Aleaciones de Berilio S.L. Buen Suceso 13 - 28008 Madrid - tel. 915 488 187 - fax 915 489 307 - paco_aguirre@aleacionesdeberilio.com

TECHNICAL TIDBITS

A PUBLICATION BY

BRUSHWELLMAN ENGINEERED MATERIALS

VOL. 5• No. 3 (800) 375-4205 Tech. Service May-June 2004

As if life weren't stressful enough... This issue goes back to the basics with an in-depth discussion of stress and strain concepts.

Electronic Connector Market - Property Spotlight

Stress-Strain Concepts Revisited

(A number of requests have come in for Technical Tidbits to revisit and reinforce some basic concepts on material properties. In response to this, Technical Tidbits is supplying a refresher on basic materials science for design engineers.) The uniaxial tensile test may very well be the most useful material characterization test available. It works simply by continuously measuring the force required to elongate a test specimen by increasing increments until it fractures. The test measures a number of important material properties as illustrated below. Most importantly, it generates stress-strain curves, which are the unique identifiers of each material tested (each material's DNA, so to speak).

Engineering stress is defined simply as instantaneous force divided by the original cross-sectional area of the test specimen. **Engineering strain** is simply the change in test specimen length divided by the original length, usually specified as a percentage. As the test proceeds, the force required to elongate the specimen increases linearly (for most materials) up to a point known as the **proportional limit**, as shown in green in Figure 1. The slope of the curve up to this point is known variously as the **elastic modulus**, **Young's modulus**, or **modulus of elasticity**.

If you strain (deform) an object, it will usually return to its original, undeformed shape when the load is removed. This is referred to as **elastic** behavior. However, if the stress is high enough, the object will permanently deform. This is referred to as **plastic** behavior. The **elastic limit** on a stress-strain curve is the point where the behavior of the material switches from elastic to plastic. If the stress (and therefore strain) applied to a material is lower than the elastic limit, both the stress and strain will return to zero (recover) when the load is removed. If, however, the elastic limit is exceeded, only the elastic strain will be recovered, and the plastic strain will remain as **permanent set**. The stress in the material will unload along a path parallel to the elastic modulus.

Since it is usually undesirable to experience permanent set in a component, engineers would like to design parts so that the expected service stress is less than the elastic limit by some reasonable factor of safety. However, the elastic limit cannot be accurately determined by a tensile test. Instead, it is found by the much more time consuming **precision elastic limit test**. However, it is easy to determine a **yield strength** from the stress-strain curve generated by a tensile test. For this reason, the yield strength of a material is more often specified than the elastic limit. The yield strength is determined by finding the stress corresponding to a specified amount of permanent set, usually 0.2% strain for strip (or 0.5% extension under load for low strength rod and wire). The 0.2% offset yield strength is found by drawing a line parallel to the elastic modulus from the 0.2% mark on the strain axis through its intercept with the stress-strain curve. (This is demonstrated by the dotted blue line in Figure 1.) Together, the yield strength, elastic limit and proportional limit are known as the **near-elastic properties**.

