength = 1255 MPa (182 ksi); tensile yield strength = 1165 MPa (169 ksi); elongation in 25 mm (1 in.) = 15%; reduction of area = 37%. Curve B: ultimate tensile strength = 1220 MPa (177 ksi); tensile yield strength = 1117 MPa (162 ksi); elongation in 25 mm (1 in.) = 13%; reduction of area = 32%. Curve C: ultimate tensile strength = 1386 MPa (201 ksi); tensile yield strength = 1317 MPa (191 ksi); elongation in 25 mm (1 in.) = 9%; reduction of area = 22%. Curve D: ultimate tensile strength = 1276 MPa (185 ksi); tensile yield strength = 1227 MPa (178 ksi); elongation in 25 mm (1 in.) = 10%; reduction of area = 22%. UNS R56260

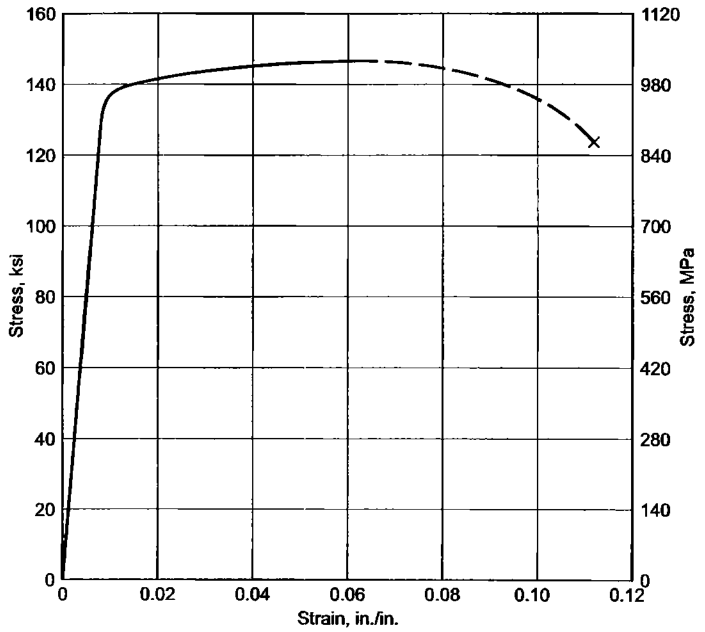
Source: Personal communication from D.H. Wilson, RMI Co. to J.R. Kattus, 31 Jan 1972. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3714, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 9



Ti.046 Ti-6Al-4V solution treated and aged titanium alloy, all forms, tensile stress-strain curves for room and elevated temperatures

Test direction: longitudinal. 0.5 h exposure.
UNS R56400/R56401

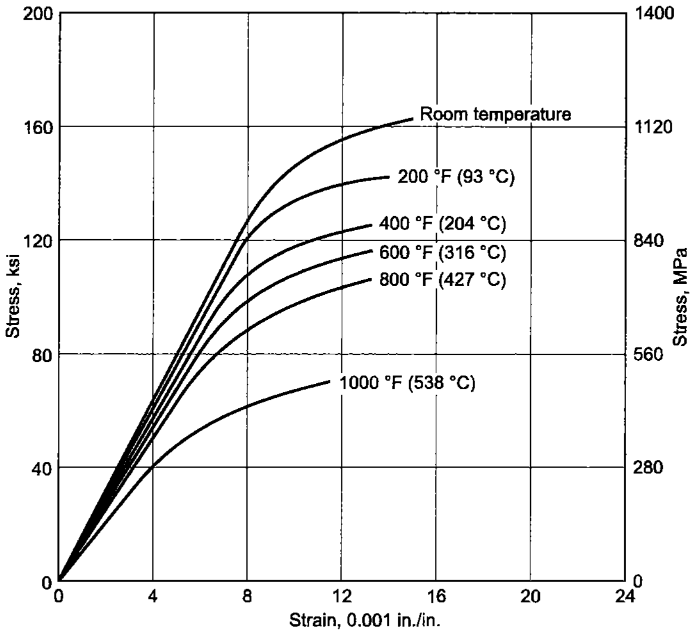
Source: *MIL-HDBK 5,* 1991. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys,* ASM International, 1994, p 592



Ti.047 Ti-6Al-4V annealed titanium alloy sheet, typical tensile stress-strain curves at room temperature (full range)

Test direction: longitudinal and transverse.
UNS R56400/R56401

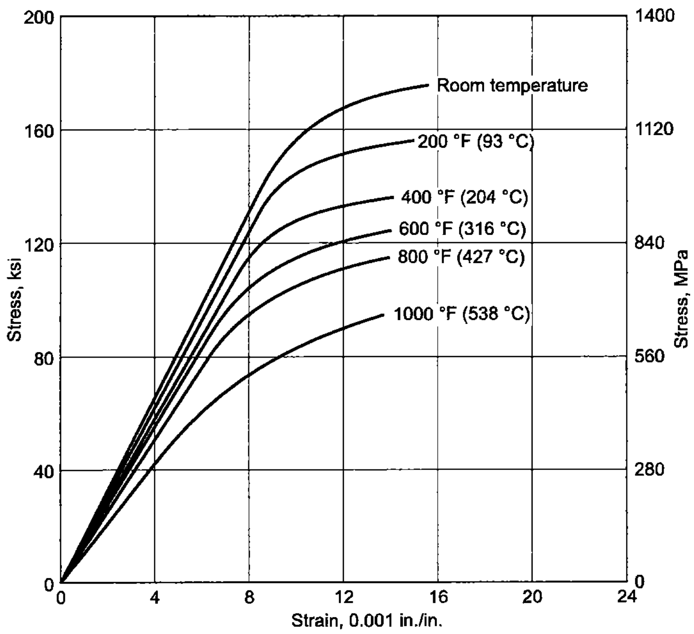
Source: *MIL-HDBK-5H,* Dec 1998, p 5–68



Ti.048 Ti-6Al-4V, solution treated and aged titanium alloy sheet, typical tensile stress-strain curves (full range) at room and elevated temperatures

Test direction: longitudinal and long transverse. 0.5 h exposure. Ramberg-Osgood parameters: *n*(room temperature) = 16, *n*(200 °F) = 22, *n*(400 °F) = 15, *n*(600 °F) = 11, *n*(800 °F) = 9.4, *n*(1000 °F) = 6.2. UNS R56400/R56401

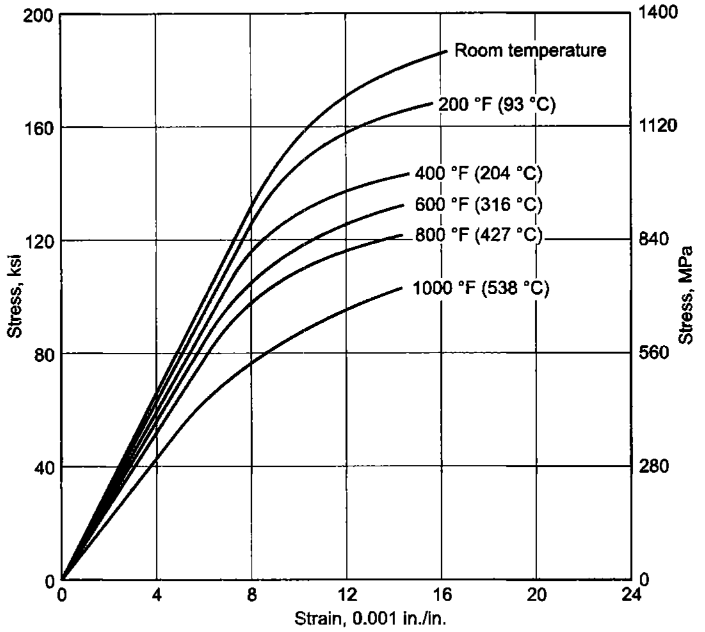
Source: *MIL-HDBK-5H*, Dec 1998, p 5–79



Ti.049 Ti-6Al-4V, solution treated and aged titanium alloy sheet, typical compressive stress-strain curves at room and elevated temperatures

Test direction: longitudinal. 0.5 h exposure. Ramberg-Osgood parameters: *n*(room temperature) = 22, *n*(200 °F) = 27, *n*(400 °F) = 22, *n*(600 °F) = 12, *n*(800 °F) = 11, *n*(1000 °F) = 5.7. UNS R56400/R56401

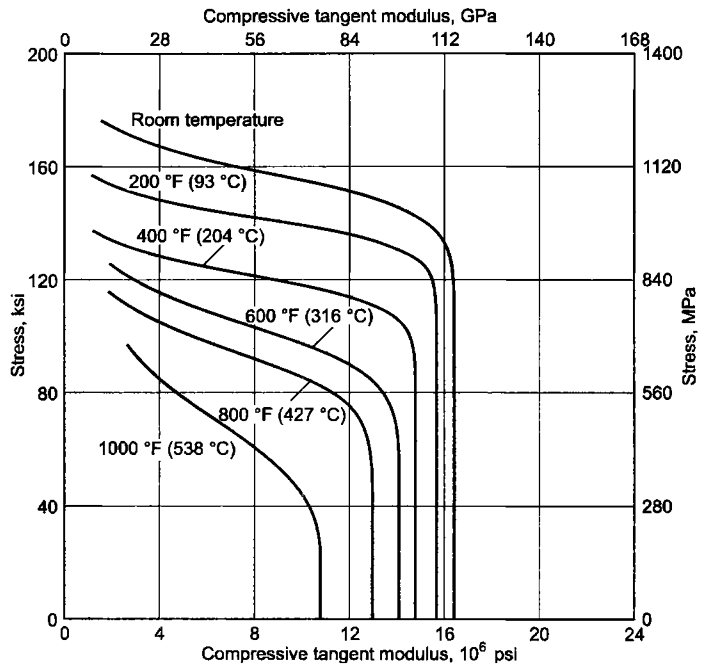
Source: *MIL-HDBK-5H*, Dec 1998, p 5–80



Ti.050 Ti-6Al-4V, solution treated and aged titanium alloy sheet, typical compressive stress-strain curves at room and elevated temperatures

Test direction: long transverse. 0.5 h exposure. Ramberg-Osgood parameters: n(room temperature) = 13, n(200 °F) = 15, n(400 °F) = 14, n(600 °F) = 10, n(800 °F) = 11, n(1000 °F) = 5.7. UNS R56400/R56401

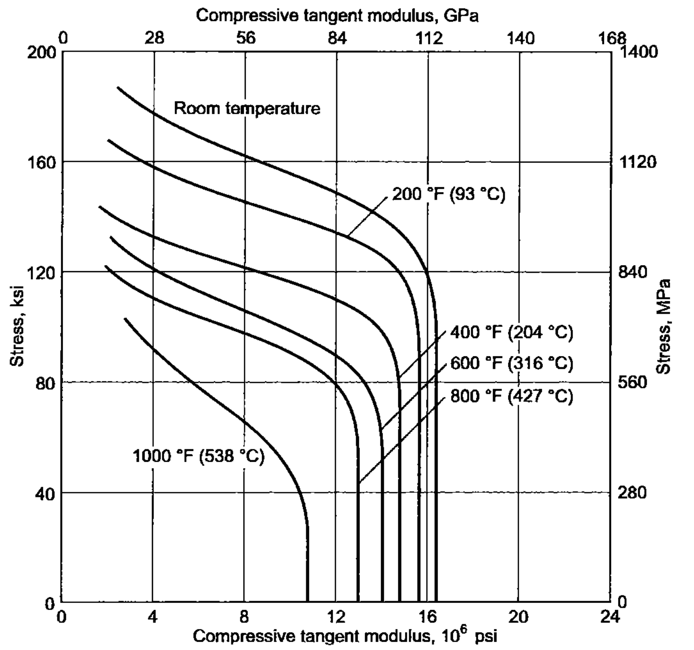
Source: *MIL-HDBK-5H*, Dec 1998, p 5–81



Ti.051 Ti-6Al-4V, solution treated and aged titanium alloy sheet, typical compressive tangent modulus curves at room and elevated temperatures

Test direction: longitudinal. 0.5 h exposure. Ramberg-Osgood parameters: n(room temperature) = 22, n(200 °F) = 27, n(400 °F) = 22, n(600 °F) = 12, n(800 °F) = 11, n(1000 °F) = 5.7. UNS R56400/R56401

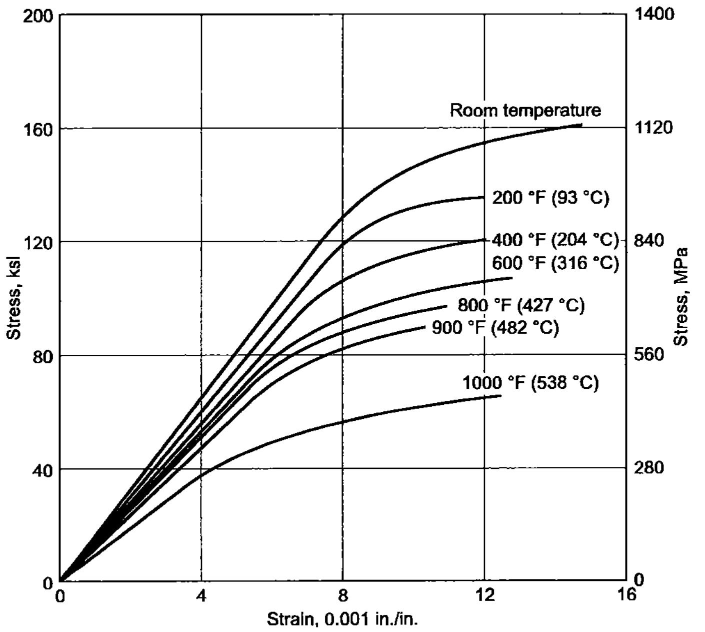
Source: *MIL-HDBK-5H*, Dec 1998, p 5–80



Ti.052 Ti-6Al-4V, solution treated and aged titanium sheet, typical compressive tangent modulus curves at room and elevated temperatures

Test direction: long transverse. 0.5 h exposure. Ramberg-Osgood parameters: n(room temperature) = 13, n(200 °F) = 15, n(400 °F) = 14, n(600 °F) = 10, n(800 °F) = 11, n(1000 °F) = 5.7. UNS R56400/R56401

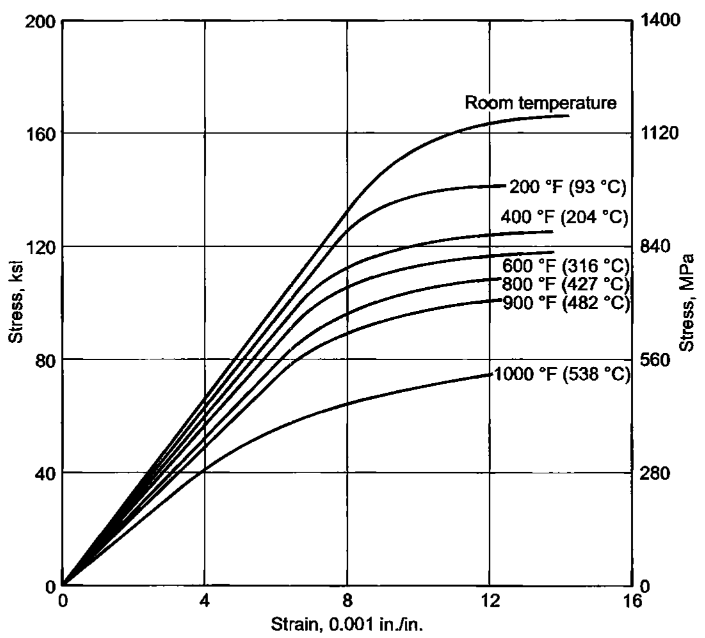
Source: *MIL-HDBK-5H*, Dec 1998, p 5–81



Ti.053 Ti-6Al-4V aged titanium alloy sheet, tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Sheet thickness = 1.6 and 3.18 mm (0.063 and 0.125 in.) Treatment: 927 °C (1700 °F), 3–20 min, water quenched, + 482–510 °C (900–950 °F), 4 h. UNS R56400/R56401

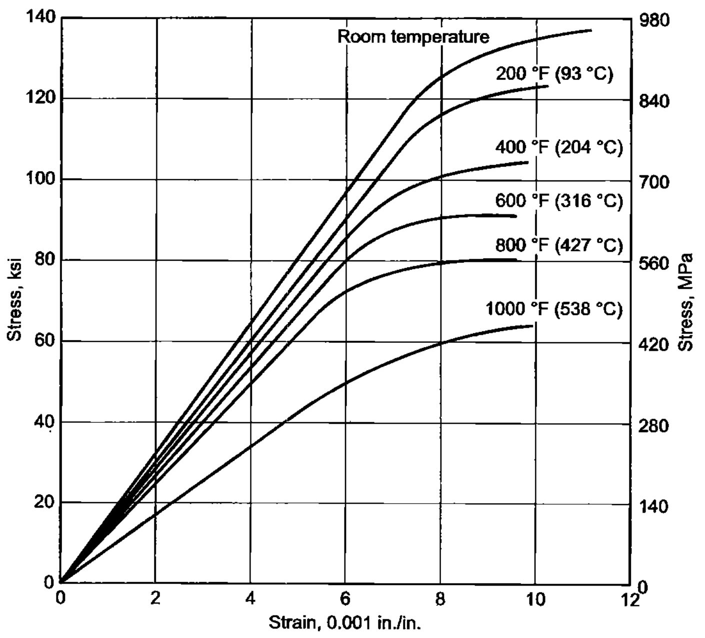
Source: "Summary of Mechanical and Physical Property Data Collected, Including Tensile Creep and Fatigue," Lockheed-Georgia, Dec 1962. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3707, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 14



Ti.054 Ti-6Al-4V aged titanium alloy sheet, tensile stress-strain curves at room and elevated temperatures

Test direction: transverse. Sheet thickness = 1.6 and 3.18 mm (0.063 and 0.125 in.). Treatment: 927 °C (1700 °F), 3–20 min, water quenched, + 482–510 °C (900–950 °F), 4 h. UNS R56400/R56401

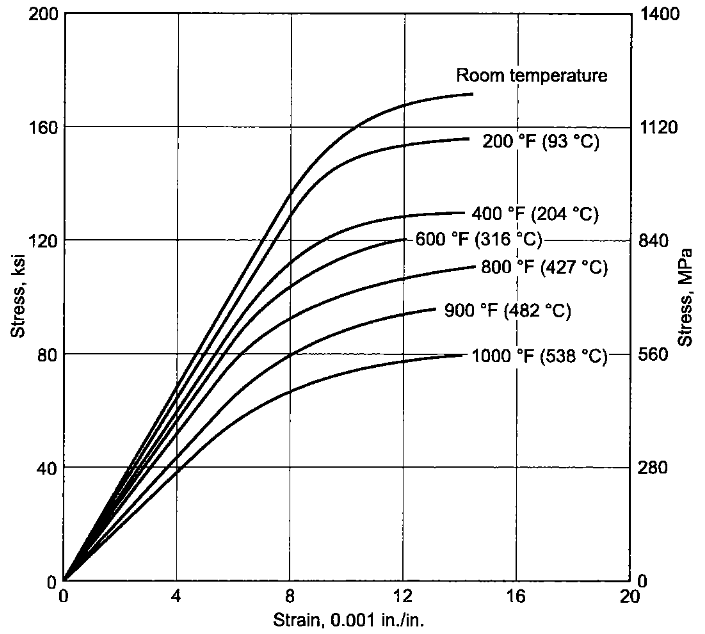
Source: "Summary of Mechanical and Physical Property Data Collected, Including Tensile Creep and Fatigue," Lockheed-Georgia, Dec 1962. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3707, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 14



Ti.055 Ti-6Al-4V annealed titanium alloy sheet, compressive tensile stress-strain curves at room and elevated temperatures

Test direction: transverse. Sheet thickness = 1.6 mm (0.063 in.). Results are the average of eight heats. UNS R56400/R56401

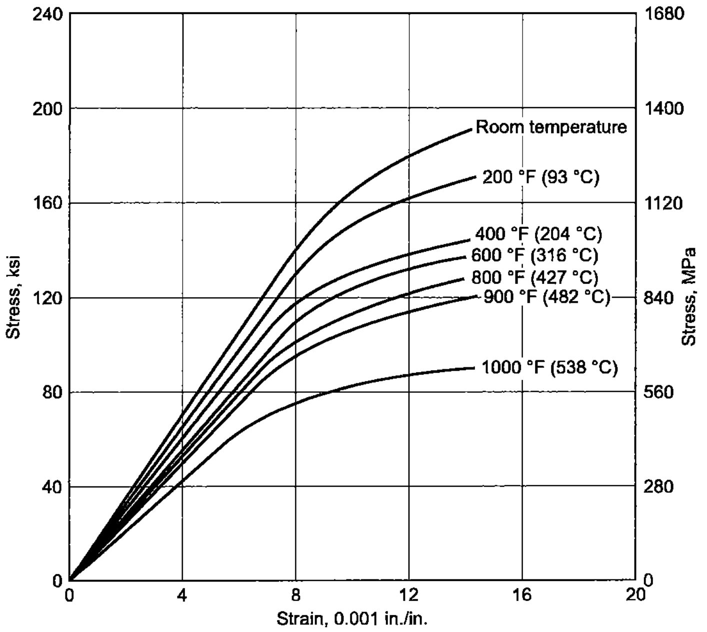
Source: J.K. Childs and M.M. Lemcoe, "Determination of Materials Design Criteria for 6Al-4V Titanium Alloy at Room and Elevated Temperatures," WADC TR 58-246, Aug 1958. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3707, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 18



Ti.056 Ti-6Al-4V aged titanium alloy sheet, compressive stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Sheet thickness = 1.6 and 3.18 mm (0.063 and 0.125 in.). Treatment: 927 °C (1700 °F), 3–20 min, water quenched, + 482–510 °C (900–950 °F), 4 h, air cooled. UNS R56400/R56401

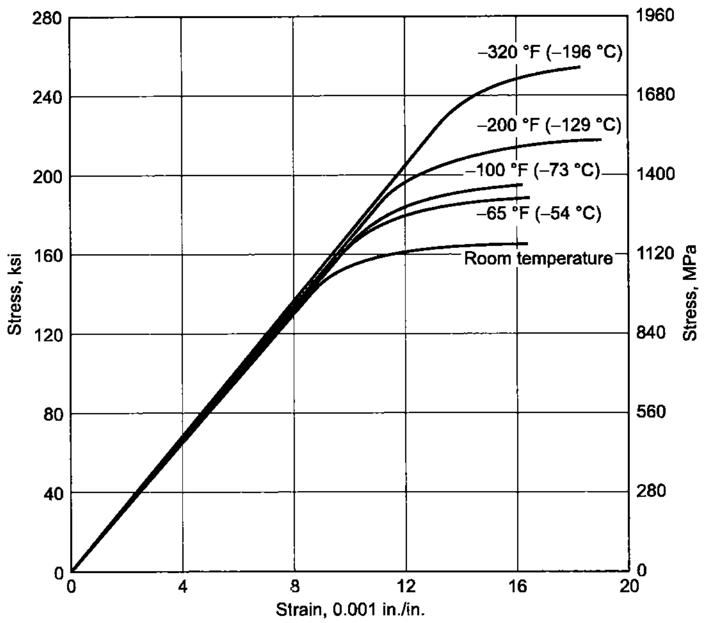
Source: "Summary of Mechanical and Physical Property Data Collected, Including Tensile Creep and Fatigue," Lockheed-Georgia, Dec 1962. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3707, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 18



Ti.057 Ti-6Al-4V aged titanium alloy sheet, compressive stress-strain curves at room and elevated temperatures

Test direction: transverse. Sheet thickness = 1.6 and 3.18 mm (0.063 and 0.125 in.). Treatment: 927 °C (1700 °F), 3–20 min, water quenched, + 482–510 °C (900–950 °F), 4 h, air cooled. UNS R56400/R56401

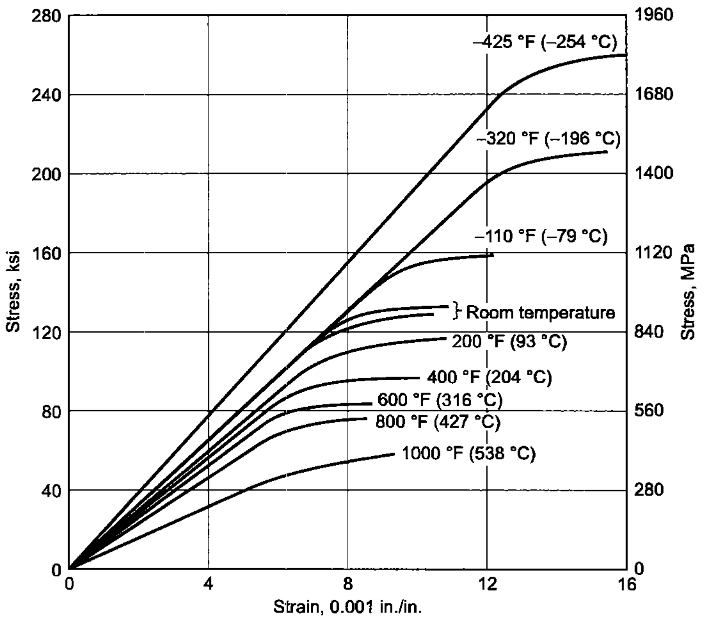
Source: "Summary of Mechanical and Physical Property Data Collected, Including Tensile Creep and Fatigue," Lockheed-Georgia, 1962. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3707, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 19



