ME 105 – Mechanical Engineering Laboratory
Spring Quarter 2003

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3. Tensile Test

Introduction

In this lab, you will study the deformation and fracture characteristics of samples under tension for three (cold-rolled) metals (steel, brass, and aluminum). Using a tensile testing machine, you will obtain a force-displacement curve for each material. From these curves and caliper measurements of the samples, you will determine the modulus of elasticity (Young's modulus), yield stress, ultimate tensile stress, ductility, and toughness of each material.

Pre-Lab Reading

Thoroughly study this handout, and review relevant material from your Strength of Materials text.

Pre-Lab Work

The following engineering tensile stress-strain data were obtained for a 0.2% C plain-carbon steel.

Stress (MPa):	0	207	379	414	469	496	510	517	524	517	503	476	448	386	352
Strain (%):	0	0.1	0.2	0.5	1.0	2.0	4.0	6.0	8.0	10.	12.	14.	16.	18.	19. (fracture)

(a) Plot the engineering stress-strain curve.

(b) Determine the ultimate tensile strength of the alloy.

(c) Determine the percent elongation at fracture.

(d) Calculate the elastic modulus of the alloy.

(e) Determine the 0.2% offset yield stress of the alloy.

(f) Make a good estimate the toughness of the alloy.

Required Equipment

- Tensile test machine
- Extensometer
- Oscilloscope
- Calipers

Technical Data

• Metal samples: (1) steel, (2) brass, (3) aluminum

•Extensometer and Load Cell are calibrated to within 1% error.

System Description

This experiment uses a tensile test machine shown schematically in Fig. 1. The machine consists of a heavy test frame with a fixed beam, a moving beam at the top (referred to as a crosshead) and a hydraulic press at the base of the frame to move the crosshead. The specimen is mounted between two grips, one attached to the fixed beam and the other attached to the crosshead. The crosshead beam contains a load cell (which works on the principle of strain gauge), which measures the tensile force on the specimen. The movement of the crosshead relative to the fixed beam generates strain within the specimen and a corresponding load. Elastic compliance in the test frame requires the use of an extensometer mounted directly to the sample to measure change in length. (The extensometer also works on the principle of strain gauges.) An oscilloscope is used to record the load and engineering strain curve versus time.

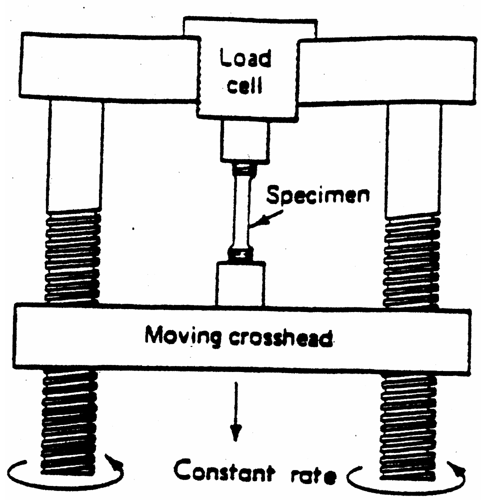

Figure 1. Tensile tests machine.

During a tension test, it is desirable to apply forces to the specimen large enough to break it. The grip region of the specimen must have a large enough area to transmit the force without significant deformation or slipping. Consequently, most specimens have a reduced-area section called the gauge region between enlarged-area grip regions. While most material properties are supposed to be specimen geometry and grip independent, there are some weak dependencies. Consequently, there are standard specimen geometries specified by the American Society for Testing Materials (ASTM). ASTM also prescribes test methods so that data reported for design purposes is obtained in a very standardized way. The specimen geometry is usually reported as part of the test results.

Background

When a load is applied to a solid, deformation results. The deformation is elastic if it is completely recovered immediately after the load is removed. Purely elastic deformation is associated with the stretching of primary bonds in materials. Stress is the force per unit area $\sigma = F / A$ and strain is the elongation per unit length $\varepsilon = \Delta L / L$. The stress and elastic strain are directly proportional and related by the Modulus of Elasticity (or Young's Modulus) which is related to the potential energy well of the interatomic bonds. Hooke's law relates these parameters,

$$\sigma = E\varepsilon \tag{1}$$

where E is Young's modulus. It is implicit here that only axial stresses and strains are of interest. Note, it is assumed $\sigma = 0$ when $\varepsilon = 0$ so that $\sigma = E\varepsilon$ represents the first part of the load displacement curve, a straight line that passes through the origin with E as the slope.