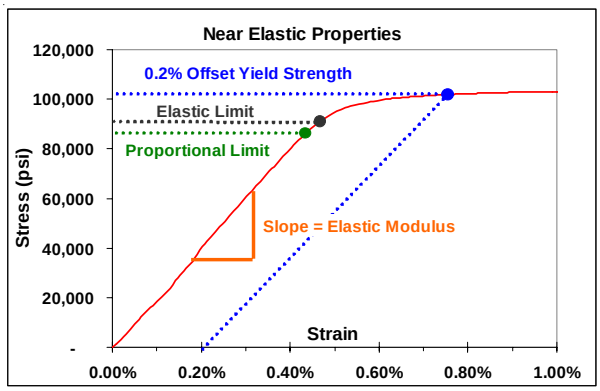


Figure 1. Stress-Strain Curve in the Near Elastic Region

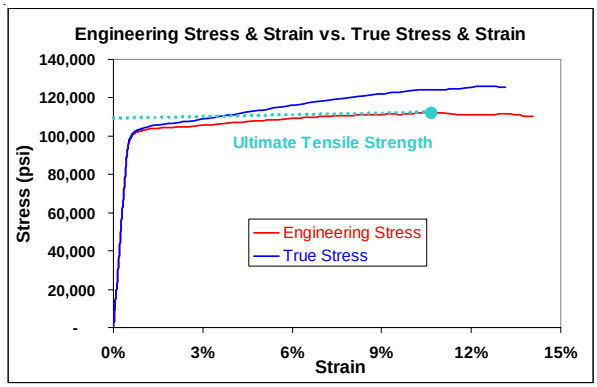


Figure 2. Types of Stress-Strain Curves for Alloy 174 HT

TT0045

After the yield strength is exceeded, the stress-strain curve continues to rise to a maximum point known as the **tensile strength** or the **ultimate tensile strength**. The strain up to this point is referred to as uniform strain, since the deformation in the specimen is uniform. However, once the tensile strength is exceeded, the test specimen begins to thin down, or **neck**, at some location along the length. All of the rest of the deformation to failure occurs at this point as the stress is concentrated in this area of reduced cross section. Since the engineering stress is determined by dividing the force load by the *original* cross sectional area, the engineering stress-strain curve begins to slope downward at this point, despite the fact that the actual stress in the specimen continues to increase. The curve continues until the specimen breaks when the fracture stress is reached.

True stress is determined by dividing the load by the smallest *actual* cross sectional area of the specimen at any given time. The corresponding **true strain** at each point of the curve is computed by taking the natural logarithm of the actual length divided by the initial length. The true stress-strain curve will increase after the tensile strength is reached. Figure 2 compares the engineering and true stress-strain curves for Brush Wellman Alloy 174 HT copper beryllium strip. Engineering and true stress and strain are related by the following equations:

$\varepsilon = strain$

$\sigma = stress$

$$\varepsilon_{Engineering} = \frac{L_f - L_0}{L_0} \qquad \sigma_{Engineering} = \frac{F}{A_0} \qquad \varepsilon_{True} = \ln\frac{L_f}{L_0} \qquad \sigma_{True} = \frac{F}{A}$$

$$\varepsilon_{True} = \ln\left(1+\varepsilon_{Engineering}\right)$$

$$\sigma_{True} = \sigma_{Engineering}\left(1+\varepsilon_{Engineering}\right)$$

The amount of energy required to fracture a material is known as its **toughness.** The area underneath the stress-strain curve up to any given point is a measure of the energy density required to strain the material to that point. Therefore, the total area underneath the stress-strain curve provides a measure of the toughness of the material.

Resilience is the amount of strain that a material can absorb without having the stress exceed the yield strength. It can be found by dividing the yield strength by the elastic modulus. Materials with high resilience can withstand greater amounts of deformation before yielding than materials with low resilience. The modulus of resilience is a measure of the strain energy density required to stress the material to the yield strength. It is the triangular area underneath the elastic portion of the stress-strain curve. It can be calculated by taking the square of the yield strength and dividing by two times the elastic modulus.

The **secant modulus** at any point on the stress-strain curve is defined as the slope of the line from the origin to that point. Some materials do not show linear behavior in the elastic region of the stress-strain curve, so the secant modulus must be used in calculations instead of the elastic modulus. (Fortunately, the copper beryllium materials show well-defined elastic modulus values.) The **tangent modulus** at any point on the curve is defined by ASTM as the instantaneous slope of the curve at that point. However, in finite element analysis (FEA), the tangent modulus takes on a somewhat different meaning. It is defined as the slope of the true stress-strain curve from the yield strength to the ultimate tensile strength. This allows the entire stress-strain curve to be mathematically approximated by two straight lines: the elastic modulus and the tangent modulus. This bilinear approximation works very well for copper beryllium, since the elastic and plastic portions of their stress-strain curves are mostly straight. This can be seen in the example curve for Alloy 174 HT as shown in Figure 2.

Stress-strain curves generated by tensile testing provide a large amount of information on the expected performance of materials in engineered designs. Future editions of Technical Tidbits will focus on these properties in detail.

Coming Next Month: The next edition of Technical Tidbits will focus on yield strength.

Written by Mike Gedeon of the Brush Wellman Alloy Marketing Applications Engineering and Technical Service Department. Mr. Gedeon is a mechanical engineer whose primary focus has been on electronic connector markets with emphasis on Finite Element Analysis, design and material selection.

References: *Tensile Testing* - Technical Tidbits, Vol. 3 # 9, September 2001
Why Good Designs Fail - Technical Tidbits, Vol. 1 # 1, August 1999
ASTM E8, ASTM E6

Health and Safety

Handling copper beryllium in solid form poses no special health risk. Like many industrial materials, beryllium-containing materials may pose a health risk if recommended safe handling practices are not followed. Inhalation of airborne beryllium may cause a serious lung disorder in susceptible individuals. The Occupational Safety and Health Administration (OSHA) has set mandatory limits on occupational respiratory exposures. Read and follow the guidance in the Material Safety Data Sheet (MSDS) before working with this material. For additional information on safe handling practices or technical data on copper beryllium, contact Brush Wellman Inc.