Ti.058 Ti-6Al-4V aged titanium alloy sheet, tensile alloy stress-strain for room and low temperatures

Test direction: longitudinal and transverse. Sheet thickness = 1.6 mm (0.063 in.). Treatment: 921 °C (1690 °F), 12 min, water quenched, + 482 °C (900 °F), 4 h. UNS R56400/R56401

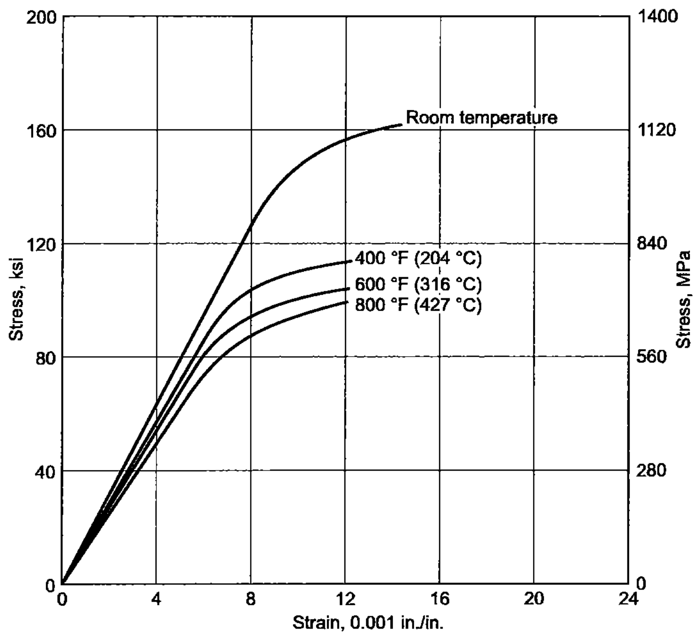
Source: "Details of Data Collected Program Test Techniques and Results for Tension, Compression, Bearing, Shear, Crippling, Joints and Physical Properties," Lockheed-Georgia, Dec 1962. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3707, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 14



Ti.059 Ti-6Al-4V annealed titanium alloy sheet, typical tensile stress-strain curves at room, elevated, and low temperatures

Sheet thickness = 1.6 mm (0.064 in.).
UNS R56400/R56401

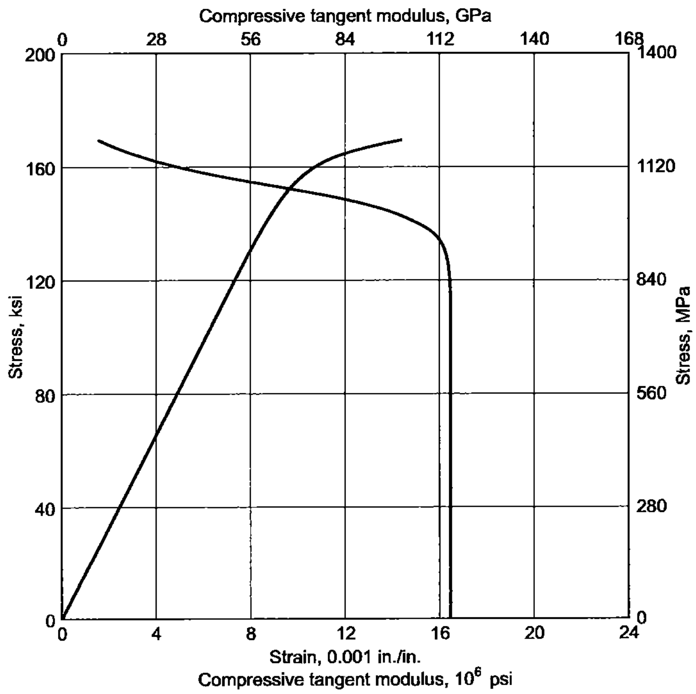
Source: J.K. Childs and M.M. Lemcoe, "Determination of Materials Design Criteria for 6Al-4V Titanium Alloy at Room and Elevated Temperatures," WADC TR 58-246, Aug 1958. R.L McGee, J.E. Campbell, R.L. Carlson, and G.K. Manning, "The Mechanical Properties of Certain Aircraft Structural Metals at Very Low Temperature," WADC TR 58-386, June 1958. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3707, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 13



Ti.060 Ti-6Al-4V titanium alloy plate, typical tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal and long transverse. Solution treated and aged. Plate thickness = 6.35–25.40 mm (0.250–1.000 in.). 0.5 h exposure. Ramberg-Osgood parameters: *n*(room temperature) = 16, *n*(400 °F) = 19, *n*(600 °F) = 15, *n*(800 °F) = 11. UNS R56400/R56401

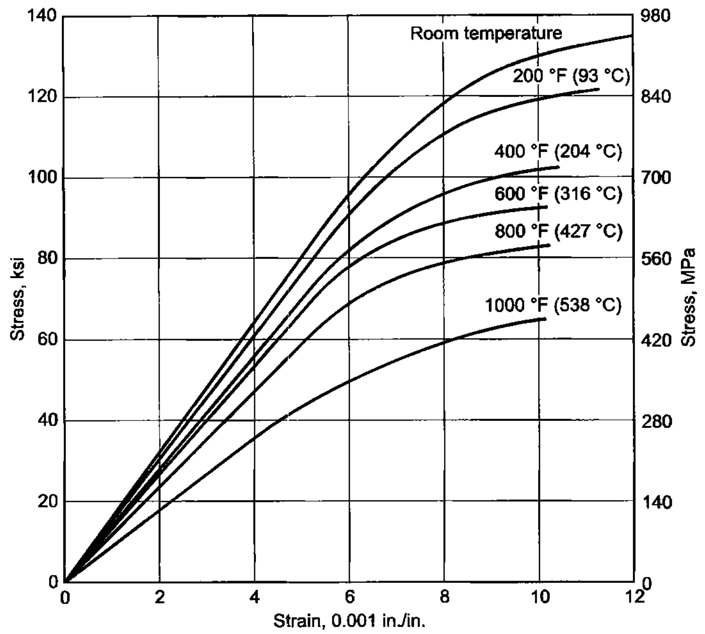
Source: *MIL-HDBK-5H*, Dec 1998, p 5–82



Ti.061 Ti-6Al-4V solution treated and aged titanium alloy plate, typical compressive stress-strain and compressive tangent modulus curves at room and elevated temperatures

Test direction: longitudinal and long transverse. Sheet thickness = 6.35–25.40 mm (0.250–1.000 in.). Ramberg-Osgood parameter: *n*(room temperature) = 26. UNS R56400/R56401

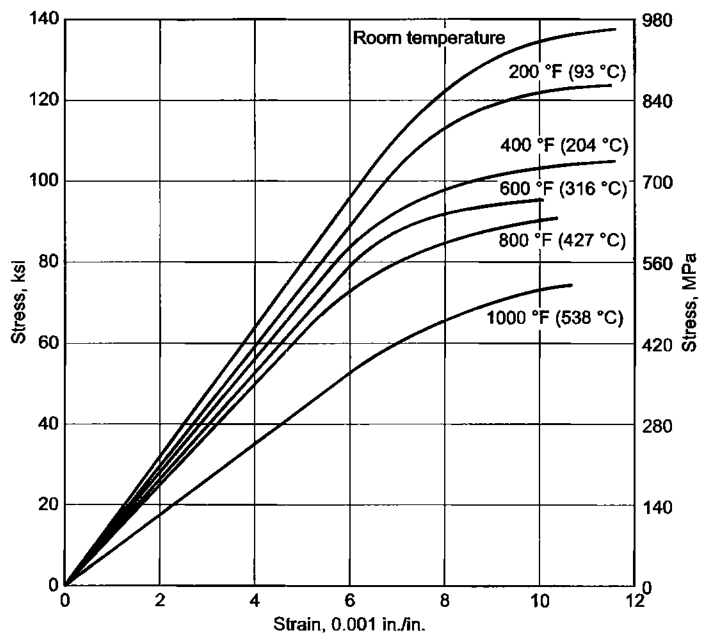
Source: *MIL-HDBK-5H*, Dec 1998, p 5–82



Ti.062 Ti-6Al-4V annealed titanium alloy bar, tensile stress-strain curves for room and elevated temperatures

Sheet thickness = 31.75 mm (1½ in.). Results are the average of 12 heats. UNS R56400/R56401

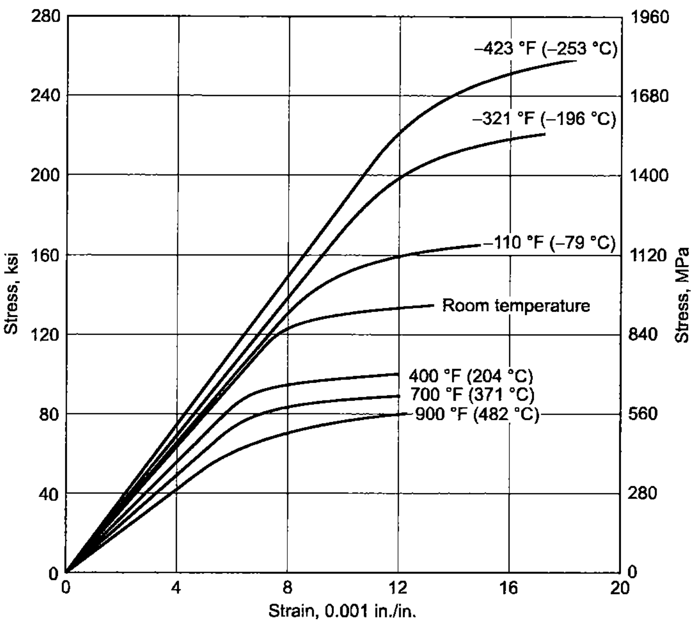
Source: J.K. Childs and M.M. Lemcoe, "Determination of Materials Design Criteria for 6Al-4V Titanium Alloy at Room and Elevated Temperatures," WADC TR 58-246, Aug 1958. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3707, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 13



Ti.063 Ti-6Al-4V annealed titanium alloy bar, compressive stress-strain curves for room and elevated temperatures

Sheet thickness = 31.75 mm (1½ in.). Results are the average of 12 heats. UNS R56400/R56401

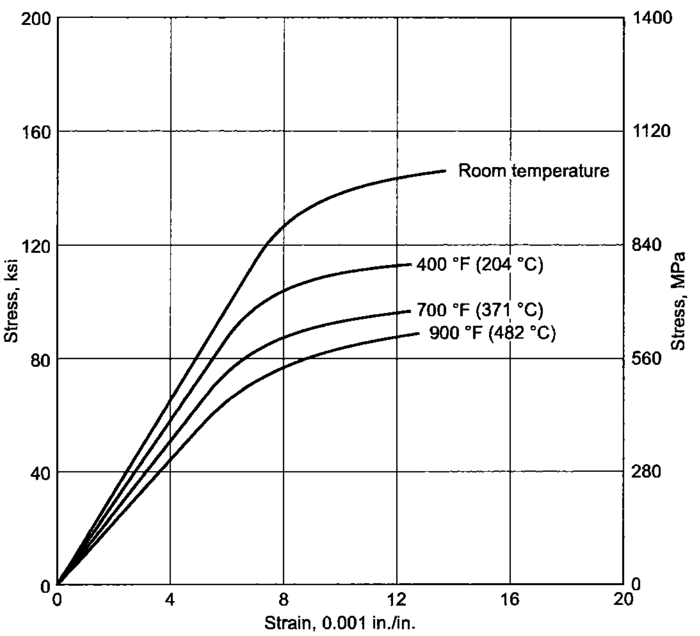
Source: J.K. Childs and M.M. Lemcoe, "Determination of Materials Design Criteria for 6Al-4V Titanium Alloy at Room and Elevated Temperatures," WADC TR 58-246, Aug 1958. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3707, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 19



Ti.064 Ti-6Al-4V annealed titanium alloy extrusion, typical tensile stress-strain curves at room, elevated, and cryogenic temperatures

0.5 h exposure. Ramberg-Osgood parameters: n(−243 °F) = 20, n(−321 °F) = 21, n(−110 °F) = 20, n(room temperature) = 33, n(400 °F) = 29, n(700 °F) = 19, n(900 °F) = 9.6. UNS R56400/R56401

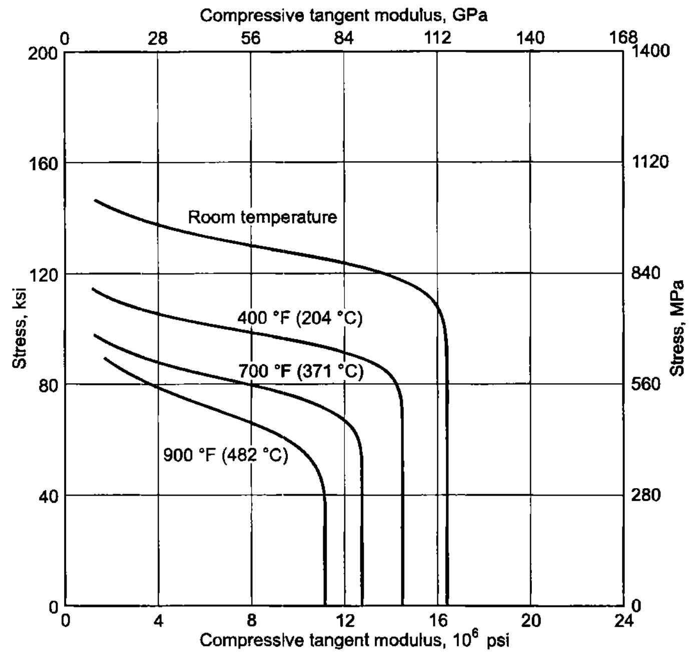
Source: *MIL-HDBK-5H*, Dec 1998, p 5–66



Ti.065 Ti-6Al-4V annealed titanium alloy extrusion, typical compressive stress-strain curves at room and elevated temperatures

0.5 h exposure. Ramberg-Osgood parameters: n(room temperature) = 21, n(400 °F) = 19, n(700 °F) = 14, n(900 °F) = 9.8. UNS R56400/R56401

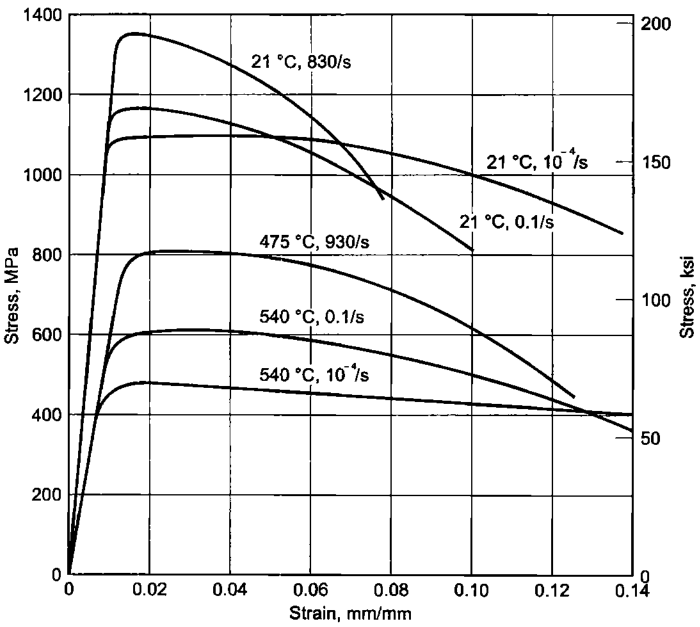
Source: *MIL-HDBK-5H*, Dec 1998, p 5–67



Ti.066 Ti-6Al-4V annealed titanium alloy extrusion, typical compressive tangent modulus curves at room and elevated temperatures

Test direction: longitudinal. 0.5 h exposure. Ramberg-Osgood parameters: *n*(room temperature) = 21, *n*(400 °F) = 19, *n*(700 °F) = 14, *n*(900 °F) = 9.8. UNS R56400/R56401

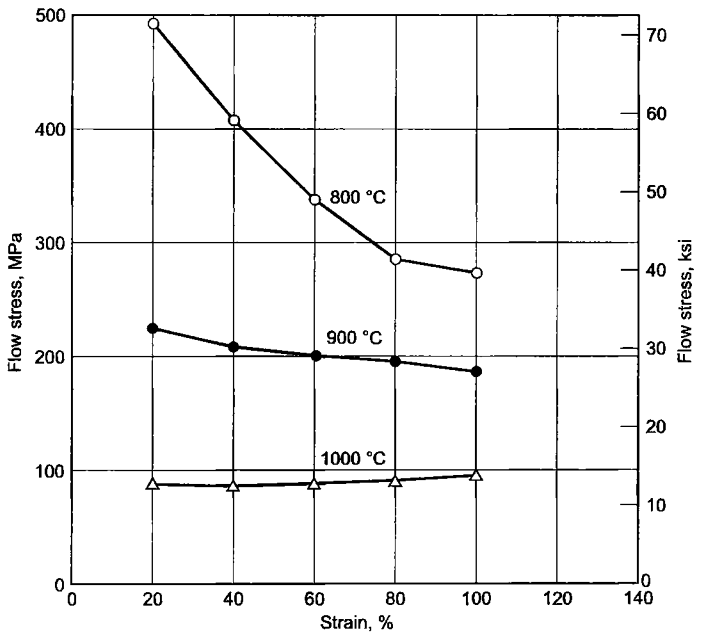
Source: *MIL-HDBK-5H*, Dec 1998, p 5–67



Ti.067 Ti-6Al-4V solution treated and aged titanium alloy rod, temperature and strain rate effects on tensile stress-strain curves

UNS R56400/R56401

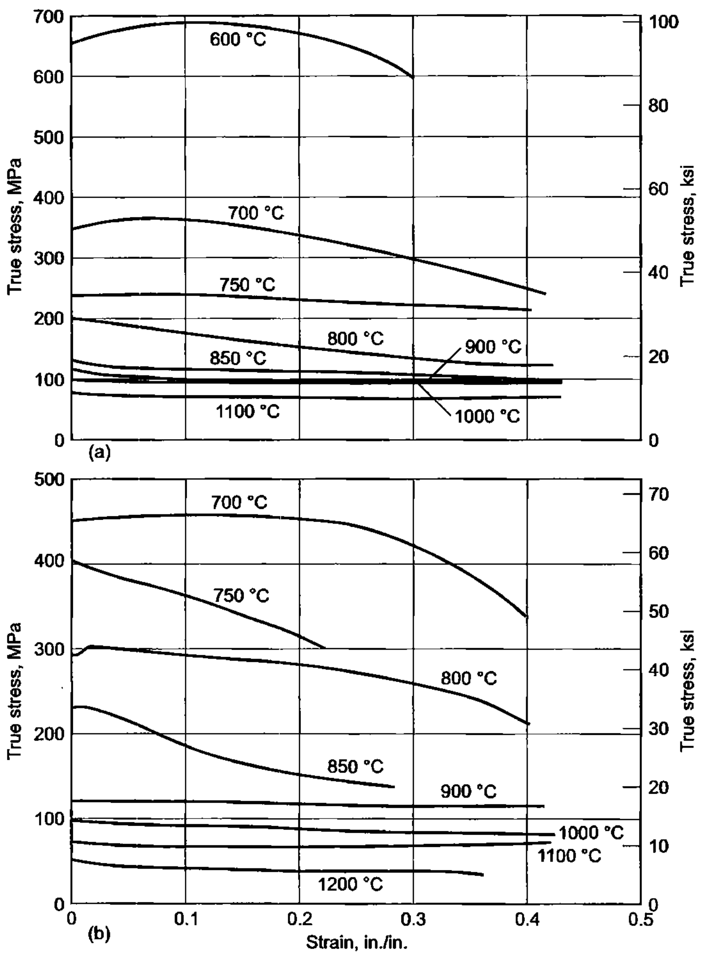
Source: D.L. McLellan and T.W. Eichenberger, "Constitutive Equation Development (COED)," Vol 1, Technical Summary, SAMSO-TR-68-320, July 1968, p 80. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 593



Ti.068 Ti-6Al-4V titanium alloy, temperature effect on flow stress-strain curves

Strain rate at 10/s with a starting microstructure of about 50% α in a transformed β matrix. UNS R56400/R56401

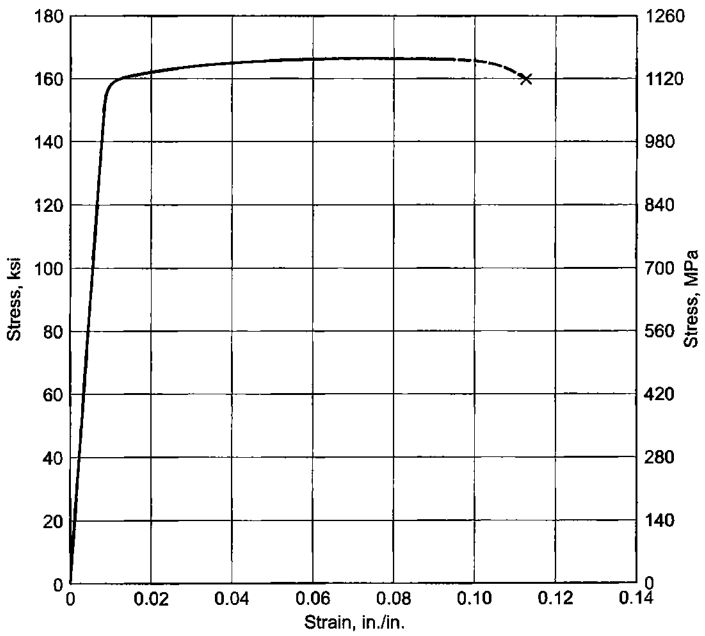
Source: G.W. Kuhlman, ALCOA, Forging Division. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 593



Ti.069 Ti-6Al-6V-2Sn titanium alloy, true stress-strain curves (a) sensitized (b) reheated

In the sensitized mode, smooth stress-strain curves are shown above 750 °C (1380 °F), and work hardening occurs below 665 °C (1220 °F). At 850 °C (1560 °F), for example, the stress level of the reheated materials is almost twice that of the sensitized material at low strain. The sensitized mode involved quenching from 1220 °C (2190 °F) to the test temperature. The reheated mode involved heating to the test temperature in 60 s.