If permanent deformation occurs, it is called plastic. The onset of plastic deformation corresponds to a stress level necessary to initiate the motion of dislocations (a type of defect) in crystalline materials. The stress necessary to produce permanent deformation is the yield strength of the material. Some materials exhibit a sharp yield point, whereas others show a slow change in slope at the end of the elastic range. In the latter, the yield strength is conventionally defined as the stress necessary to produce a plastic strain of 0.2% (elongation). In some materials part or all of the deformation remaining after the load is removed may be gradually recovered with time, in which case the deformation is anelastic.

In ductile materials, the strain to fracture is relatively large compared with brittle materials. Plastic deformation of ductile materials can require progressively higher stresses because dislocations multiply in the process and their motion becomes more difficult due to the increased degree of interaction among them. This process is called work-hardening. Sometimes it is possible to observe bands propagating along the specimen during work-hardening. These are Lüders bands indicating the multiplication and motion of dislocations. They will not be visible unless the specimen is highly polished. Uniform elongation of the gauge length occurs when the hardening rate is faster than the decrease in cross sectional area:

$$d\sigma / \sigma \geq -dA / A. \tag{2}$$

If the hardening rate is too low, a runaway situation called necking develops. This corresponds to the load reaching a maximum, at which point the tensile deformation is inhomogeneous and strain is no longer uniform. The corresponding stress is called the ultimate tensile strength or UTS. The elongation to failure, which is the permanent engineering strain after fracture, is an expression of material ductility. It does not include elastic strain but does include the uniform strain and the localized, necking, strain. The elongation to failure is usually stated as percent strain over a given gauge length.

The deformation process is terminated by fracture. In a brittle material this occurs by the propagation of cracks initiated at the microscopic flaws in the material. Cracks propagate by cleavage, which involves breaking of atomic bonds along specific crystallographic planes, with the work of fracture spent primarily on creating a new surface (i.e., surface energy). On the other hand, ductile materials tend to fail by nucleation of microvoids at second phase particles, and the subsequent growth and coalescence of these microvoids. Since plastic deformation consumes significant amounts of energy in the form of creation and motion of dislocations, ductile tearing is usually associated with a higher work of fracture. The area under the engineering stress-strain curve is a measure of the energy needed to fracture the specimen. It has units of work/unit volume of the gauge length and is sometimes a measure of a material's toughness.

$$W/(A_o L_o) = \int_0^{\varepsilon} \sigma d\varepsilon \tag{3}$$

Engineering stress is the force per unit **original** cross-sectional area of the specimen $\sigma = F / A_o$. Engineering strain is the elongation per unit **original** length of the specimen $\Delta L / L_o$. The true stress and strain are determined from the instantaneous dimensions during the test. Consequently, 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 which 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 continuing deformation falls off. The average stress based on original area likewise decreases, and this produces the fall-off in the stress-strain curve beyond the point of maximum load. Actually, the metal continues to strain-harden all the way up 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, it is found that the stress-strain curve increases continuously up to fracture, as shown in Fig 2. If the strain measurement is also based on instantaneous measurements, the curve, which is obtained, is known as a true-stress-true-strain curve. This is also known as a flow curve since 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.

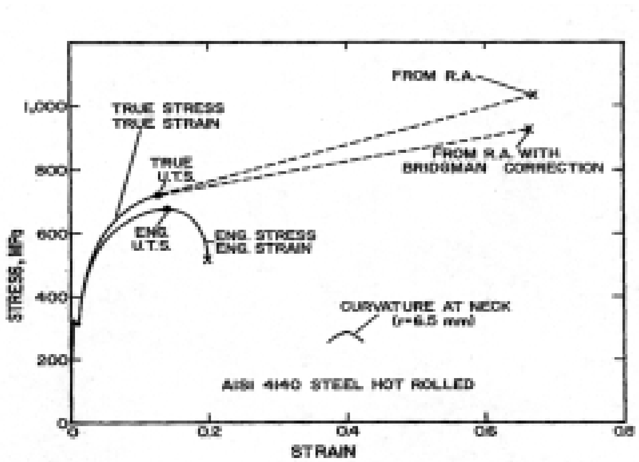

Figure 2. True stress-strain versus engineering stress-strain.