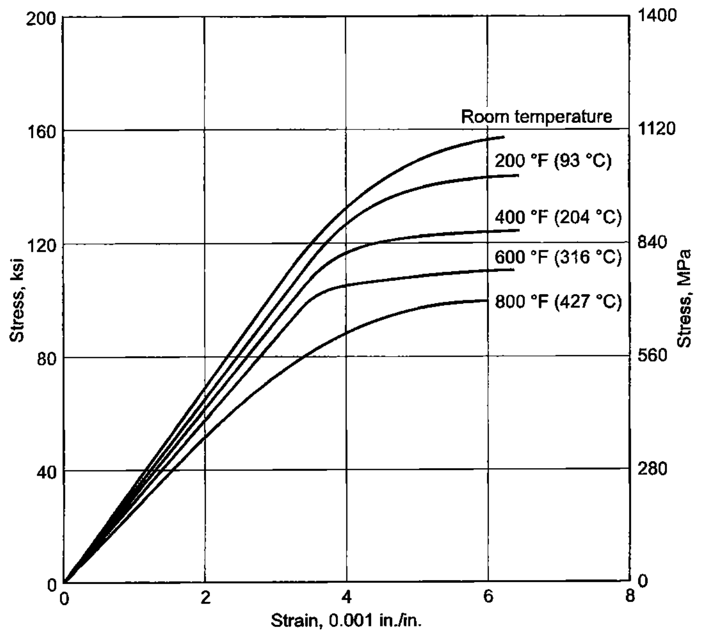
Source: H.G. Suzuki et al., Effect of Phase Transformation on the Hot Workability of Ti-8Al-6V-2Sn, Ti-5Al-2.5Sn, and Other Alloys, *Sixth World Conference on Titanium*, P. Lacombe, R. Tricot, and G. Beranger, Ed., Les Editions de Physique, Paris, 1989, p 1427–1432. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 663



Ti.070 Ti-6Al-6V-2Sn annealed titanium alloy sheet, typical tensile stress-strain curves (full range) at room temperature

Test direction: longitudinal and long transverse. UNS R56620

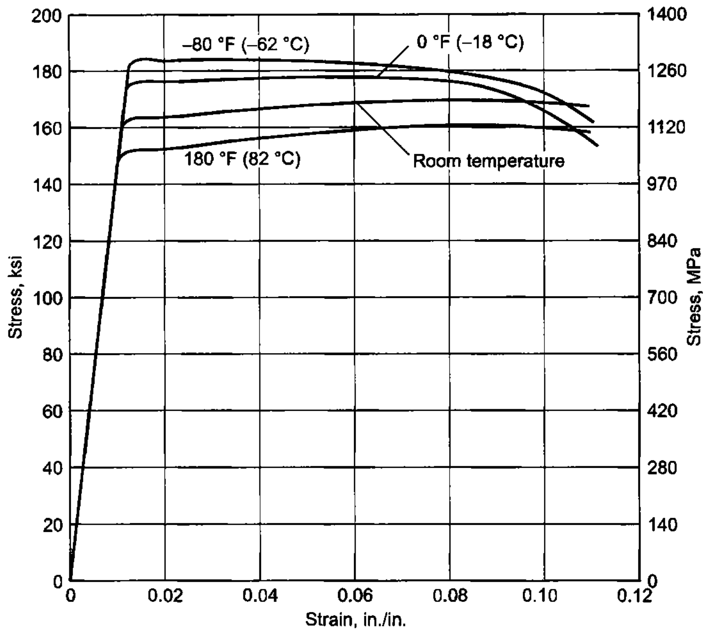
Source: *MIL-HDBK-5H*, Dec 1998, p 5–108



Ti.071 Ti-6Al-6V-2Sn annealed titanium alloy sheet, tensile stress-strain curves at room and elevated temperatures

Annealed, 760 °C (1400 °F), 4 h. UNS R56620

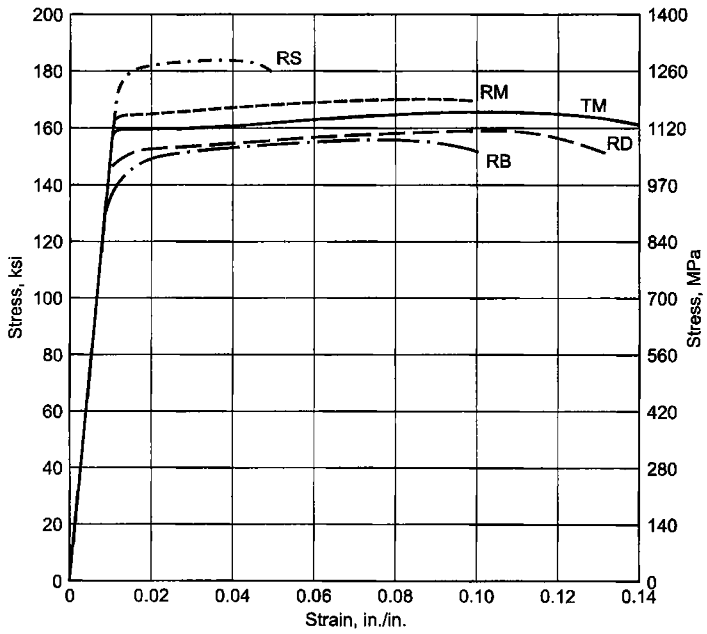
Source: "Properties of Ti-6Al-6V-2Sn," Timet Titanium Engineering Bulletin No. 10, TMCA, Sept 1967. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3715, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 25



Ti.072 Ti-6Al-6V-2Sn mill-annealed titanium alloy plate, tensile stress-strain curves at several temperatures

Plate thickness = 12.7 mm (0.5 in.). Tensile yield strength = 1120 MPa (163 ksi). Tested to ASTM-399-70T. UNS R56620

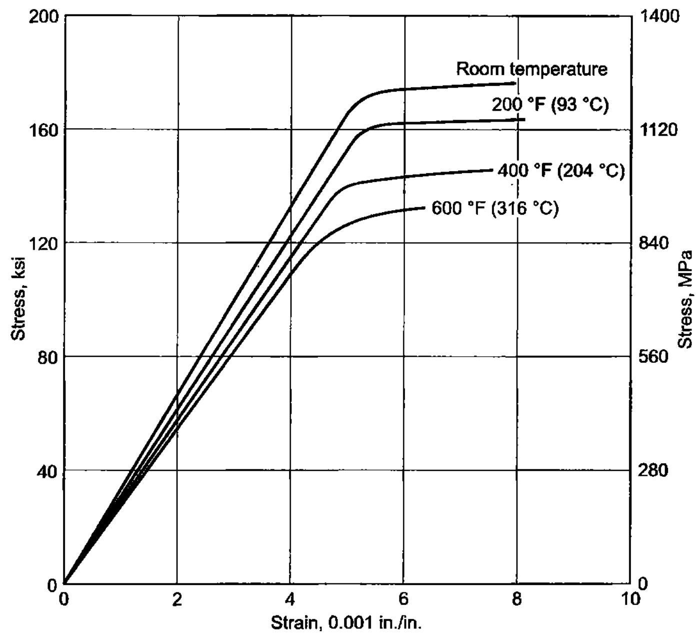
Source: M.F. Amateau, W.D. Hanna, and E.G. Kendall, "F-15 Program Final Report: Ti-6Al-6V-2Sn and Ti-6Al-4V Fatigue Crack Propagation," ATR-72(9990), The Aerospace Corp., Sept 1971. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3715, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 26



Ti.073 Ti-6Al-6V-2Sn titanium alloy plate, tensile stress-strain curves at room temperature for different heat treatments

All curves 12.7 mm (0.5 in.) except RS which is 32 mm (1.25 in.). Heat treatment: RB, beta annealed, 1010 °C (1850 °F), 1 h in vacuum, argon cooled. RD, duplex annealed, 927 °C (1700 °F), 1 h in vacuum, argon cooled + 760 °C (1400 °F), 1 h, argon cooled. RM and TM, mill annealed. RS, solution treated and aged, 913 °C (1675 °F), 0.25 h, water quenched + 593 °C (1100 °F), 4 h. Yield strengths MPa (ksi): RB, 965 (140); RD, 1040 (151); RM, 1123 (163); RS, 1193 (173); TM, 1096 (159). Tested to ASTM-399-70T. UNS R56620

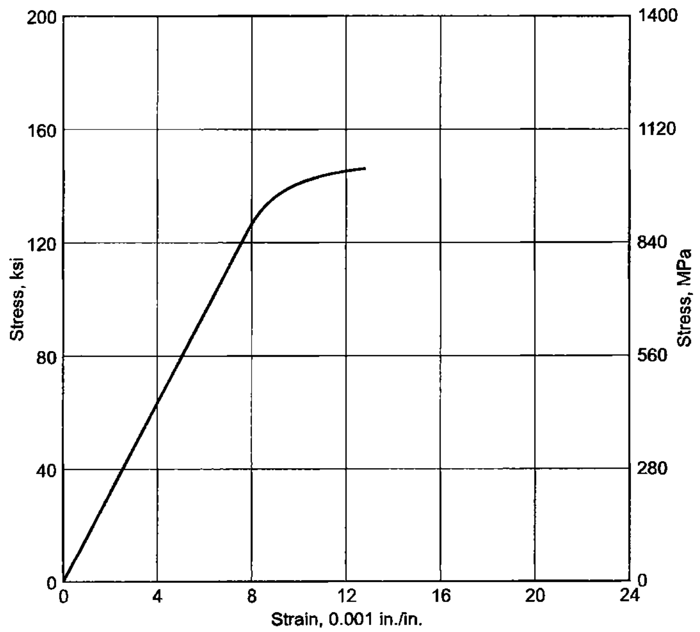
Source: M.F. Amateau, W.D. Hanna, and E.G. Kendall, "F-15 Program Final Report: Ti-6Al-6V-2Sn and Ti-6Al-4V Fatigue Crack Propagation," ATR-72(9990), The Aerospace Corp., 1971. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3715, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 13



Ti.074 Ti-6Al-6V-2Sn aged titanium bar, tensile stress-strain curves for room and elevated temperatures

Treatment: 870 °C (1600 °F), 1 h, water quenched + 565 °C (1050 °F), 4 h. UNS R56620

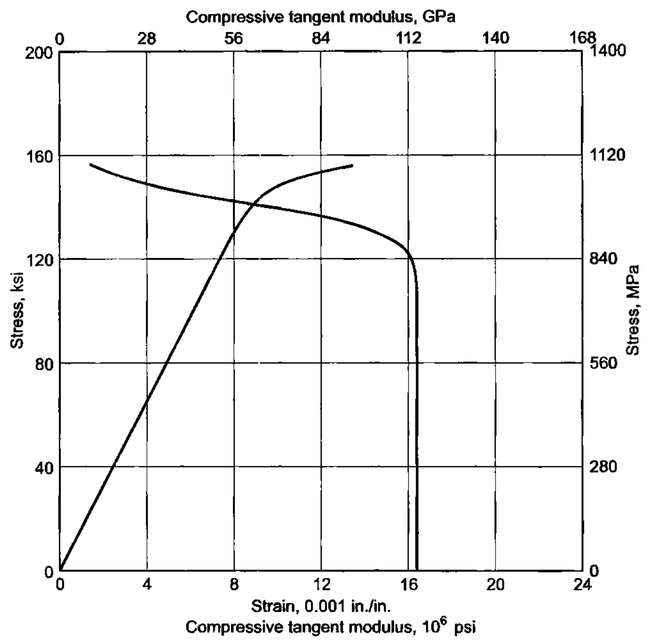
Source: *Aerospace Structural Metals Handbook*, Vol 4, Code 3715, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 25



Ti.075 Ti-6Al-6V-2Sn annealed titanium alloy extrusion, typical tensile stress-strain curve at room temperature

Specimen tested in longitudinal direction. Ramberg-Osgood parameter: n(longitudinal) = 30. UNS R56620

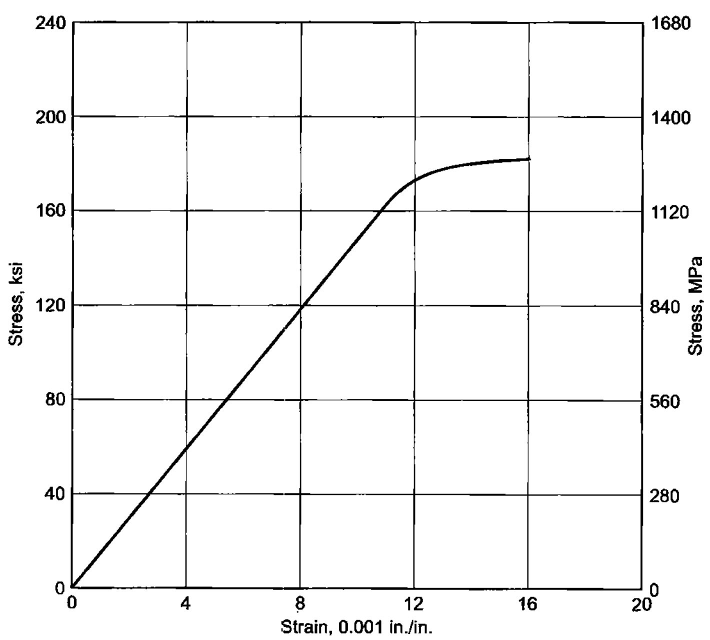
Source: *MIL-HDBK-5H*, Dec 1998, p 5–107



Ti.076 Ti-6Al-6V-2Sn annealed titanium alloy extrusion, typical compressive stress-strain and compressive tangent modulus curves at room temperature

Test direction: longitudinal. Ramberg-Osgood parameters: *n*(longitudinal) = 22. UNS R56620

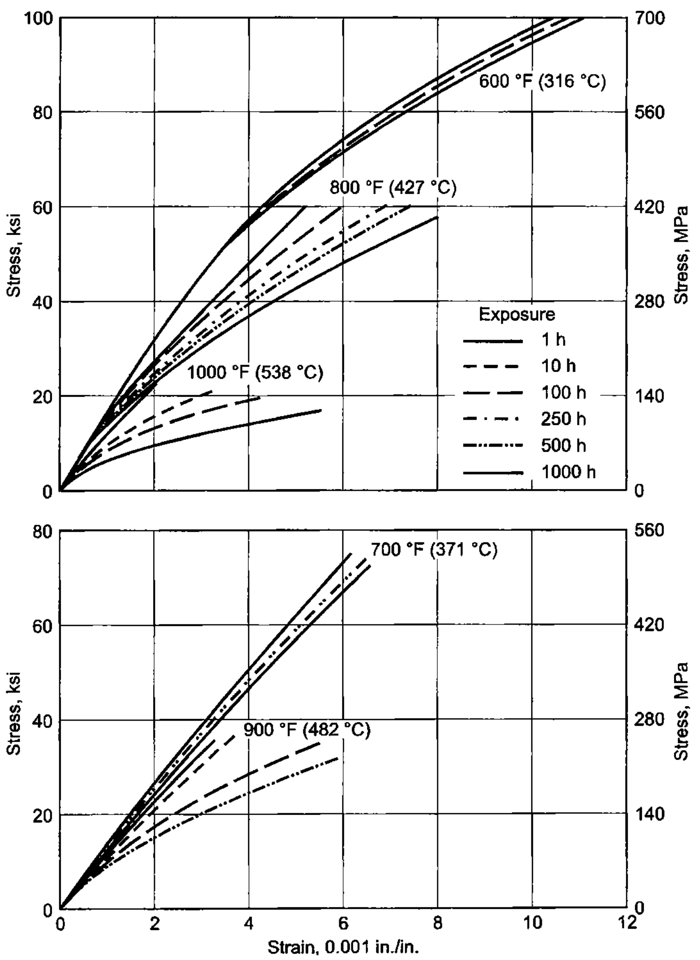
Source: *MIL-HDBK-5H*, Dec 1998, p 5–107



Ti.077 Ti-6Al-6V-2Sn heat treated titanium alloy forging, tensile stress-strain curve at room temperature

Forging size: 127 × 152 mm (5 × 6 in.). Treatment: 870 °C (1600 °F), 1 h, water quenched + 593 °C (1100 °F), 4 h. UNS R56620

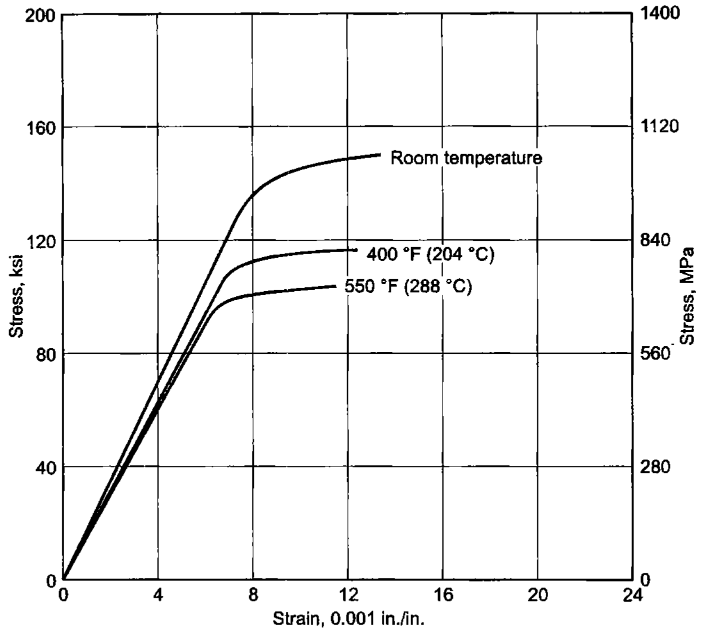
Source: *Aerospace Structural Metals Handbook*, Vol 4, Code 3715, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



Ti.078 Ti-7Al-4Mo titanium alloy forged bar, isochronous tensile stress-strain curves at elevated temperatures

Treatment: 982–1010 °C (1800–1850 °F) + 788 °C (1450 °F), 1 h, force cooled to 566 °C (1050 °F), air cooled + 566 °C (1050 °F), 24 h air cooled. UNS R56740

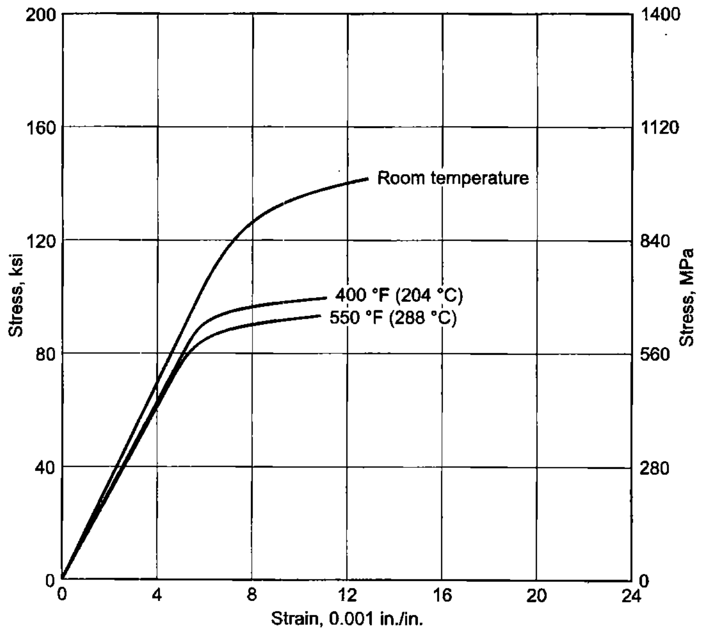
Source: "Tentative Data Sheet for Crucible C-135aMo7Al-4Mo," Crucible Steel Co., Dec 1958. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3708, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 20



Ti.079 Ti-8Al-1Mo-1V single-annealed titanium alloy sheet, typical tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal and long transverse. 0.5 h exposure. Ramberg-Osgood parameters: n(room temperature) = 33, n(400 °F) = 50, n(500 °F) = 50. UNS R54810

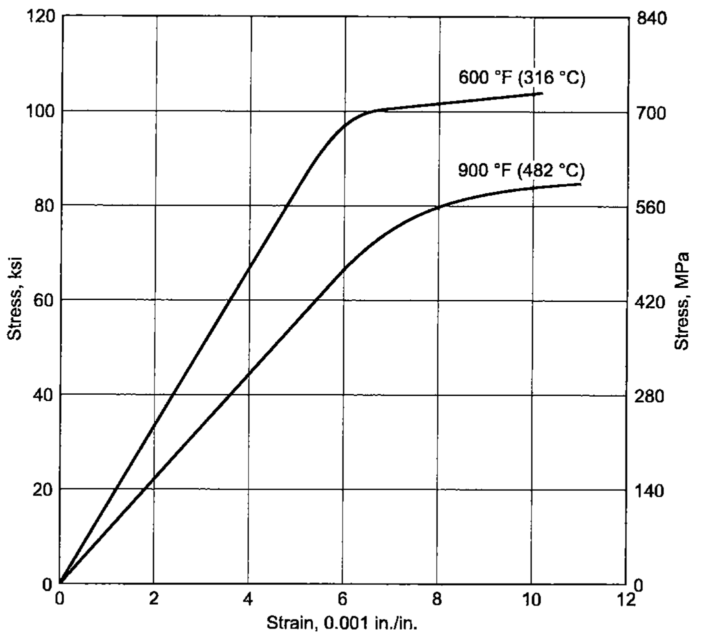
Source: *MIL-HDBK-5H*, Dec 1998, p 5–34



Ti.080 Ti-8Al-1Mo-1V duplex-annealed titanium alloy sheet, typical tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal and long transverse. 0.5 h exposure. Ramberg-Osgood parameters: n(room temperature) = 16, n(400 °F) = 32, n(550 °F) = 24. UNS R54810

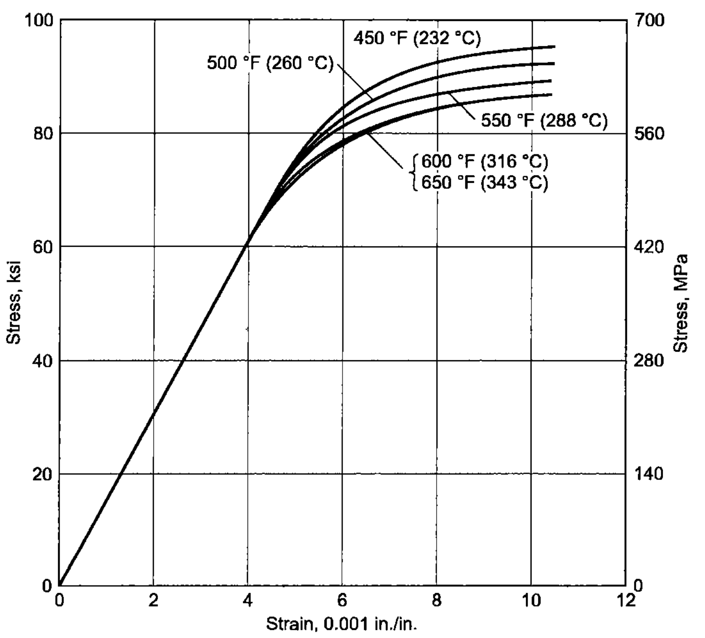
Source: *MIL-HDBK-5H*, Dec 1998, p 5–36



Ti.081 Ti-8Al-1Mo-1V mill-annealed titanium alloy sheet, stress-strain curves at elevated temperatures

Sheet thickness = 1.3 mm (0.050 in.). Treatment: 788 °C (1450 °F), 8 h, force cooled. UNS R54810

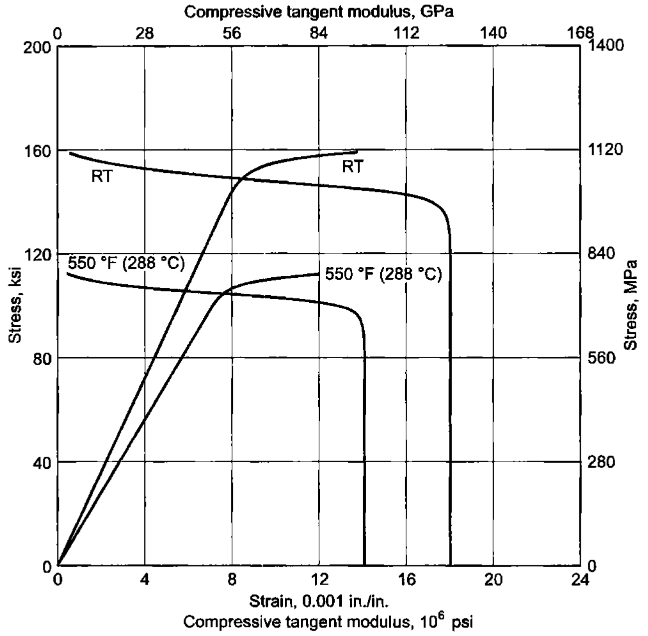
Source: "Creep Strength of Ti-8Al-1Mo-1V at 600 and 900 F," Titanium Metals Corp., 1962. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3709, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 10



Ti.082 Ti-8Al-1Mo-1V duplex-annealed titanium alloy sheet, stress-strain curves at elevated temperatures

Test direction: longitudinal. Sheet thickness = 1.3 mm (0.050 in.). Duplex anneal: 788 °C (1450 °F), 8 h, force cooled + 788 °C (1450 °F), 15 min, air cooled. UNS R54810

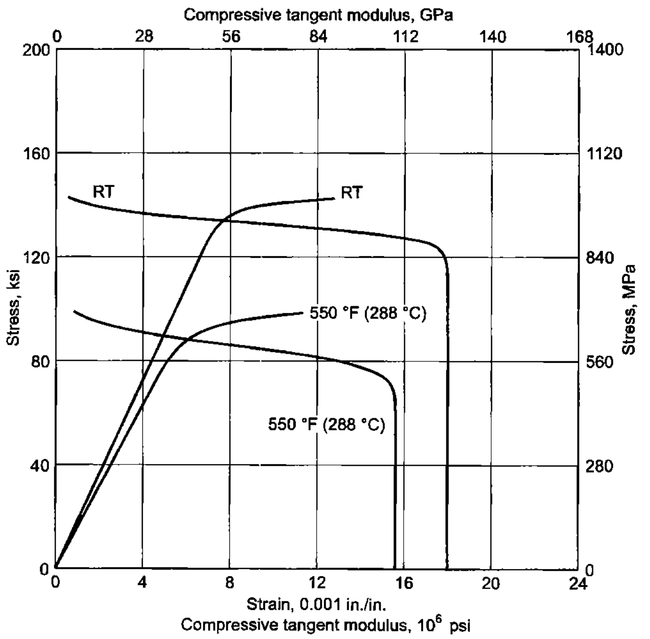
Source: C.W. Alesch, "Onset of Creep Stress Measurement of Metallic Materials," Convair, 1964. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3709, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 10



Ti.083 Ti-8Al-1Mo-1V single-annealed titanium alloy sheet, typical compressive stress-strain and compressive tangent modulus curves at room and elevated temperatures

Test direction: longitudinal and long transverse. 0.5 h exposure at temperature. RT, room temperature. Ramberg-Osgood parameters: n(RT) = 50, n(550 °F) = 50. UNS R54810

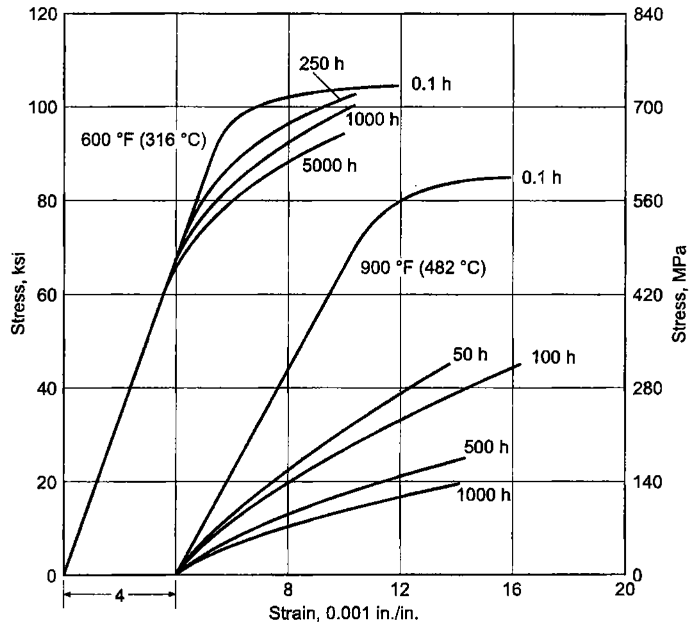
Source: *MIL-HDBK-5H*, Dec 1998, p 5–34



Ti.084 Ti-8Al-1Mo-1V duplex-annealed titanium alloy sheet, typical compressive stress-strain and compressive tangent modulus curves at room and elevated temperatures

Test direction: longitudinal and long transverse. 0.5 h exposure. RT, room temperature. Ramberg-Osgood parameters: n(RT) = 50, n(500 °F) = 22. UNS R54810

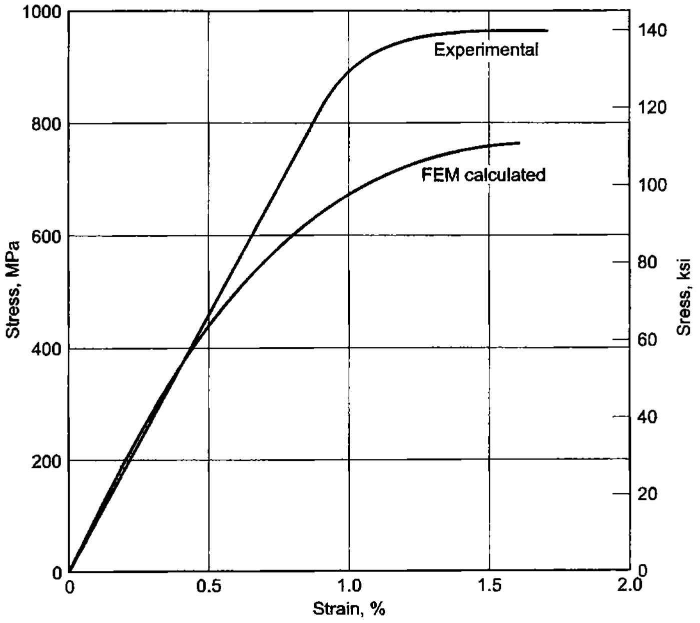
Source: *MIL-HDBK-5H*, Dec 1998, p 5–36



Ti.085 Ti-8Al-1Mo-1V mill-annealed titanium alloy sheet, isochronous stress-strain curves at elevated temperatures

Test direction: longitudinal. Treated: 788 °C (1450 °F), 8 h, force cooled. UNS R54810

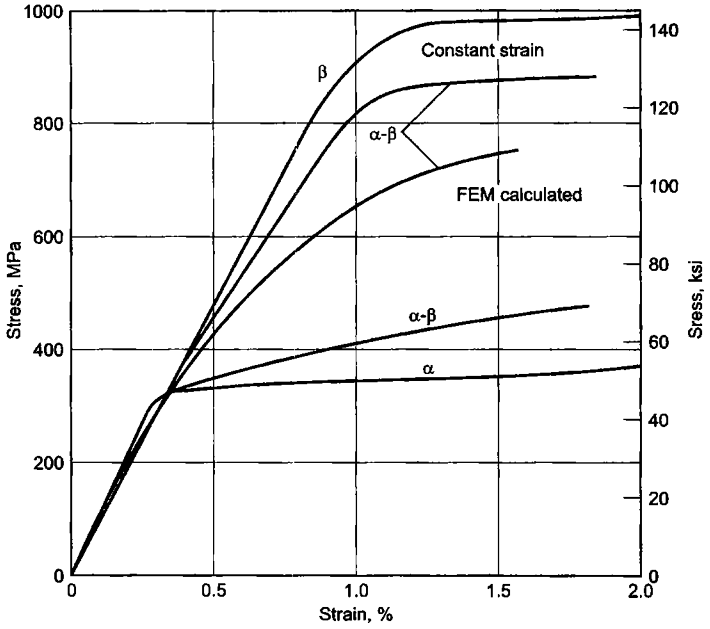
Source: "Creep Strength of Ti-8Al-1Mo-1V at 600 and 900 F," Titanium Metals Corp., 1962. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3709, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 18



Ti.086 Ti-8Mn titanium alloy, comparison of experimental and calculated stress-strain curves

UNS R56080

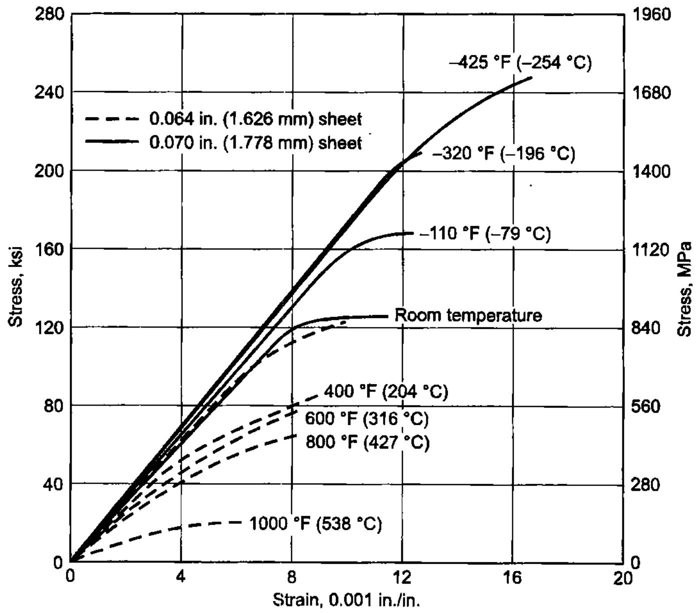
Source: H. Margolin et al., Calculations of Stress-Strain Curves and Stress Strain Distribution for an Alpha-Beta Ti-8Mn Alloy, *Mater. Sci. Eng.*, Vol 34, 1978, p 203–211. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 763



Ti.087 Ti-8Mn titanium alloy, stress-strain curves for α, β, and α-β phases

UNS R56080

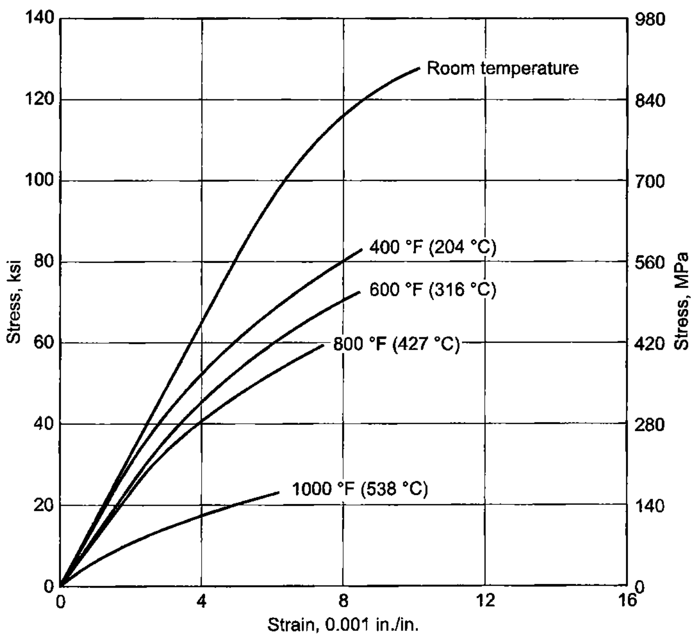
Source: H. Margolin et al., Calculations of Stress-Strain Curves and Stress Strain Distribution for an Alpha-Beta Ti-8Mn Alloy, *Mater. Sci. Eng.*, Vol 34, 1978, p 203–211. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 763



Ti.088 Ti-8Mn annealed titanium alloy sheet, tensile stress-strain curves at various temperatures

Sheet thickness = 1.63 and 1.78 mm (0.064 and 0.070 in.). 0.5–100 h exposure. UNS R56080

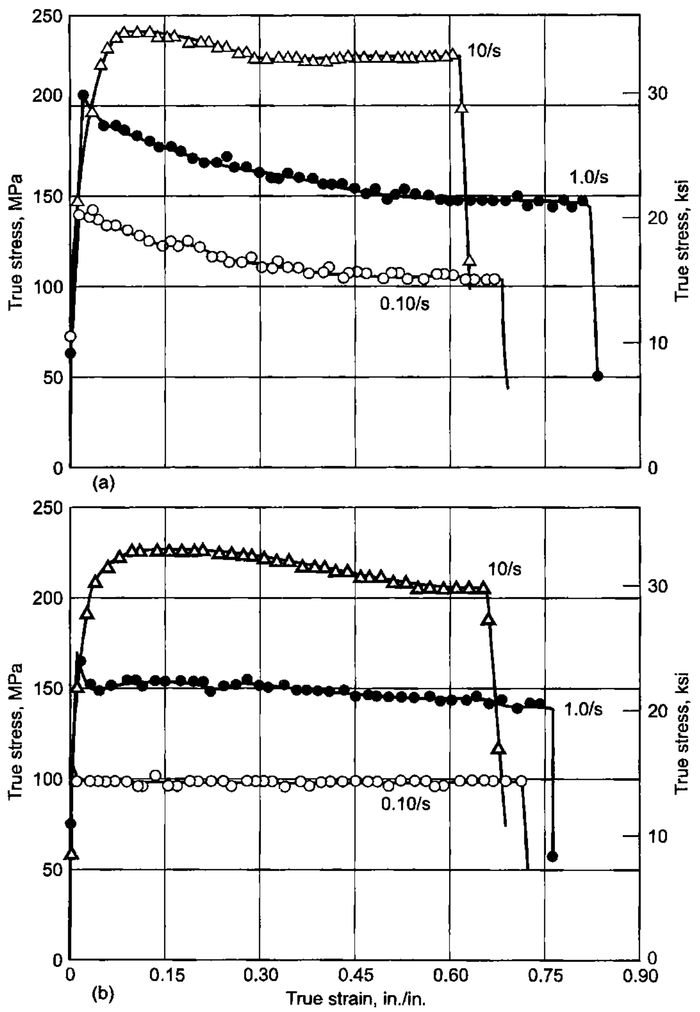
Source: R.L. McGee, J.E. Campbell, R.L. Carlson, and G.K. Manning, "The Mechanical Properties of Certain Aircraft Structural Metals at Very Low Temperatures," WADC TR 58-386, 1958. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3712, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 3



Ti.089 Ti-8Mn annealed titanium alloy sheet, compressive stress-strain curves at room and elevated temperatures

Sheet thickness = 1.78 mm (0.070 in.). 0.5–100 h exposure. UNS R56080

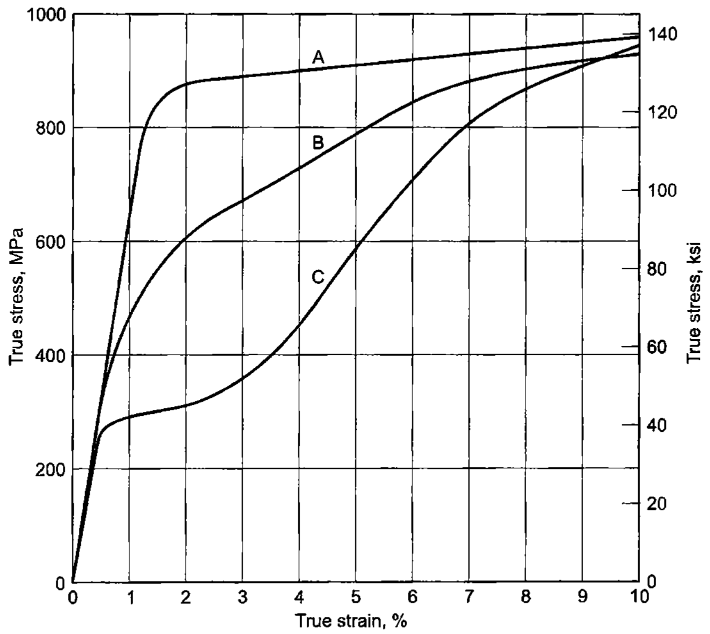
Source: D.E. Miller, "The Determination of Physical Properties of Ferrous and Non-Ferrous Structural Sheet Materials at Elevated Temperatures," AF Technical Report 6517, Part 3, Wright Air Dev. Cen., June 1954. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3712, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 4



Ti.090 Ti-10V-2Fe-3Al titanium alloy, true stress-strain curves for β and α + β processed material

Tested at 790 °C (1455 °F) at various strain rates for (a) β structure and (b) α + β structure

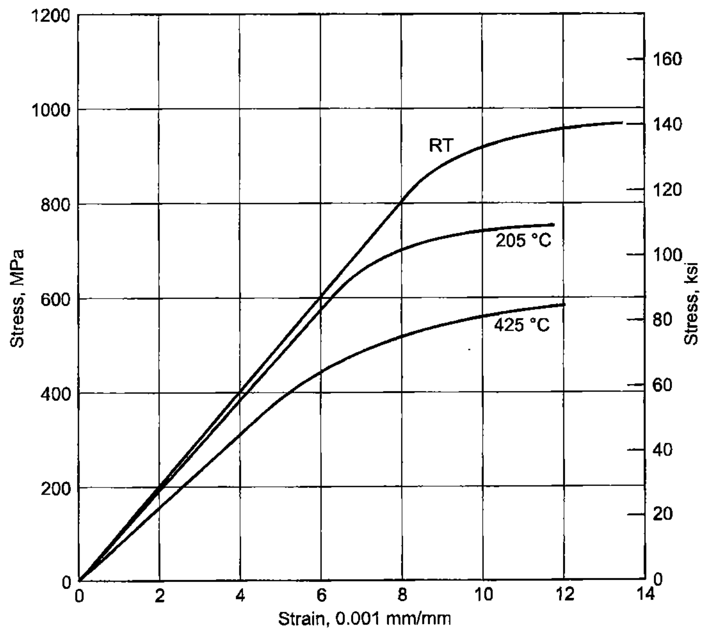
Source: G.W. Kuhlman et. al., *Sixth World Conference on Titanium*, P. Lacombe, R. Tricot, and G. Beranger, Ed., Les Editions de Physique, Paris, 1989, p 1269–1275. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 860



Ti.091 Ti-10V-2Fe-3Al titanium alloy, true longitudinal tensile stress-strain curves, effect of α fraction on unaged material

UTS, ultimate tensile strength; TYS, tensile yield strength. Curve A: α, 30 vol%; UTS, 875 MPa; TYS, 831 MPa. Curve B: α, 10 vol%; UTS, 877 MPa; TYS, 467 MPa. Curve C: α, 0 vol%; UTS, 878 MPa; TYS, 262 MPa. Increasing the amount of α increases the yield strength but does not affect the ultimate tensile strength. The β transus was 805 ± 3 °C (1480 °F), somewhat high compared to other heats. This is probably due to oxygen content (0.15 wt%), which is on high side of normal range. Treatments above 600 °C (1110 °F) done by vacuum encapsulating specimens wrapped in tantalum foil. Below 600 °C treatments were performed in a liquid nitrate salt bath. Strain rate = 0.00055/s

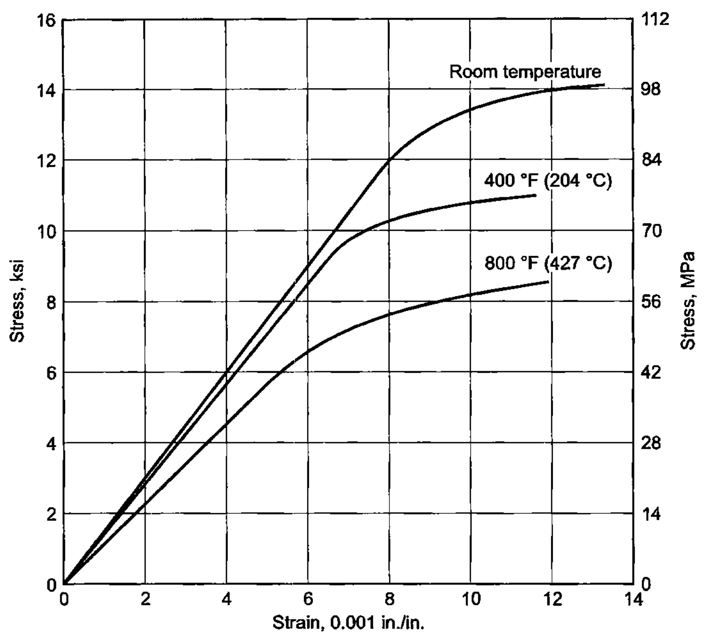
Source: T.W. Duerig, G.T. Terlinde, and J.C. Williams, Phase Transformations and Tensile Properties of Ti-10V-2Fe-3Al, *Metall. Trans.* A, Vol 11, Dec 1980, p 1987. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 859



Ti.092 Ti-10V-2Fe-3Al solution treated and overaged titanium alloy bar, tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Round bar. Maximum O, 0.16 wt%; maximum N, 0.05 wt%

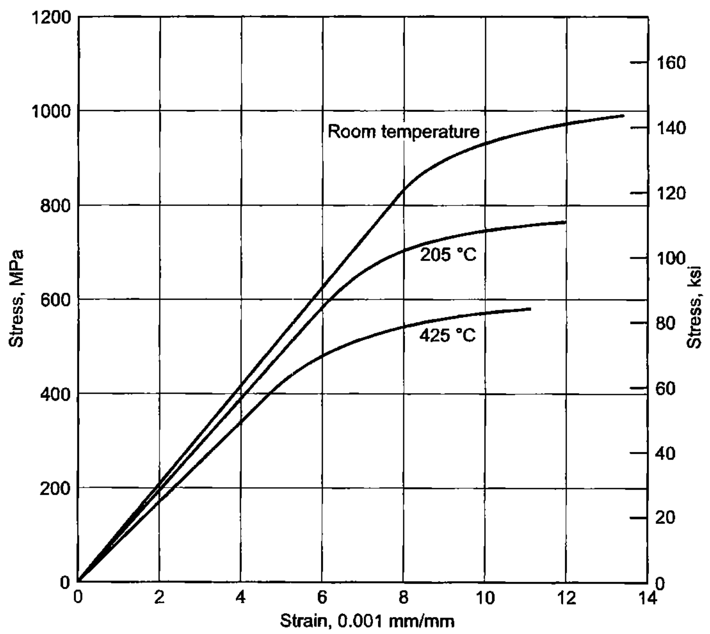
Source: O.L. Deel, "Engineering Data on New Aerospace Structural Materials," AFML-TR-77-198, Battelle-Columbus Laboratories, 1977, p 97. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 859



Ti.093 Ti-10V-2Fe-3Al heat treated titanium alloy bar, typical tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Bar diameter = 76 mm (3 in.). Heat treated: 760 °C (1400 °F), 1 h, force cooled + 566 °C (1050 °F), 8 h, air cooled

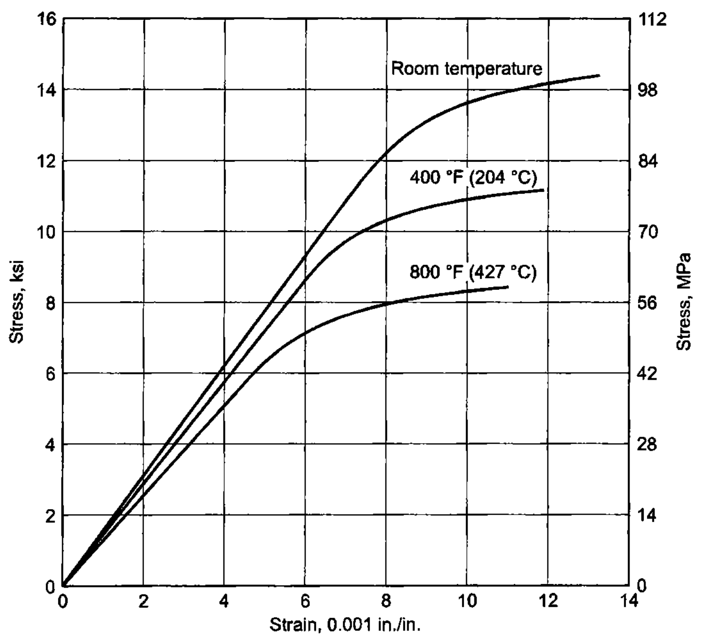
Source: O.L. Deel, "Engineering Data on New Aerospace Structural Materials," AFML-TR-77-198, Batelle-Columbus Laboratories, 1977. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3726, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 44



Ti.094 Ti-10V-2Fe-3Al solution treated and overaged titanium alloy bar, compressive stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Round bar

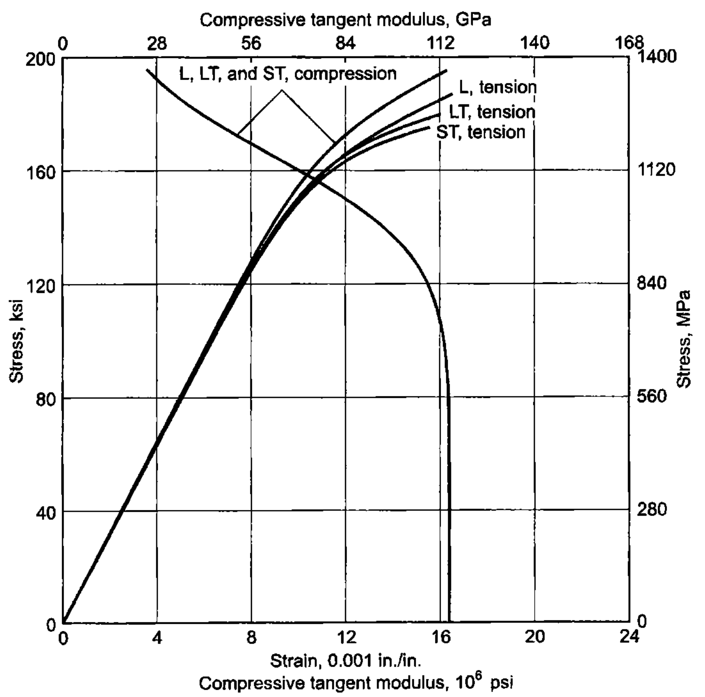
Source: O.L. Deel, "Engineering Data on New Aerospace Structural Materials," AFML-TR-77-198, Batelle-Columbus Laboratories, 1977, p 98. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 859



Ti.095 Ti-10V-2Fe-3Al heat treated titanium alloy bar, typical compressive stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Bar diameter = 76 mm (3 in.). Heat treated: 760 °C (1400 °F), 1 h, force cooled + 566 °C (1050 °F), 8 h, air cooled