There is no significant difference in the engineering and true strains when all measurements are of small strains (typically when deformation is still elastic). For the instantaneous true strain increment $d\varepsilon$, we have

$$d\varepsilon = \frac{dL}{L} \qquad (4)$$

and by integration

$$\int_0^{\varepsilon} d\varepsilon = \int_{L_0}^{L_0+\Delta L} dL / L$$

we have

$$\varepsilon = \ln\left(\frac{L_0 + \Delta L}{L_0}\right) = \ln(1 + \Delta L / L_0) \cong \Delta L / L_0 \,. \qquad (5)$$

For strains of about 1%, the error in using the engineering strain, versus the true strain, is of order of 10^{-4}.

Most data you will be exposed to are engineering stress and strain unless otherwise specified. The yield stress, ultimate tensile stress, and elastic or Young's modulus of a material can all be determined from the engineering stress-strain curve for that material. The curve shown in Fig. 3 is typical of metallic behavior. At small strain values (the elastic region), the relationship between stress and strain is nearly linear. Within this region, the slope of the stress-strain curve is defined as the elastic modulus. Since many metals lack a sharp yield point, i.e. a sudden, observable transition between the elastic region and the plastic region, the yield point is often defined as the stress that gives rise to a 0.2% permanent plastic strain. By this convention, a line is drawn parallel to the elastic region of the material, starting at a strain level of 0.2% strain (or 0.002 m/m.). The point at which this line intersects the curve is called the yield point or the yield stress. The ultimate tensile strength (stress), in contrast, is found by determining the maximum stress reached by the material.

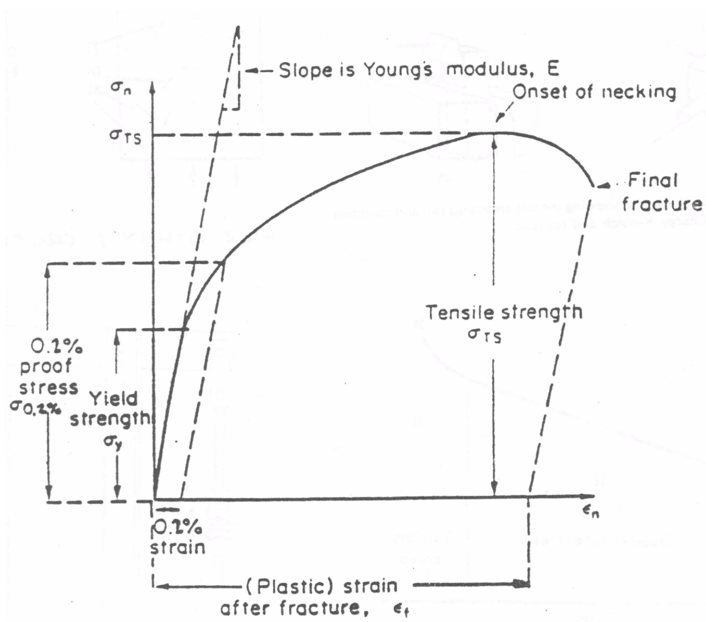

Figure 3. Characteristics of the engineering stress-strain curve

Experimental Procedure

Scribe lines at either end of the sample's gauge section. Using calipers, measure the initial gage length and cross-sectional area of the test samples for later calculations.

Follow the operation instructions for the tensile test machine to load and test each specimen (this will be provided in the lab). Be careful to avoid placing any part of your body at a pinch point. Record both load and strain versus time with the oscilloscope so you can obtain load versus strain for the test. After each test, note the nature of the plastic deformation in each material (i.e. necking, brittle fracture, extensive plastic flow). Estimate the estimate values for the final gage length by placing two halves of each broken sample together and measuring the distance between scribe lines.

Using the brass sample bend the specimen 90º and then straighten it again. Measure the deformation and fracture characteristics of this sample.

Repeat up to 5 times the tensile test measurements on each metal, starting with brass (followed by the other metals if time permits).

Experiment Report

Give careful thought to a list of questions that you feel are import to the results of this lab and that define a theme for your report. Annotate your report as directed. Be sure to include uncertainty analysis as appropriate. Include in the reduction of data the quantities described below. Be sure to include error bars on all experimental data points that appear in plots. Make sure to comment on the physical source of any particularly "bad" measurements.

In your discussion please address differences that are observed in stress strain curves for the three metals. Comment on the effect of bending then straightening the brass sample before testing. Report the following data for each of the samples you test:

Young's modulus
0.2% yield strength
Ultimate Tensile Stress
Ductility according to elongation at fracture
Material toughness according to energy needed to fracture the specimen