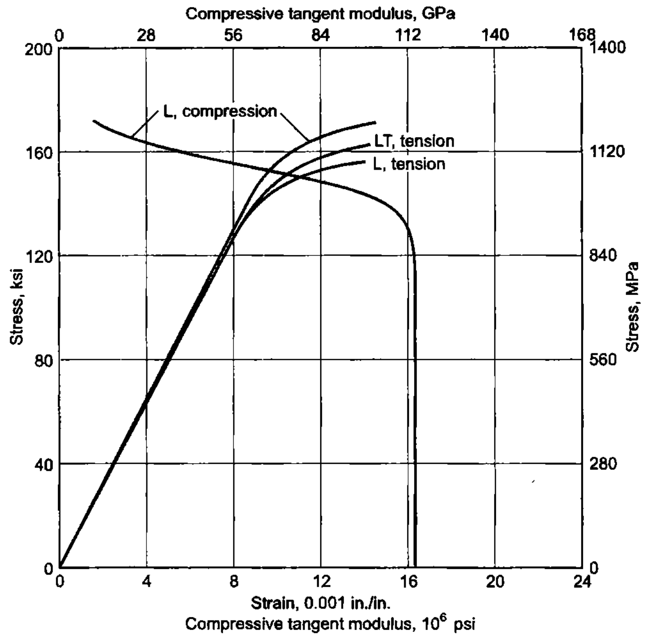
Source: O.L. Deel, "Engineering Data on New Aerospace Structural Materials," AFML-TR-77-198, Batelle-Columbus Laboratories, 1977. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3726, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 46



Ti.096 Ti-10V-2Fe-3Al solution treated and aged titanium alloy die forging, typical tensile stress-strain, compressive stress-strain, and compressive tangent modulus curves

Test directions: longitudinal (L), long transverse (LT), and short transverse (ST). Thickness = 78.74–83.82 mm (3.100–3.300 in.). Die forging aged 482–510 °C (900–950 °F). Ramberg-Osgood parameters: *n*(L, tension) = 9.6, *n*(LT, tension) = 13, *n*(ST, tension) = 13, *n*(L, compression) = 18, *n*(LT, compression) = 15, *n*(ST, compression) = 18

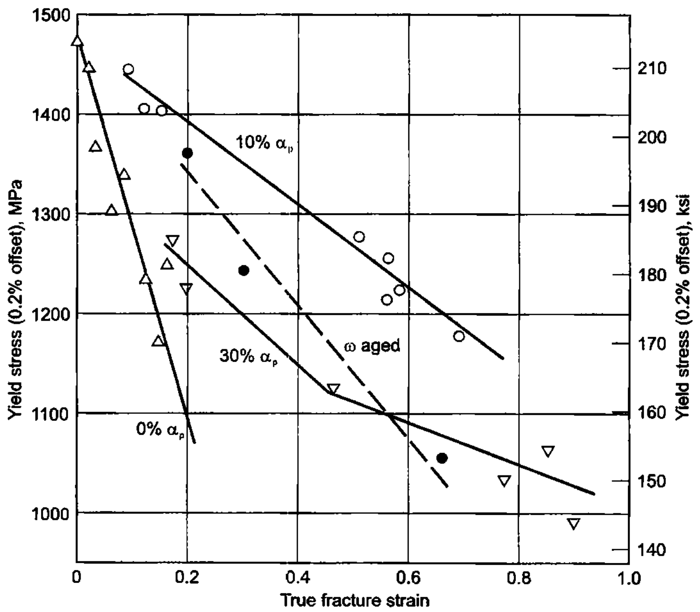
Source: *MIL-HDBK-5H*, Dec 1998, p 5–137



Ti.097 Ti-10V-2Fe-3Al solution treated and aged titanium alloy hand forging, typical tensile stress-strain, compressive stress-strain, and compressive tangent modulus curves

Test directions: longitudinal (L), long transverse (LT), and short transverse (ST). Hand forging aged 510–538 °C (950–1000 °F). Ramberg-Osgood parameters: *n*(L, tension) = 24, *n*(LT, tension) = 20, *n*(L, compression) = 21

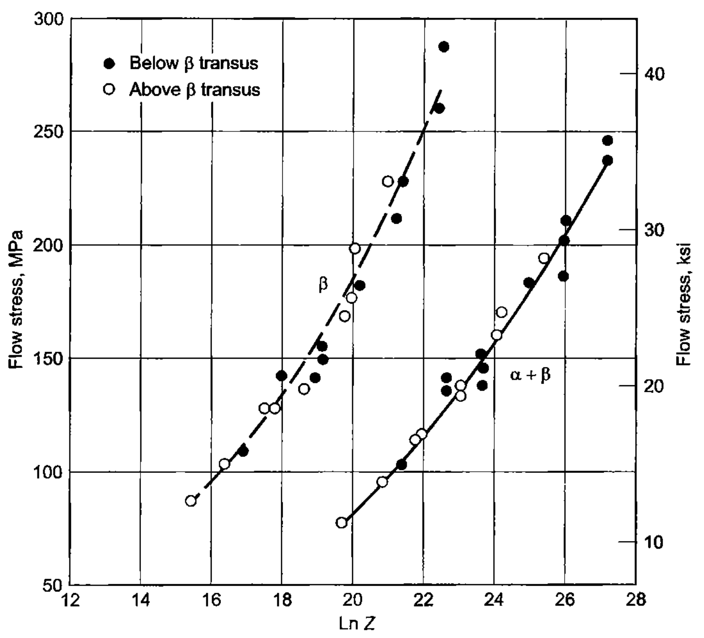
Source: *MIL-HDBK-5H*, Dec 1998, p 5–137



Ti.098 Ti-10V-2Fe-3Al titanium alloy, strength ductility trend curve showing effect of varying amounts of primary α

Data on yield strength versus tensile fracture strain can be plotted for each of several primary α volume fractions, as shown in this figure. These data show that the alloy in the most ductile condition at any of the strength levels studied is that which contains a small (~0.1) volume fraction of primary α. This condition represents a compromise in the sense that alloys containing no primary α unavoidably have grain-boundary α, whereas at higher volume fractions of primary α, strain localization tends to occur between the primary α particles. Both grain-boundary α and strain localization lead to premature fracture initiation, and thus the alloy that does not exhibit either of these conditions has better ductility.

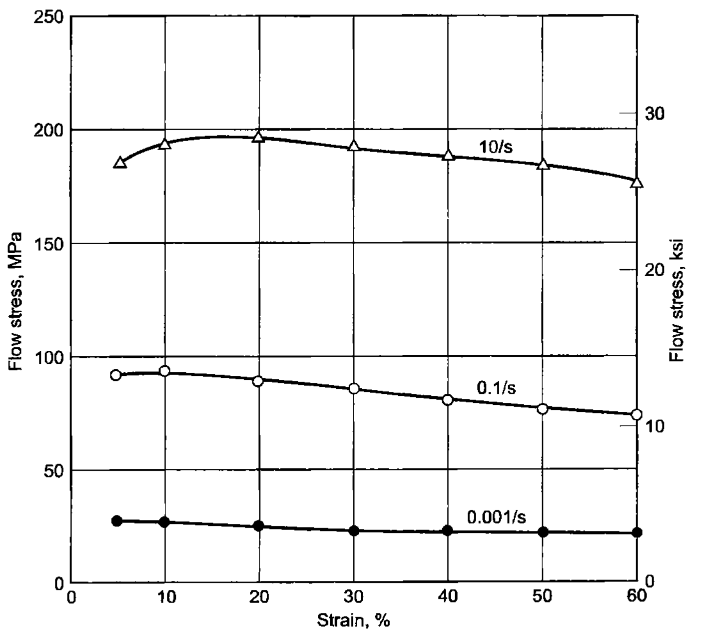
Source: G. Krauss, Ed., *Deformation, Processing, and Structure*, ASM Materials Science Seminar, 1982, American Society for Metals, 1984, p 323



Ti.099 Ti-10V-2Fe-3Al titanium alloy, effect of microstructure on flow stress

Ln Z is the temperature-compensated strain rate as defined by C.D. Zener and J.H. Hollaman, *J. Appl. Phys.*, Vol 15, 1944, p 22–32

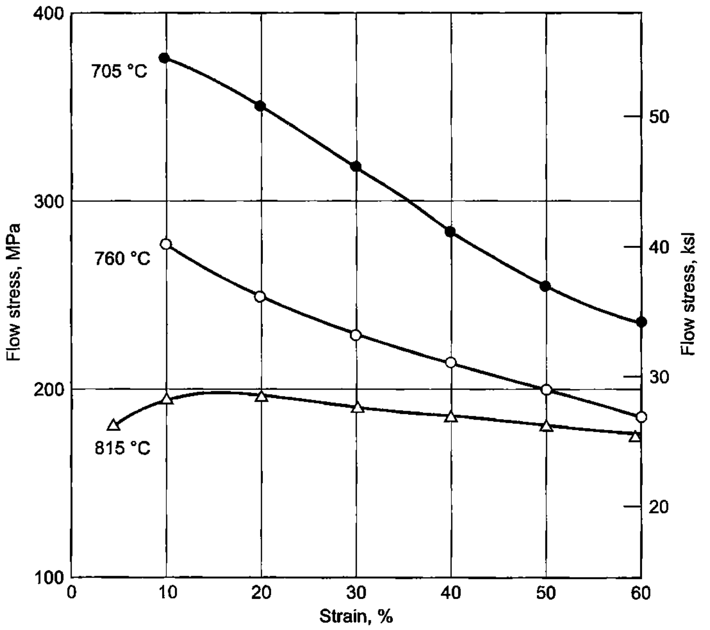
Source: G.W. Kuhlman et al., *Sixth World Conference on Titanium*, P. Lacombe, R. Tricot, and G. Beranger, Ed., Les Editions de Physique, Paris, 1989, p 1269–1275. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 860



Ti.100 Ti-10V-2Fe-3Al titanium alloy, flow stress versus strain

Effect of strain rate at 815 °C (1500 °F)

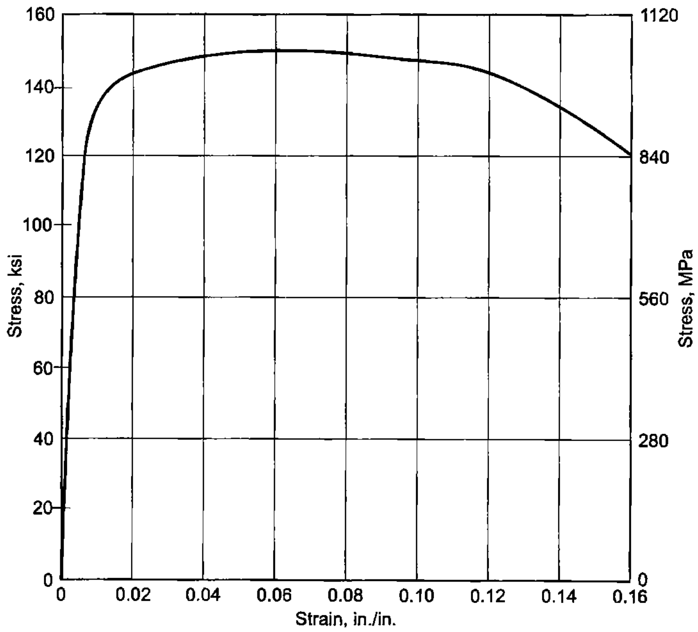
Source: R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 860



Ti.101 Ti-10V-2Fe-3Al titanium alloy, flow stress versus strain

Effect of forging temperature at 10/s strain rate

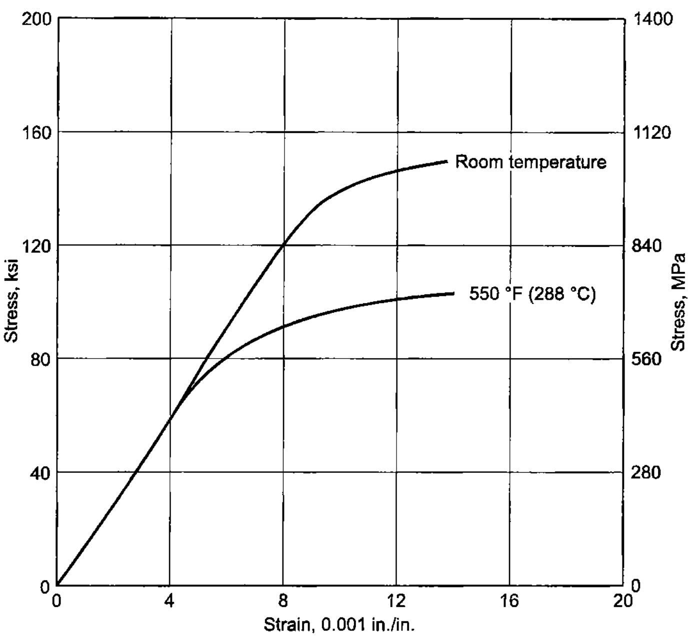
Source: R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 860



Ti.102 Ti-11Sn-5Zr-2.25Al-1Mo-0.21Si titanium alloy, forging, large ring, tensile stress-strain curve at room temperature

Heat treated in full section: 900 °C (1650 °F), 1 h, fan cooled + 500 °C (930 °F), 24 h, air cooled

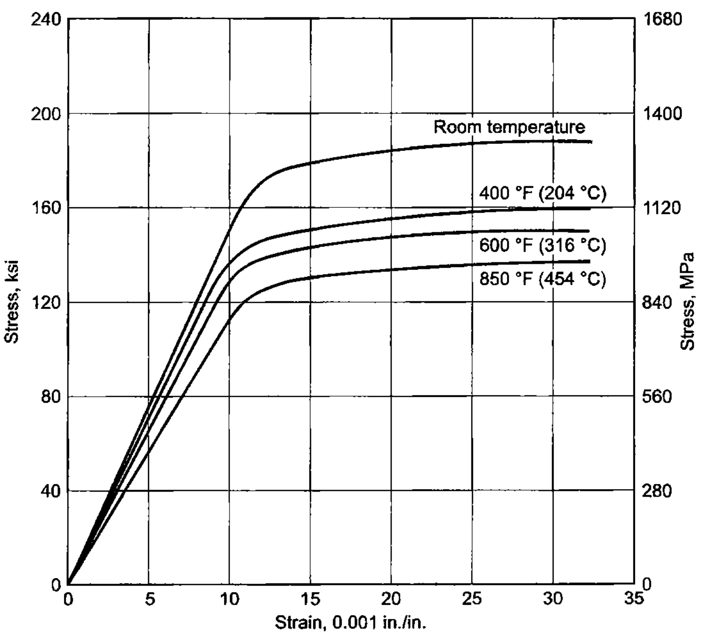
Source: R.F. Simenz and W.L. Macoritto, "Evaluation of Large Ti-6Al-4V and IMI-679 Forging," Technical Report AFML-TR-66-57, Lockheed-California Co., 1966. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3711, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 21



Ti.103 Ti-11Sn-5Zr-2.25Al-1Mo-0.21Si titanium alloy forging, large ring, compressive stress-strain curves at room temperature and 288 °C (550 °F)

Specimen size: 15.88 mm (0.625 in.) diam; 44.45 mm (1.750 in.) long. Heat treated in full section: 900 °C (1650 °F), 1 h, fan cooled + 500 °C (930 °F), 24 h, air cooled

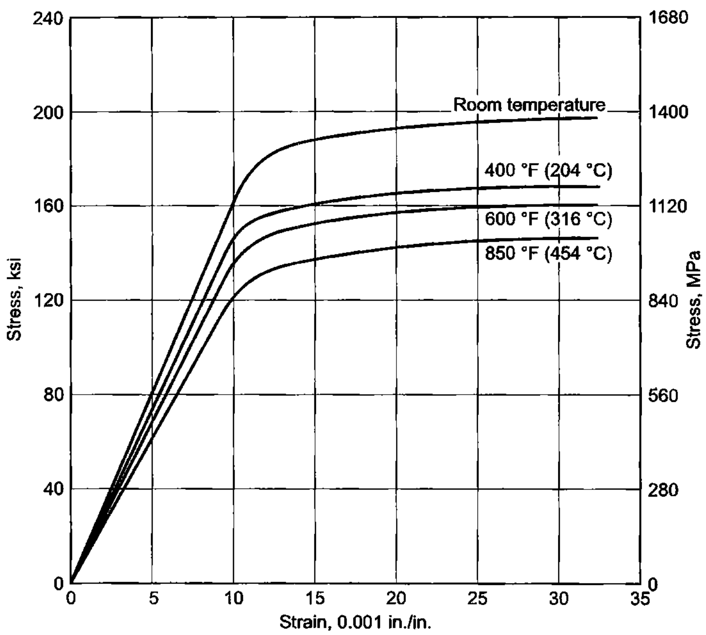
Source: R.F. Simenz and W.L. Macoritto, "Evaluation of Large Ti-6Al-4V and IMI-679 Forging," Technical Report, AFML-TR-66-57, Lockheed-California Co., 1966. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3711, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 28



Ti.104 Ti-11.5Mo-6Zr-4.5Sn titanium alloy sheet, typical tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Sheet thickness = 1.6 mm (0.063 in.). Solution treated + 510 °C (950 °F), 8 h, air cooled. UNS R58030

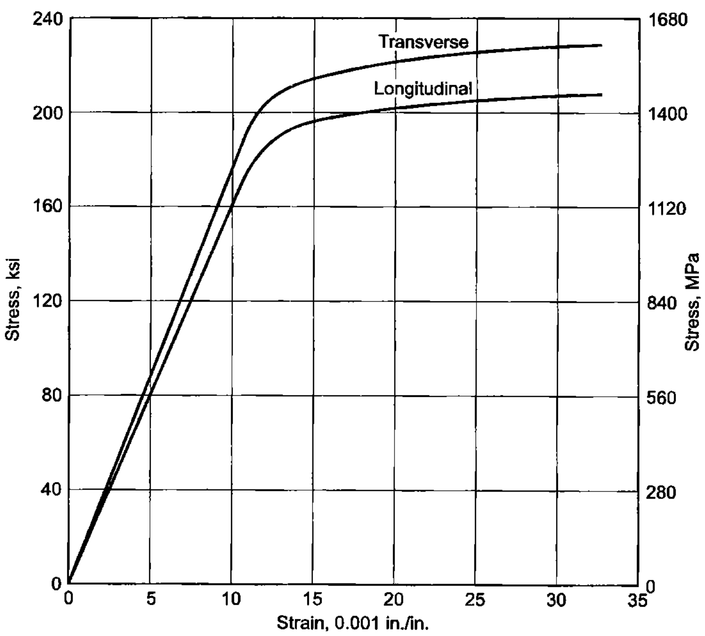
Source: O.L. Deel and H. Mindlin, "Engineering Data on New and Emerging Structural Materials," AFML-TR-70-252, Batelle-Columbus Laboratories, Oct 1970. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3722, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 33



Ti.105 Ti-11.5Mo-6Zr-4.5Sn titanium alloy sheet, typical tensile stress-strain curves at room and elevated temperatures

Test direction: transverse. Sheet thickness = 1.6 mm (0.063 in.). Solution treated + 510 °C (950 °F), 8 h, air cooled. UNS R58030

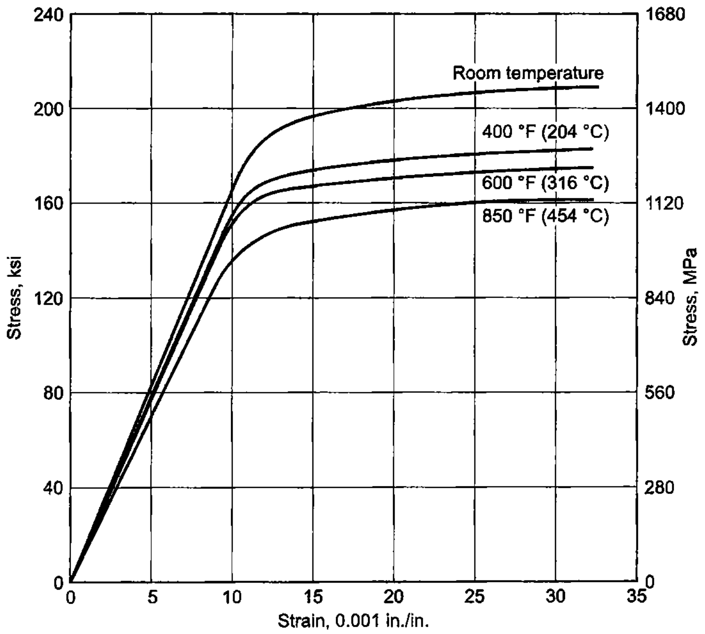
Source: O.L. Deel and H. Mindlin, "Engineering Data on New and Emerging Structural Materials," AFML-TR-70-252, Batelle-Columbus Laboratories, Oct 1970. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3722, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 33



Ti.106 Ti-11.5Mo-6Zr-4.5Sn titanium alloy sheet, typical compressive stress-strain curves

Sheet thickness = 1.6 mm (0.063 in.). Solution treated + 510 °C (950 °F), 8 h, air cooled. UNS R58030

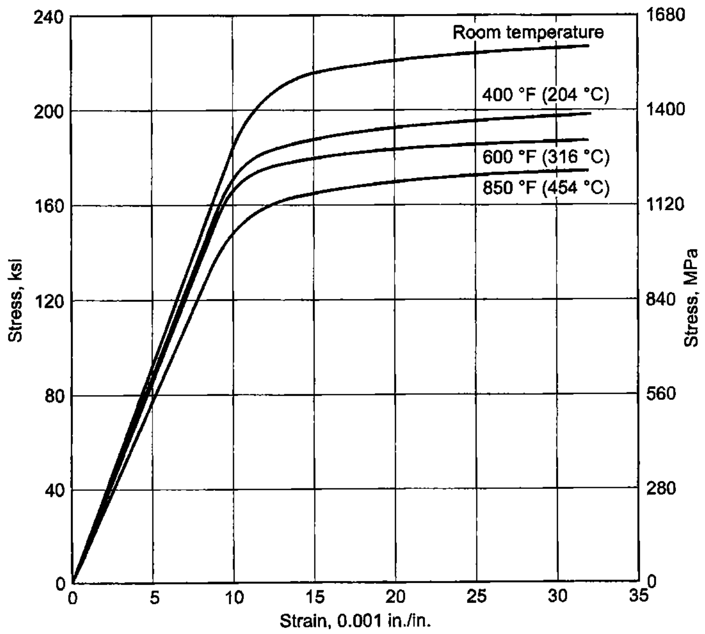
Source: O.L. Deel and H. Mindlin, "Engineering Data on New and Emerging Structural Materials," AFML-TR-70-252, Batelle-Columbus Laboratories, Oct 1970. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3722, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 30



Ti.107 Ti-11.5Mo-6Zr-4.5Sn titanium alloy sheet, typical compressive stress-strain curves at room and elevated temperatures

Test direction: longitudinal. Sheet thickness = 1.6 mm (0.063 in.). Solution treated + 510 °C (950 °F), 8 h, air cooled. UNS R58030

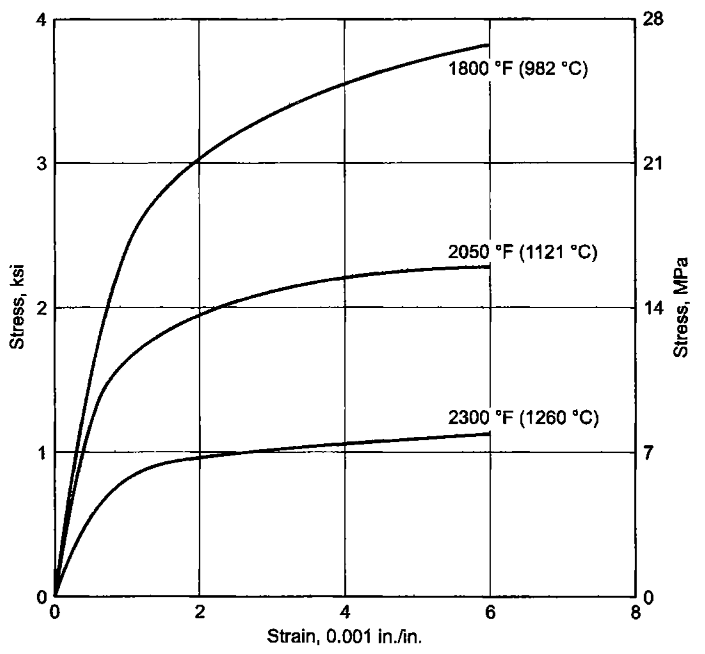
Source: O.L. Deel and H. Mindlin, "Engineering Data on New and Emerging Structural Materials," AFML-TR-70-252, Batelle-Columbus Laboratories, Oct 1970. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3722, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 35



Ti.108 Ti-11.5Mo-6Zr-4.5Sn titanium alloy sheet, typical compressive stress-strain curves at room and elevated temperatures

Test direction: transverse. Sheet thickness = 1.6 mm (0.063 in.). Solution treated + 510 °C (950 °F), 8 h, air cooled. UNS R58030

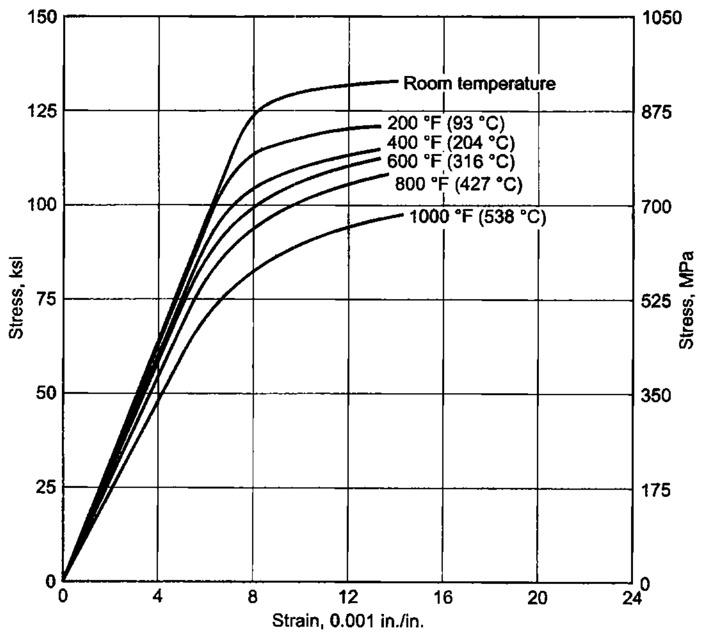
Source: O.L. Deel and H. Mindlin, "Engineering Data on New and Emerging Structural Materials," AFML-TR-70-252, Batelle-Columbus Laboratories, Oct 1970. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3722, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 35



Ti.109 Ti-13V-11Cr-3Al titanium alloy, tensile stress-strain curves at very high temperatures

UNS R58010

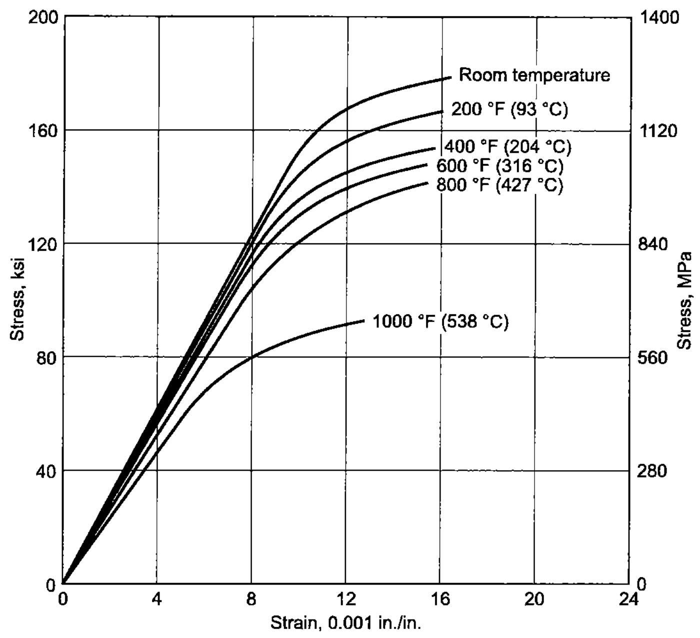
Source: P.E. Moorhead, "Tensile and Creep Properties of Columbium, Tantalum and Titanium Alloys at Elevated Temperatures," Bell Laboratory Report BLR-62-26M, Dec 1962. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3712, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 11



Ti.110 Ti-13V-11Cr-3Al annealed titanium alloy sheet, typical tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal and long transverse. 0.5 h exposure. Ramberg-Osgood parameters: n(room temperature) = 43, n(200 °F) = 30, n(400 °F) = 17, n(600 °F) = 12, n(800 °F) = 11, n(1000 °F) = 10. UNS R58010

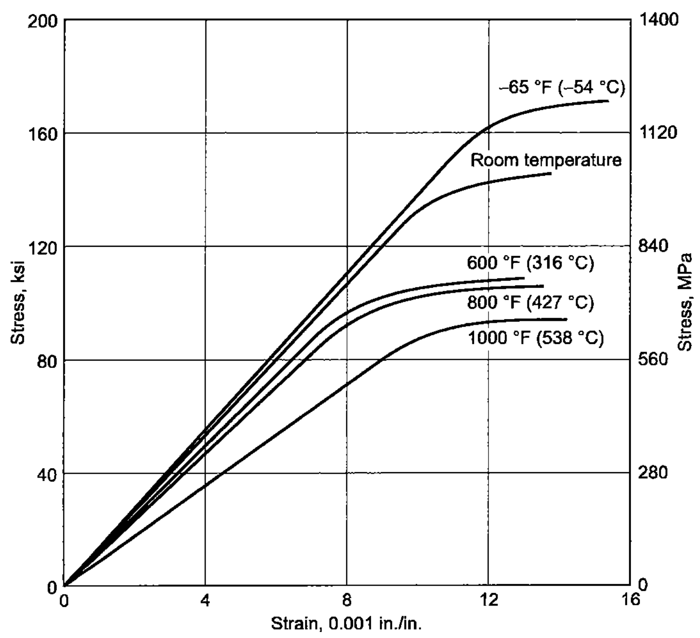
Source: *MIL-HDBK-5H*, Dec 1998, p 5–118



Ti.111 Ti-13V-11Cr-3Al solution treated and aged titanium alloy sheet, typical tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal and long transverse. 0.5 h exposure. Ramberg-Osgood parameters: n(room temperature) = 23, n(200 °F) = 17, n(400 °F) = 16, n(600 °F) = 15, n(800 °F) = 11, n(1000 °F) = 10. UNS R58010

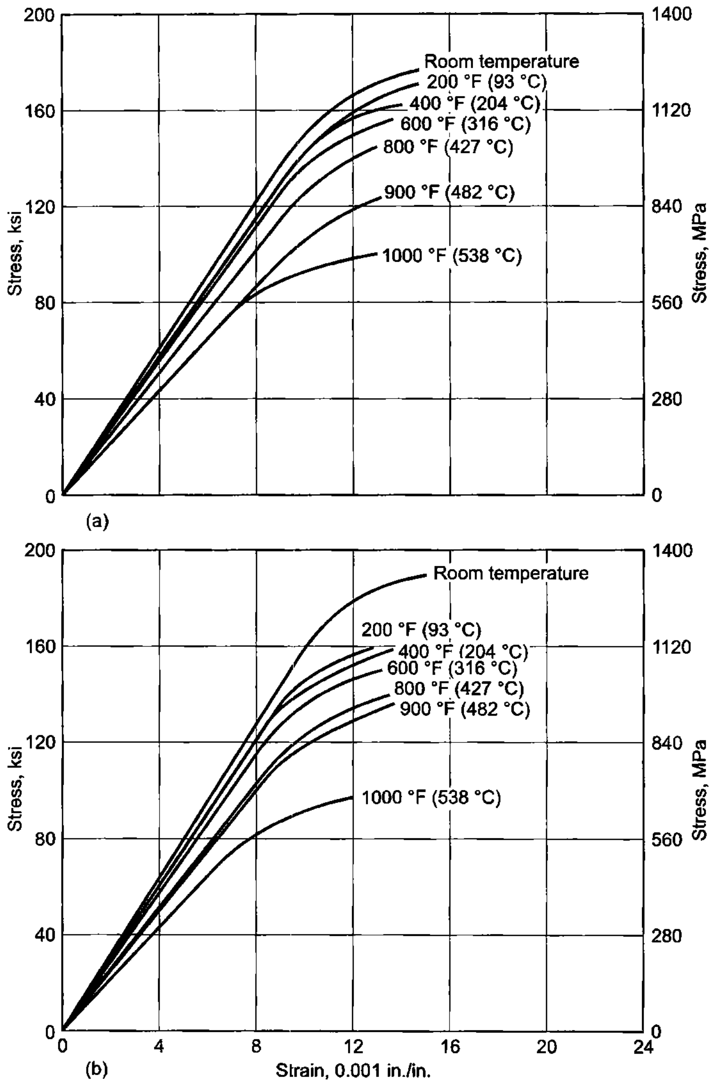
Source: *MIL-HDBK-5H*, Dec 1998, p 5–125



Ti.112 Ti-13V-11Cr-3Al solution treated titanium alloy sheet, tensile stress-strain curves at room and various temperatures

Sheet thickness = 1 mm (0.040 in.). UNS R58010

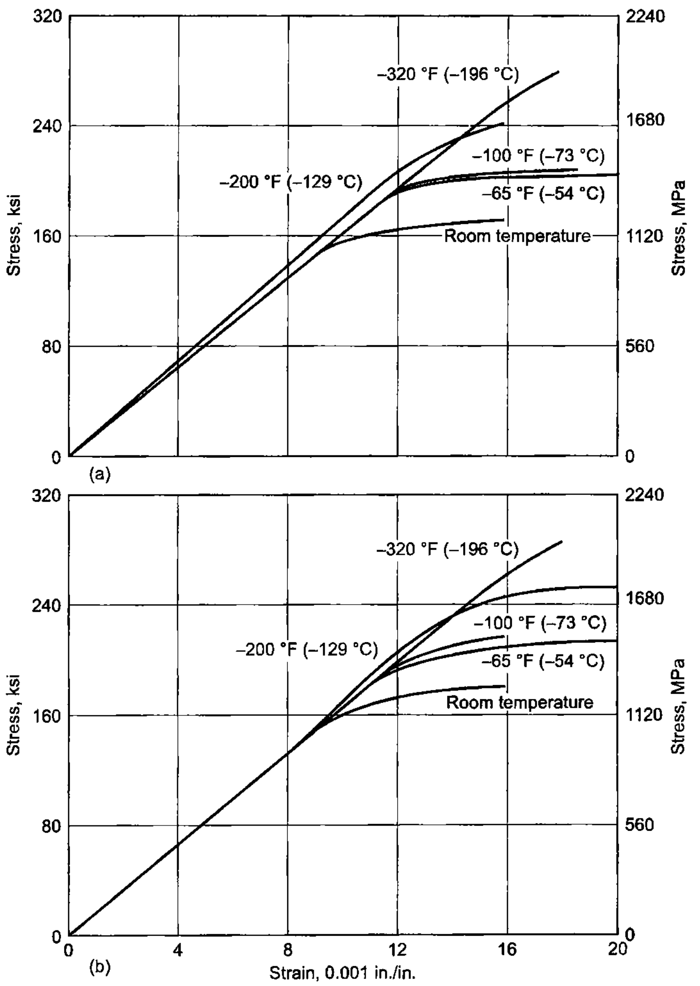
Source: "Data Sheet B 120 VCA," Titanium Alloys Issue 2, TDS-2007-5M, Crucible Steel Co. of America, Dec 1960. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3712, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 11



Ti.113 Ti-13V-11Cr-3Al solution treated and aged titanium alloy sheet, tensile stress-strain curves at room and elevated temperatures

Test direction: longitudinal (a) and transverse (b). Sheet thickness = 3.18 mm (0.125 in.). UNS R58010

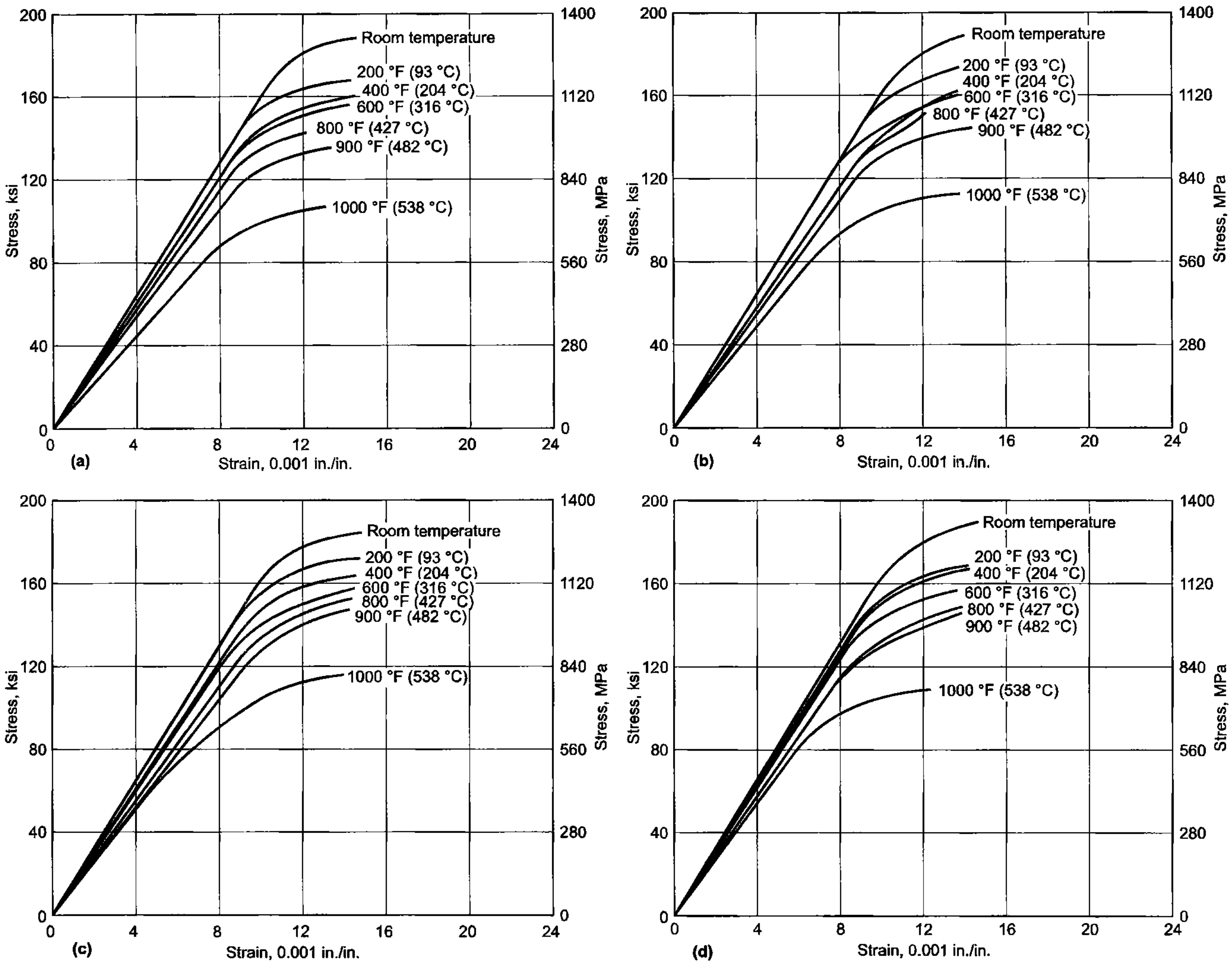
Source: P.J. Hughes, "Determination of Design Data for Heat Treated Titanium Alloy Sheet," Vol I, ASD-TR-62-335, May 1962. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3712, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 11



Ti.114 Ti-13V-11Cr-3Al solution treated and aged titanium alloy sheet, tensile stress-strain curves at room and low temperatures

Test direction: longitudinal (a) and transverse (b). Sheet thickness = 1.6 mm (0.063 in.). UNS R58010

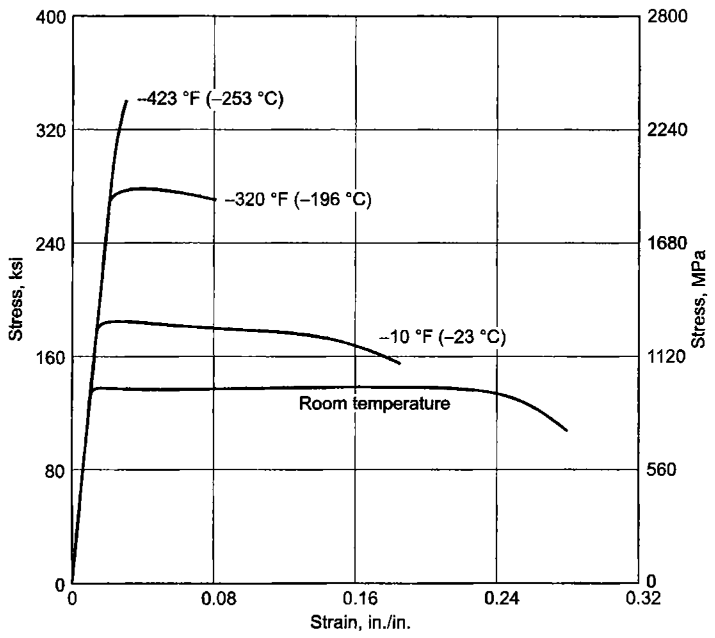
Source: W.M. McGee and R.B. Mathews, "Determination of Design Data for Heat Treated Titanium Alloy Sheet," Vol 2a, ASD-TR-62-335, May 1962. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3712, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



Ti.115 Ti-13V-11Cr-3Al solution treated and aged titanium alloy sheet, typical compressive stress-strain curves at room and elevated temperatures

(a) Sheet thickness = 1.6 mm (0.063 in.); test direction: longitudinal. (b) Sheet thickness = 1.6 mm (0.063 in.); test direction: transverse. (c) Sheet thickness = 3.18 mm (0.125 in.); test direction: longitudinal. (d) Sheet thickness = 3.18 mm (0.125 in.); test direction: transverse. UNS R58010

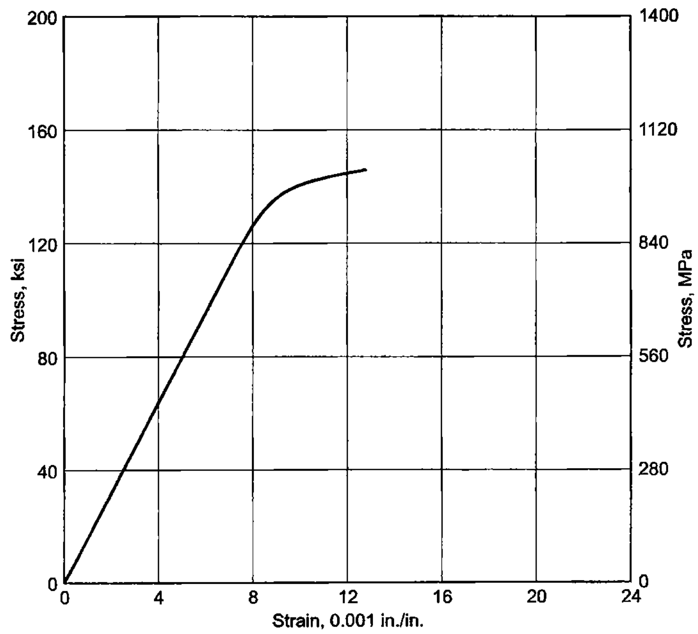
Source: P.J. Hughes, "Determination of Design Data for Heat Treated Titanium Alloy Sheet," Vol I, ASD-TR-62-335, 1962. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3712, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 14



Ti.116 Ti-13V-11Cr-3Al solution treated titanium alloy bar, tensile stress-strain curves at room and low temperatures

UNS R58010
Bar diameter = 19 mm (¾ in.)

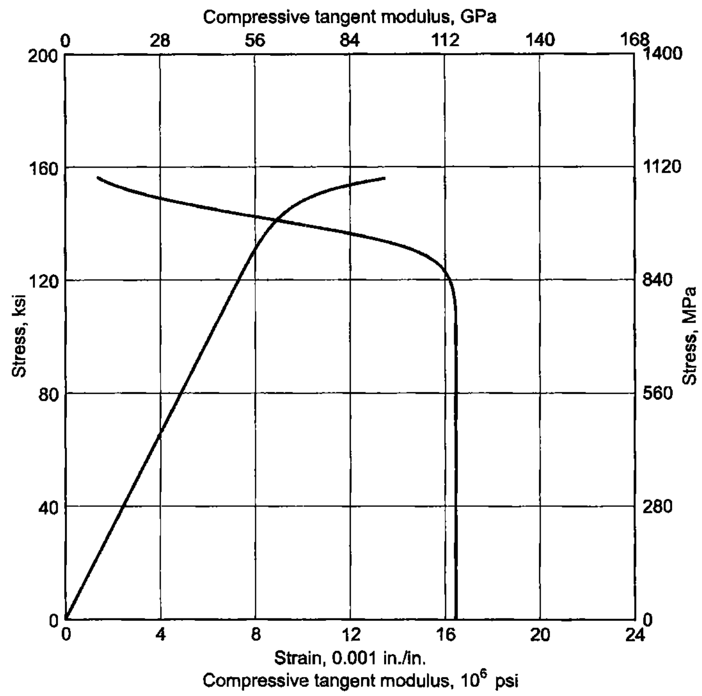
Source: F.R. Schwartzberg, S.H. Osgood, R.D. Keys, and T.F. Kiefer, "Cryogenic Materials Data Handbook," Progress Report No. 1, ML-TDR-64-280, Suppl., 1965. As published in *Aerospace Structural Metals Handbook*, Vol 4, Code 3712, CINDAS/USAF CRDA Handbooks Operation, Purdue University, 1995, p 12



Ti.117 Ti-15V-3Cr-3Sn-3Al solution treated and aged titanium sheet, typical tensile stress-strain curve at room temperature

Test direction: longitudinal. Aged at 538 °C (1000 °F). Ramberg-Osgood parameter: *n*(longitudinal) = 30

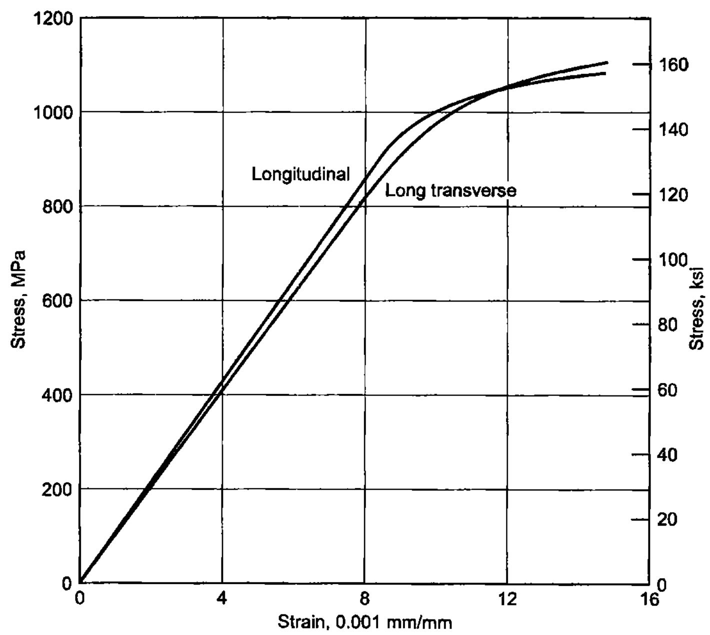
Source: *MIL-HDBK-5H*, Dec 1998, p 5–132



Ti.118 Ti-15V-3Cr-3Sn-3Al solution treated and aged titanium alloy sheet, typical compressive stress-strain and compressive tangent modulus curves

Aged at 538 °C (1000 °F). Ramberg-Osgood parameter: *n*(longitudinal) = 26

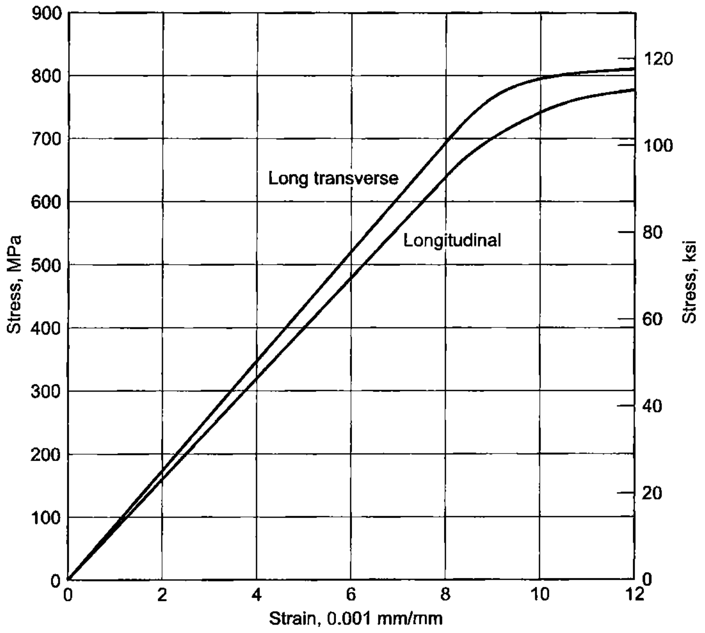
Source: *MIL-HDBK-5H*, Dec 1998, p 5–132



Ti.119 Ti-15V-3Cr-3Sn-3Al solution treated and aged titanium alloy sheet, typical tensile stress-strain curves

Test direction: longitudinal and long transverse. Sheet thickness = 0.5–1.9 mm (0.020–0.076 in.)

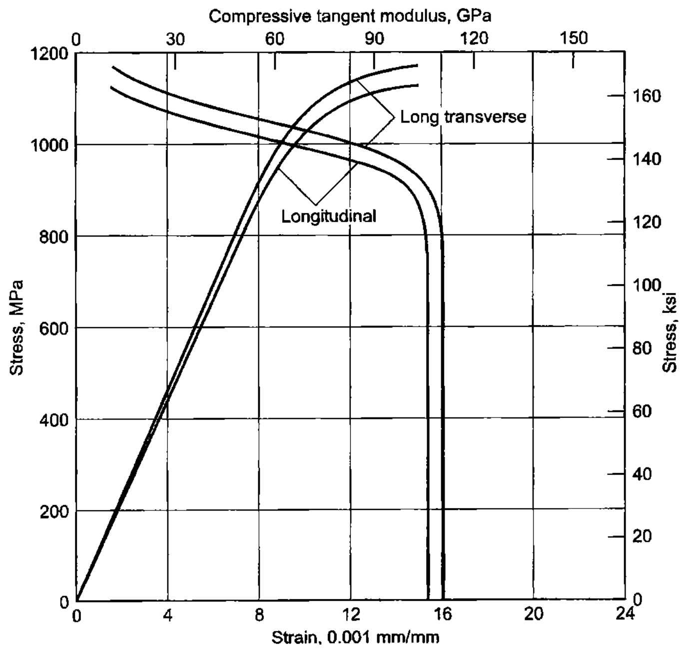
Source: MIL-HDBK-5, 1991. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 913



Ti.120 Ti-15V-3Cr-3Sn-3Al solution treated titanium alloy sheet, typical tensile stress-strain curves

Test direction: longitudinal and long transverse. Sheet thickness = 0.53–3.17 mm (0.021–0.125 in.)

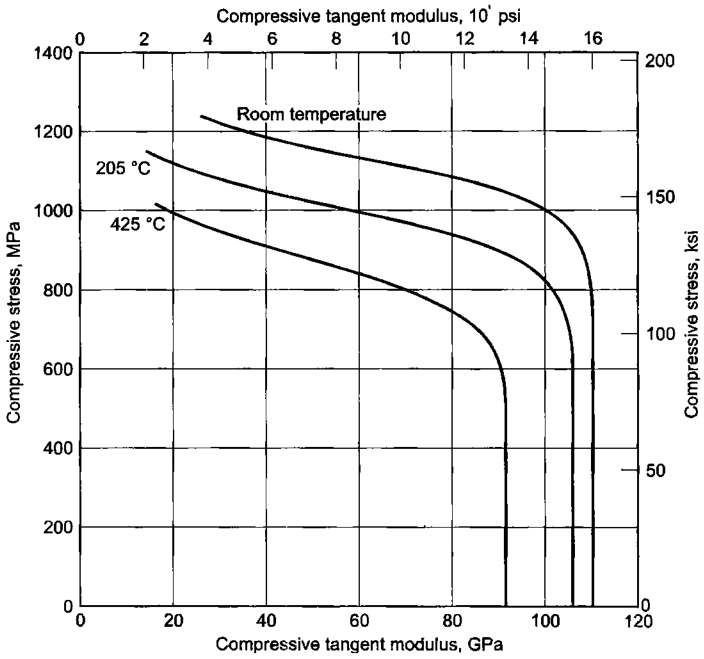
Source: MIL-HDBK-5, 1991. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 913



Ti.121 Ti-15V-3Cr-3Sn-3Al aged titanium alloy sheet, typical compressive stress-strain and compressive tangent modulus curves

Test direction: longitudinal and long transverse. Sheet thickness = 0.5–1.9 mm (0.020–0.076 in.). Aged at 540 °C (1000 °F)

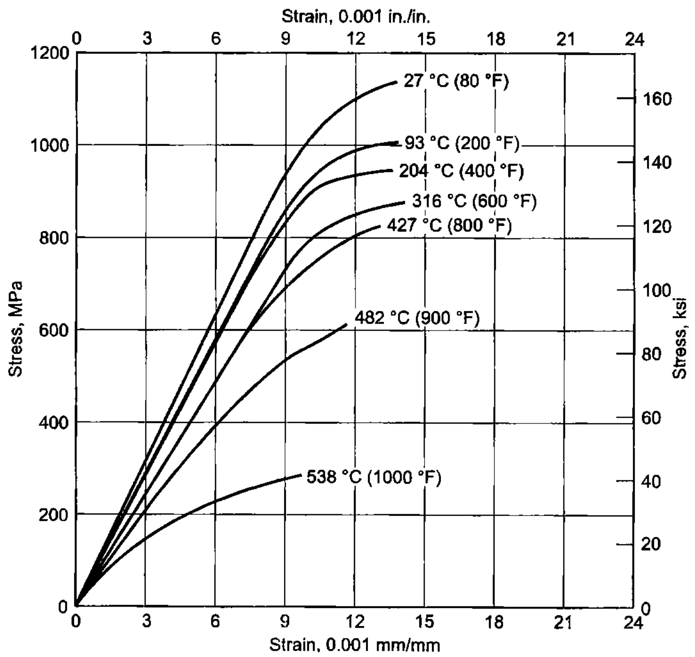
Source: *MIL-HDBK-5E*, 1988. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 913



Ti.122 Ti-15V-3Cr-3Sn-3Al solution treated and aged titanium alloy, typical compressive tangent modulus curves for room and elevated temperatures

Test direction: transverse

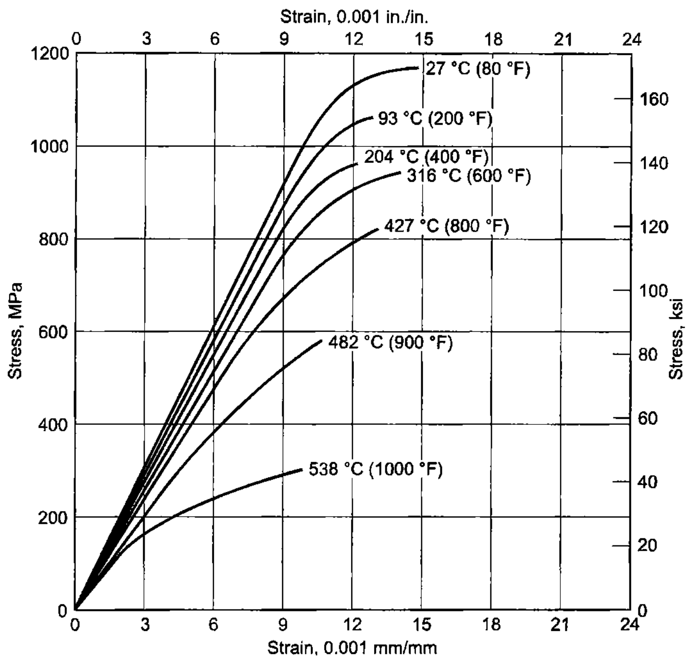
Source: Collected Engineering Data Sheets, AFML-TR-78-179, 1978. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 913



Ti.123 Ti-16V-2.5Al solution treated and aged titanium alloy sheet, typical tensile stress-strain curves for various temperatures

Test direction: longitudinal. Sheet thickness = 1.6 mm (0.063 in.)

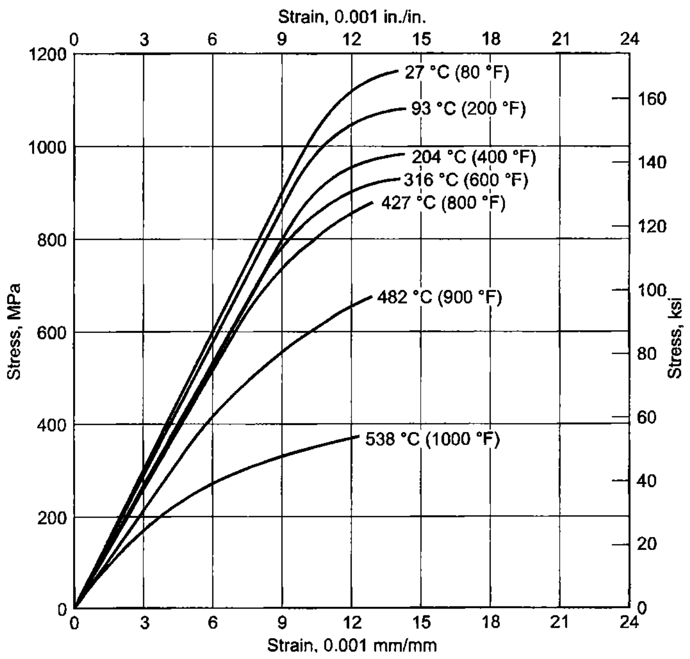
Source: "Determination of Design Data for Heat Treated Titanium Alloy Sheet," Report No. ASD-TDR-62-335, Vol 1, Lockheed-Georgia, Dec 1962. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 1007



Ti.124 Ti-16V-2.5Al solution treated and aged titanium alloy sheet, typical tensile stress-strain curves for various temperatures

Test direction: transverse. Sheet thickness = 1.6 mm (0.063 in.)

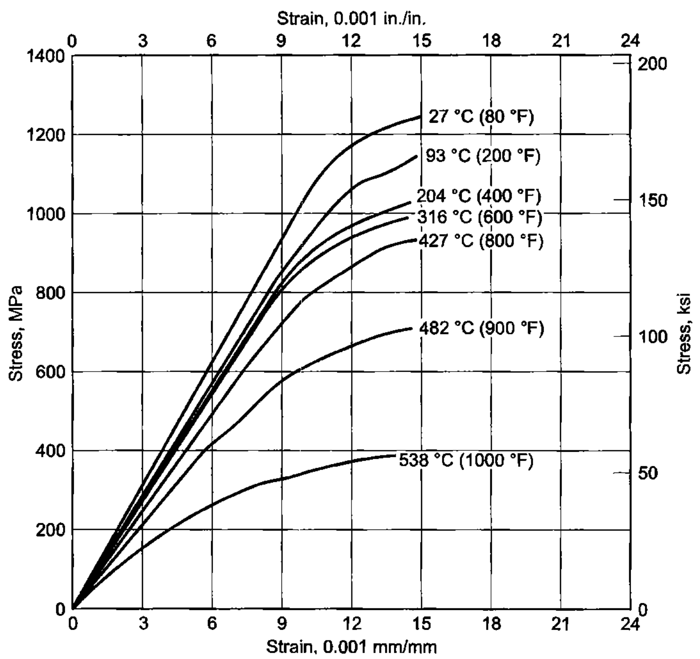
Source: "Determination of Design Data for Heat Treated Titanium Alloy Sheet," Report No. ASD-TDR-62-335, Vol 1, Lockheed-Georgia, Dec 1962. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 1007



Ti.125 Ti-16V-2.5Al solution treated and aged titanium alloy sheet, typical compressive stress-strain curves for various temperatures

Test direction: longitudinal. Sheet thickness = 1.6 mm (0.063 in.)

Source: "Determination of Design Data for Heat Treated Titanium Alloy Sheet," Report No. ASD-TDR-62-335, Vol 1, Lockheed-Georgia, Dec 1962. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 1006

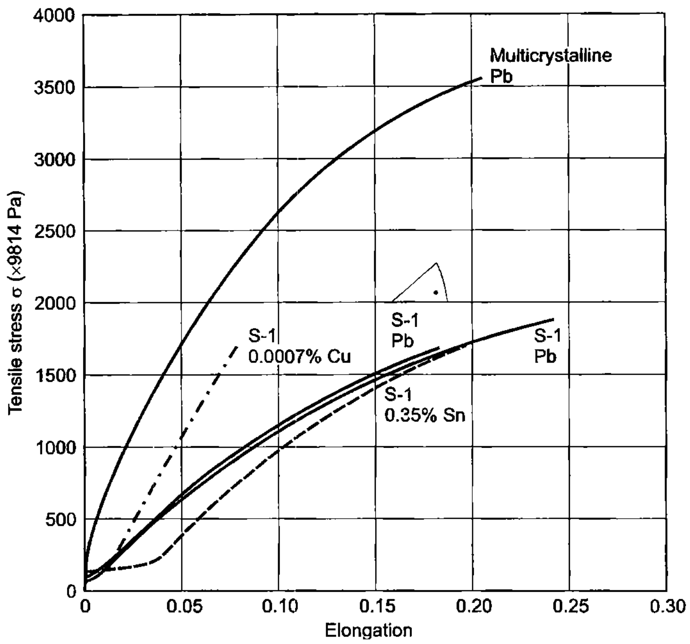


Ti.126 Ti-16V-2.5Al solution treated and aged titanium alloy sheet, typical transverse compressive stress-strain curves for various temperatures

Test direction: transverse. Sheet thickness = 1.6 mm (0.063 in.)

Source: "Determination of Design Data for Heat Treated Titanium Alloy Sheet," Report No. ASD-TDR-62-335, Vol 1, Lockheed-Georgia, Dec 1962. As published in R. Boyer, G. Welsch, and E. Collings, Ed., *Materials Properties Handbook: Titanium Alloys*, ASM International, 1994, p 1006

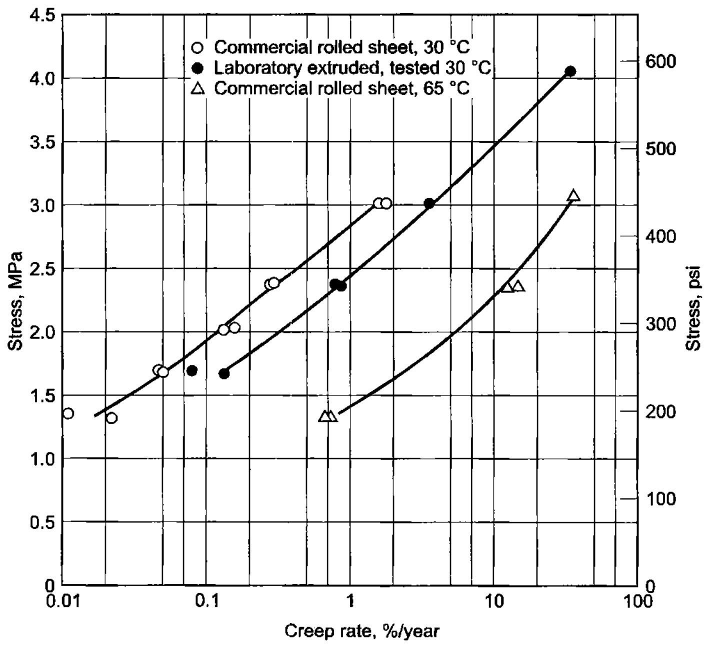
Pure Metals and Miscellaneous Alloys (MA)



MA.001 Lead and lead alloy single crystals, tensile stress-elongation curves

Tested at 77 K (−321 °F)

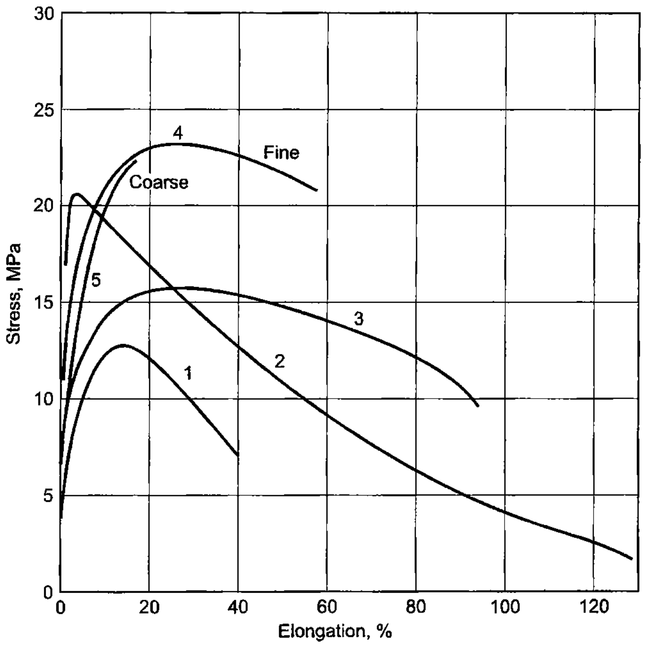
Source: S. Guruswamy, *Engineering Properties and Applications of Lead Alloys,* Marcel Dekker. As prepared for the International Lead Zinc Research Organization, Inc., p 110



MA.002 +99.90% lead sheet, stress versus creep rate

Test specimens 19 × 32 mm (3/4 × 1/8 in.) with 250 mm (10 in.) gage length. Specimen longitudinal

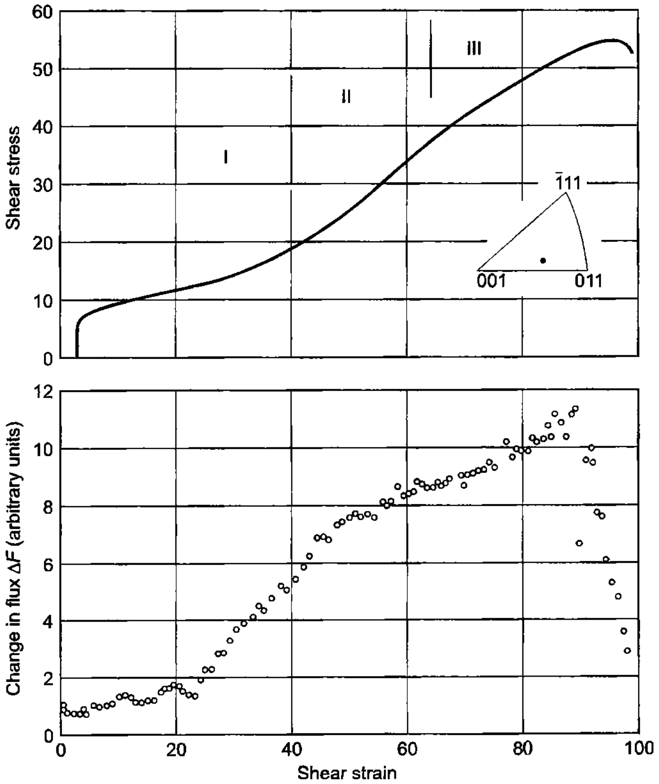
Source: Lead and Lead Alloys, *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials,* Vol 2, *ASM Handbook,* ASM International, 1990, p 549



MA.003 Refined lead and lead alloys, stress-strain curves

Curve 1, refined lead. Other curves, various alloys. Curve 4 is fine grained, and curve 5 is course grained. Lead has little mechanical strength, and its strength is very sensitive to changes in chemical composition. Variation of 99.99% purity (UNS L50010) to 99.9999% purity (UNS L50001) can result in a change in ultimate tensile strength from 14 to 9 MPa. Changes in rate of strain of testing cause similar variation. Creep strength (Pb.004) is more significant.

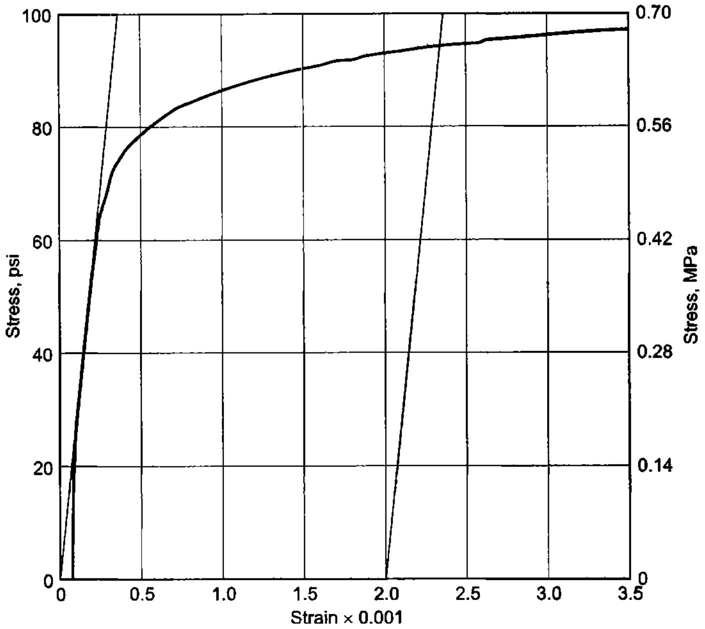
Source: B.P. Haigh and B. Jones, *J. Inst. Metals,* Vol 51, 1933, p 49. As published in W. Hofmann, *Lead and Lead Alloys,* Springer Verlag, 1970, p 201



MA.004 Pb-5In lead rod, stress-strain curve (top) and change in flux versus strain (bottom)

Top: stress-strain measured at 4.2 K and a strain rate of 0.0001/s. Bottom: the change in flux accompanying the motion of dislocation as a function of shear strain

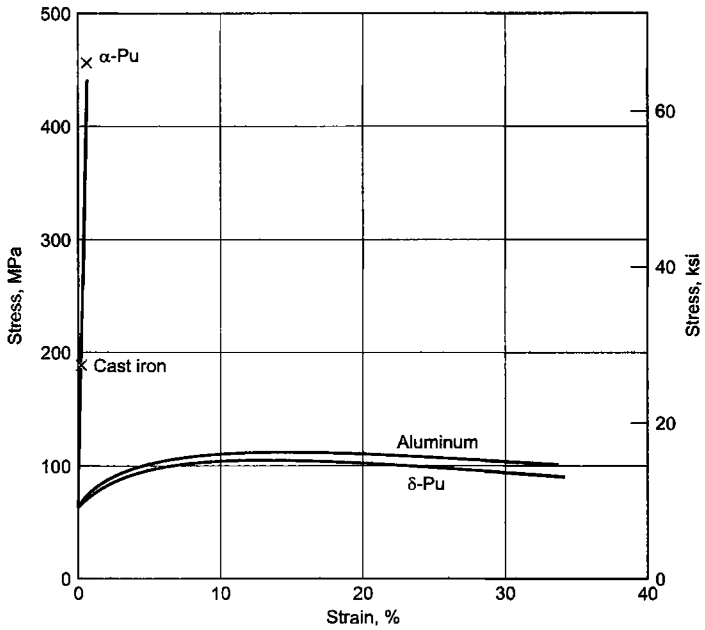
Source: C.S. Pang and J.M. Galligan, in *Precious Metals: Science and Technology,* The International Precious Metals Institute, 1991, p 61



MA.005 Battery grade lithium (2% impurities), compressive stress-strain curves

Test direction: longitudinal. Sample size = 42.9 mm diam × 89 mm (1.688 in. diam × 3.5 in.) tested at room temperature at 3.81 mm/min (0.15 in./min). Modulus of elasticity = 1880 MPa (273 ksi); 0.2% yield strength = 0.652 MPa (94.5 psi). Other tests with rates varying from 0.127–3.81 mm/min (0.05–0.15 in./min) yielded an average modulus of elasticity of 1900 MPa (276 ksi) and an average 0.2% yield strength of 0.558 MPa (81 psi).

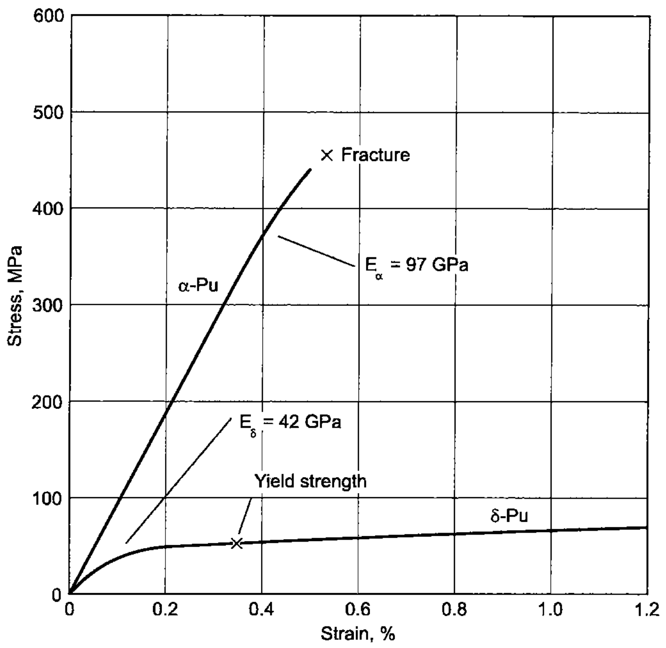
Source: Private communication with R. Schultz, Fermi National Accelerator Laboratory, March 2002



MA.006 α-Pu and δ-Pu-1.7 Ga plutonium room temperature full-range stress-strain curves

Full range uniaxial stress-strain curves for unalloyed α-plutonium and fcc δ-phase Pu-1.7 Ga (at.%). X is fracture point compared to cast iron fracture point. δ-phase is ductile and work hardens like aluminum.

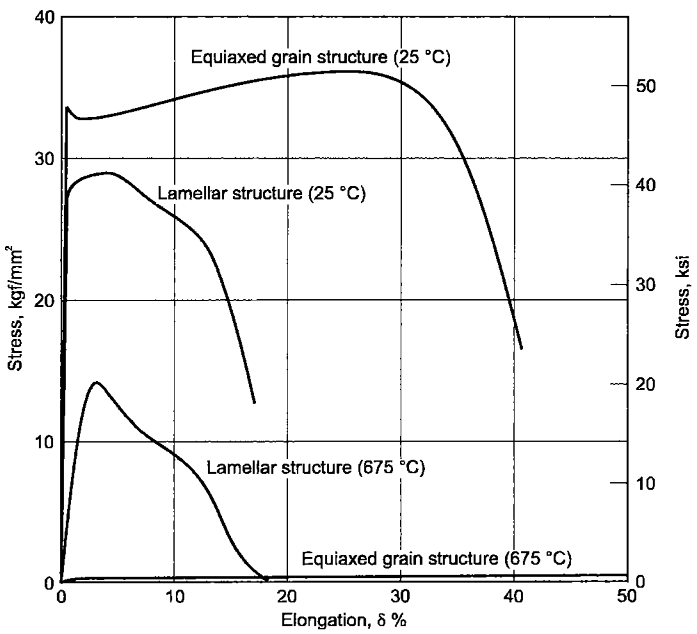
Source: S.S. Hecker and M.F. Stevens, *Mechanical Behavior of Plutonium and Its Alloys,* Los Alamos Science, Los Alamos National Laboratory, Vol II (No. 26), 2000, p 339



MA.007 α-Pu and δ-Pu-1.7 Ga plutonium room temperature expanded-range stress-strain curves

Expanded-range uniaxial stress-strain curves for unalloyed α-plutonium and fcc δ-phase Pu-1.7 Ga (at.%). Modulus of elasticity, α-plutonium, 97 GPa; δ-plutonium, 42 GPa.

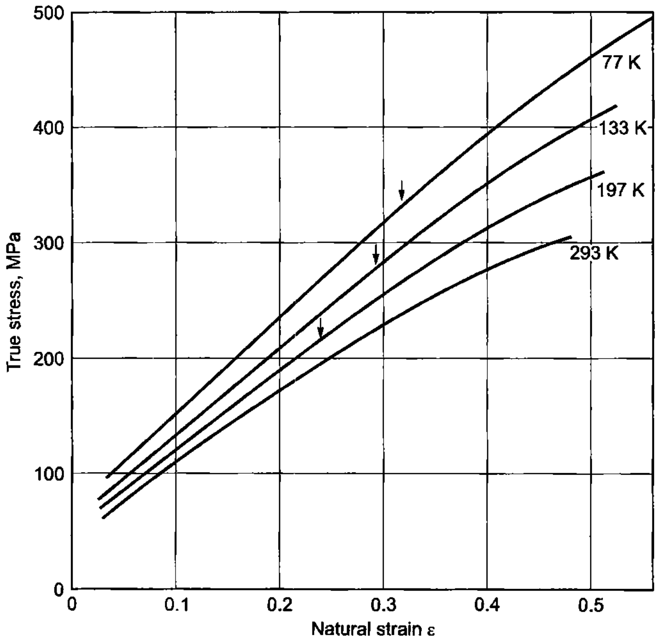
Source: S.S. Hecker and M.F. Stevens, *Mechanical Behavior of Plutonium and Its Alloys,* Los Alamos Science, Los Alamos National Laboratory, Vol II (No. 26), 2000, p 339



MA.008 Silver-copper eutectic alloys, stress-strain curves at 25 and 625 °C for lamellar and equiaxed grain structure

Lamellar structure produced by unidirectional solidification had an initial strain rate of 0.020/min. Equiaxed structure produced by extrusion and recrystallization had an initial strain rate of 0.025/min. It is superplastic at 675 °C with low stress and elongation as great as 500%.

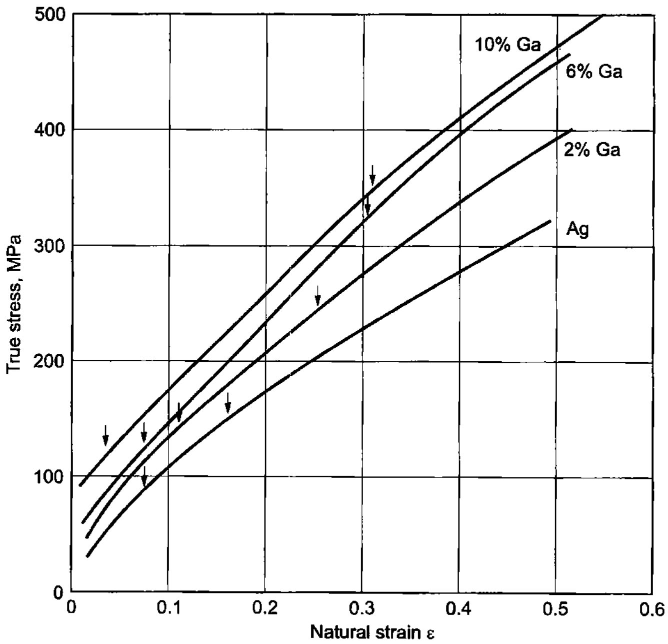
Source: H.E. Cline and D. Lee, *Precious Metals: Science and Technology,* The International Precious Metals Institute, 1991, p 645



MA.009 Silver, Ag-6Sn alloy, stress-strain curves for silver and silver-6 at.% Sn solid solution at various temperatures

Arrows indicate end of linear hardening range (stage 2).

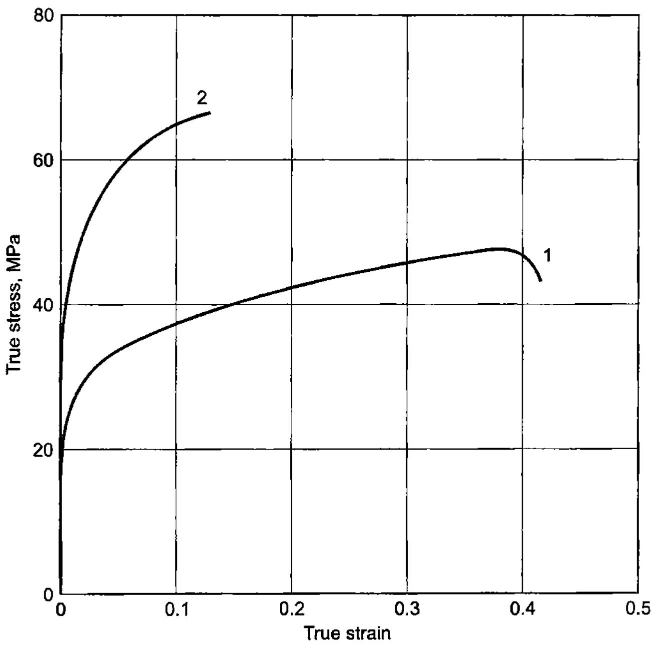
Source: R.W.K. Honeycombe, *The Plastic Deformation of Metals*, American Society for Metals, 1984, p 233



MA.010 Silver, Ag-Ga alloy, stress-strain curves for silver and silver-gallium solid solutions

Tested at 77 K, constant grain size. Arrows indicate linear hardening range (stage 2).

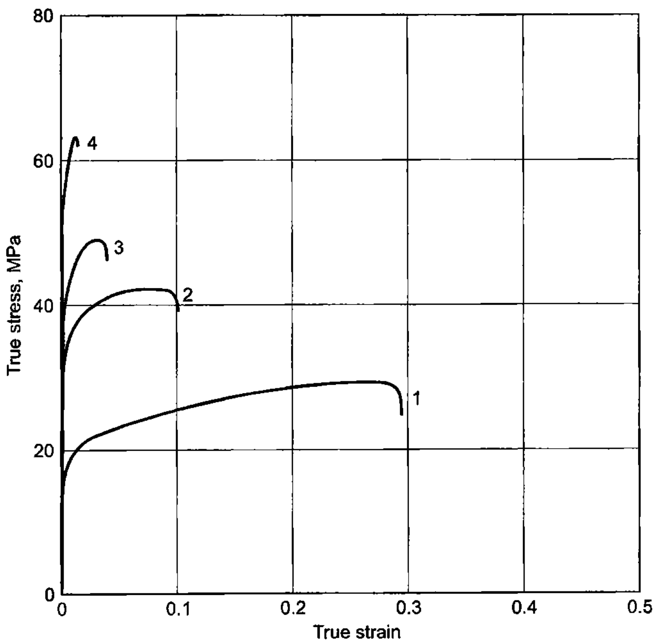
Source: R.W.K. Honeycombe, *The Plastic Deformation of Metals*, American Society for Metals, 1984, p 235



MA.011 Sn-0.5Bi tin solder, true stress-strain at –20 °C (–4 °F)

Curve 1,Sn-0.5 Bi at.% (Sn-0.9 Bi wt%); curve 2, Sn-1.5 Bi at.% (Sn-2.6 Bi wt%). Strain rate 5×10^{-5} s^{-1}.

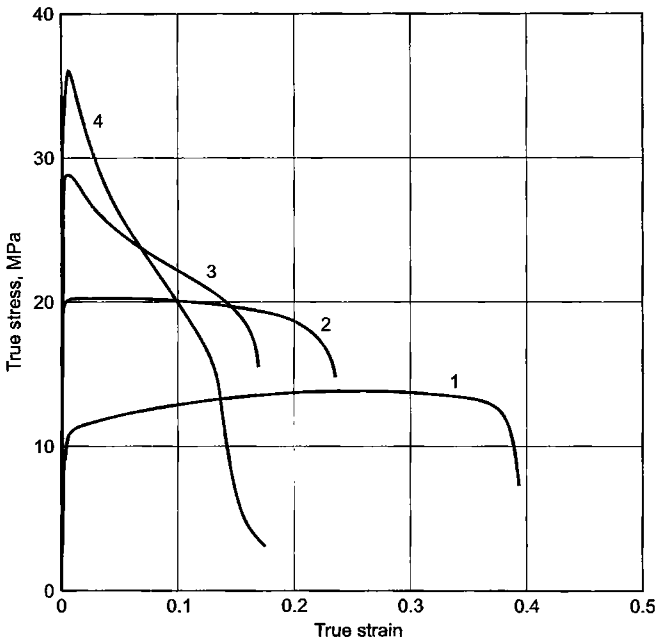
Source: T. Reinikainien and J. Kivilahti, Deformation Behavior of Dilute SnBi (0.5 to 6 At. Pct) Solid Solution, as published in *Metall. Mater. Trans. A*, ASM, Vol 30A, Jan 1999, p 126



MA.012 Sn-3.0Bi tin solder, true stress-strain at 90 °C (194 °F)

Curve 1, Sn-0.5 Bi at.% (Sn-0.9 Bi wt%); curve 2, Sn-1.5 Bi at.% (Sn-2.6 Bi wt%); curve 3, Sn-3.0 Bi at.% (Sn-5.2 Bi wt%); curve 4, Sn-6.0 Bi at.% (Sn-10.0 Bi wt%). Strain rate 5×10^{-5} s^{-1}.

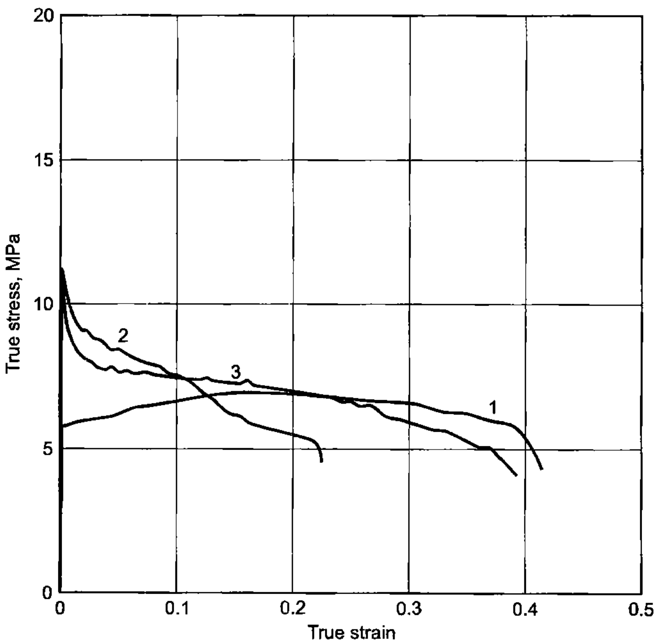
Source: T. Reinikainien and J. Kivilahti, Deformation Behavior of Dilute SnBi (0.5 to 6 At. Pct) Solid Solution, as published in *Metall. Mater. Trans. A*, ASM International, Vol 30A, Jan 1999, p 126



MA.013 Sn-1.5Bi tin solder, true stress-strain at 23 °C (73 °F)

Curve 1, Sn-0.5 Bi at.% (Sn-0.9 Bi wt%); curve 2, Sn-1.5 Bi at.% (Sn-2.6 Bi wt%); curve 3, Sn-3.0 Bi at.% (Sn-5.2 Bi wt%); curve 4, Sn-6.0 Bi at.% (Sn-10.0 Bi wt%). Strain rate 5×10^{-5} s^{-1}.

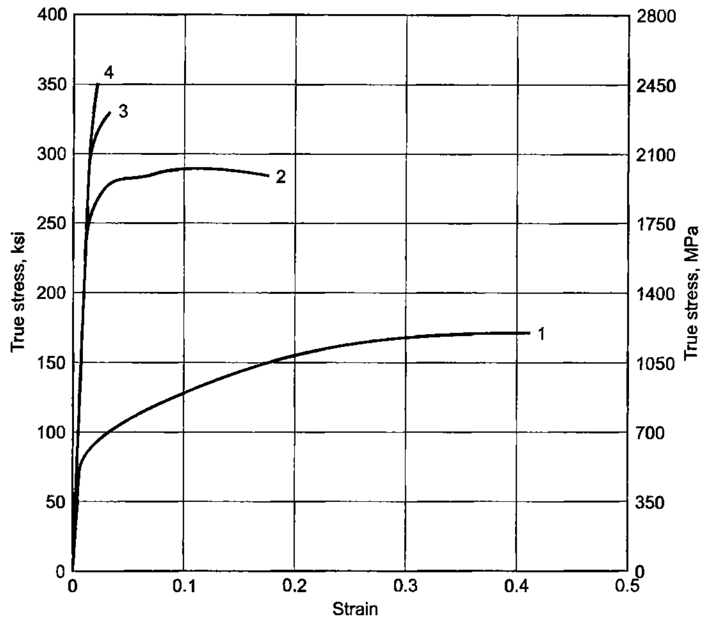
Source: T. Reinikainien and J. Kivilahti, Deformation Behavior of Dilute SnBi (0.5 to 6 At. Pct) Solid Solution, as published in *Metall. Mater. Trans. A*, ASM International, Vol 30A, Jan 1999, p 126



MA.014 Sn-6.0Bi tin solder, true stress-strain at 150 °C (302 °F)

Curve 1, Sn-0.5 Bi at.% (Sn-0.9 Bi wt%); curve 2, Sn-1.5 Bi at.% (Sn-2.6 Bi wt%); curve 3, Sn-3.0 Bi at.% (Sn-5.2 Bi wt%). Strain rate 5×10^{-5} s^{-1}.

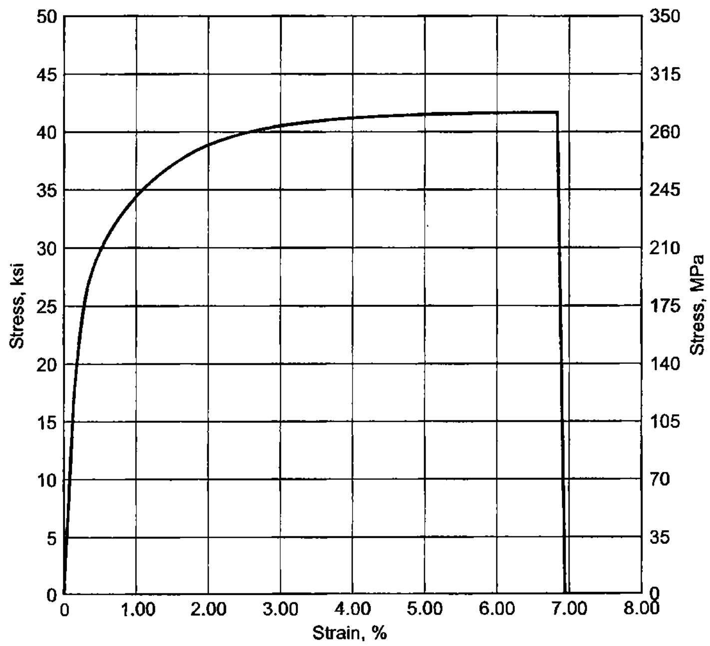
Source: T. Reinikainien and J. Kivilahti, Deformation Behavior of Dilute SnBi (0.5 to 6 At. Pct) Solid Solution, as published in *Metall. Mater. Trans. A*, ASM, Vol 30A, Jan 1999, p 126



MA.015 Uranium alloys, compressive stress-strain for high hardness alloys

Comparison of curve 1, pure uranium; curve 2, U-3 Mo (wt %); curve 3, U-5 Re (wt %); and curve 4, U-3Mo-0.5 Cr (wt %). Alloys were annealed 700 to 800 °C, 2 h; water quenched, tempered 400 °C, 2 h.

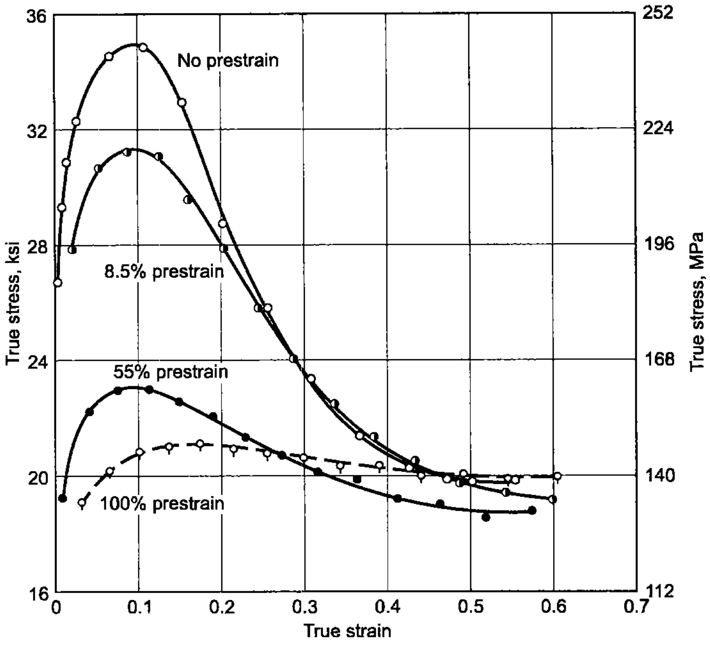
Source: P.A.Kulin, J. De Avellar, and R. Jenkins, The Preparation of Uranium Alloys of High Density and High Hardness, as published in *W.D. Wilkinson Uranium Metallurgy,* Vol II: Uranium Corrosion and Alloys, Interscience Publishers, 1962, p 870



MA.016 ZA3F1 zinc flats, tensile stress-strain curve

Flat size: 12.7 × 6.35 mm (0.5 × 0.25 in.). Five specimens were tested. Average ultimate tensile strength, 281.8 MPa (40.87 ksi), average yield strength, 194.1 MPa (28.15 ksi)

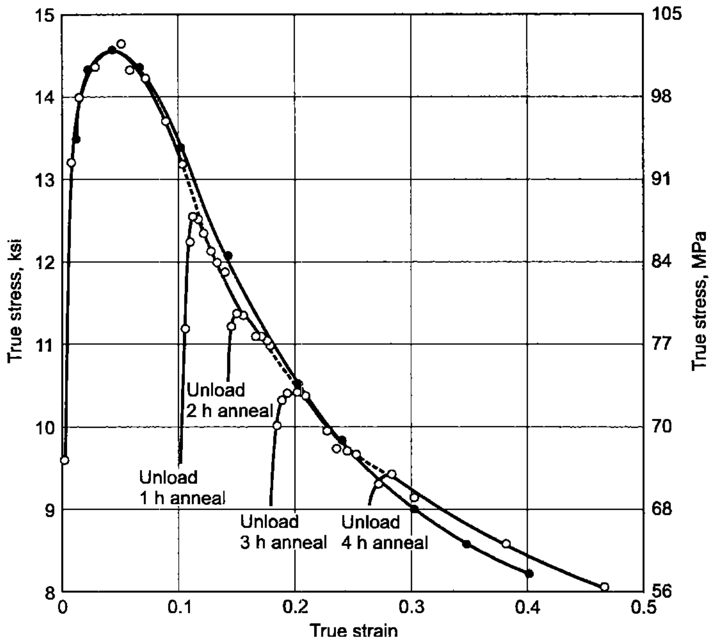
Source: Noranda Technology Centre, Pointe Claire, Quebec, Canada



MA.017 Powder-metallurgy zinc rod, effect of various amounts of prestrain at 240 °C (464 °F) on stress-strain behavior at room temperature

Rods compressed longitudinally at room temperature. Initial strain rate 0.067/min. Curves indicate that specimens which had been prestrained 55% or more at 240 °C (464 °F) no longer strain-softened appreciably and were considerably weaker than material that contained the much larger, elongated grains.

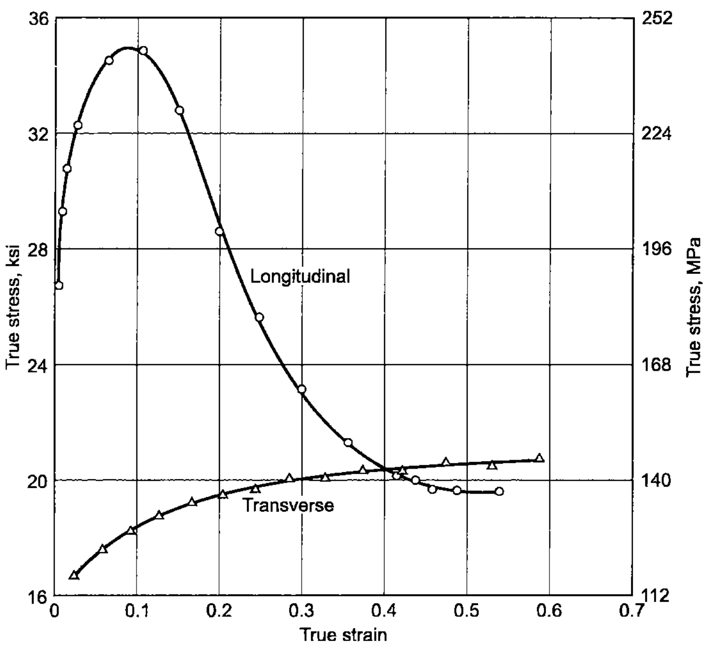
Source: G.R. Edwards, J.C. Payne, and O.D. Sherby, Strain Softening in Powder Metallurgy Zinc, *Met. Trans. A*, Oct 1971, p 2956



MA.018 Powder-metallurgy zinc rod, compressive stress-strain curves with effect of strain aging at 0.6 T_m

T_m, melting temperature. These curves compare true stress-strain curves for a continuously deformed sample and for a sample (solid circles) that was unloaded and annealed at several points in strain (open circles). Both samples were compressed, parallel to the extrusion axis at 140 °C (0.6 T_m) and at initial strain rate of 0.067/min. No drop in flow stress was ever observed when the interrupted test was continued, even after a 4 h anneal at 0.6 T_m on a sample deformed to 25% true strain. The effects of strain rate and temperature on the degree of strain softening in powder-metallurgy zinc were also inconsistent with dynamic recovery. Strain softening was enhanced by high strain rate and low temperature, being most prominent at –76 °C and 0.17/min.

Source: G.R. Edwards, J.C. Payne, and O.D. Sherby, Strain Softening in Powder Metallurgy Zinc, *Met. Trans. A*, Oct 1971, p 2956



MA.019 Powder-metallurgy zinc rod, compressive stress-strain curves at room temperature

Comparison of longitudinal (parallel to extrusion axis) and transverse (perpendicular to extrusion axis) mechanical behavior for powder-metallurgy zinc rods at room temperature with an initial strain rate 0.067/min

Source: G.R. Edwards, J.C. Payne, and O.D. Sherby, Strain Softening in Powder Metallurgy Zinc, *Met. Trans. A,* Oct 1971, p 2957

Alloy Index

UNS Index

The Unified Numbersing System (UNS) is a joint effort of the Society of Automotive Engineers (SAE) and ASTM International providing designations for the purpose of metal and alloy identification. The designation is not a specification. No requirements are established or implied.