Lab 3 – Tension Test

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Objectives
Experimentally determine the yield strength, tensile strength, and modules of elasticity and ductility of given materials.

Concepts
The linear relationship is Hooke's Law that represents elastic deformation. If the stress is removed in this region of the test, the sample will return to its original shape without permanent deformation. The slope of the curve, E, is the modulus of elasticity or Young's Modulus, which is analogous to a spring constant.

When the stress level is increased beyond the elastic limit, the stress exceeds the yield stress ($\sigma_y$) and permanent deformation takes place. This permanent deformation is also called plastic deformation. Materials, which experience extensive plastic deformation often, undergo localized deformation called necking before final failure.
Background

The tensile test is a method to measure the mechanical properties of materials. It relates the effect of a uniaxial tensile load (force) on the elongation (change in length) of a standard specimen. From knowledge of the specimen geometry, we can calculate the engineering stress and strain from the load vs. elongation data. Engineering stress ($\sigma_E$) is equal to the force (F) per unit area based on the original cross-sectional area ($A_o$) of the sample and does not take into account that this cross-section decreases as the test progresses:

$$\sigma_E = \frac{F}{A_o}$$

### Tensile Specimen Properties

<table>
<thead>
<tr>
<th>Tensile Specimen</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>1018 Steel</td>
<td></td>
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<tr>
<td>1040 Steel</td>
<td></td>
</tr>
<tr>
<td>2024 Aluminum</td>
<td></td>
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<tr>
<td>Brass Alloy</td>
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Engineering strain is based on the original length of the gage length of the sample ($l_o$) and equals the elongation (the change in length, $\Delta l = l - l_o$) of the sample divided by the original length:

$$\varepsilon_E = \frac{\Delta l}{l_o}$$

Since both $\Delta l$ and $l_o$ have units of length, strain has dimensionless units and is expressed as either (m/m) or (in/in). It is also common to express engineering strain as percent strain or percent elongation:

% Engineering strain = engineering strain x 100% = % elongation

In the first part of the stress vs. strain diagram, the curve is usually linear and follows the relationship $\sigma = E \varepsilon$. This linear relationship is Hooke's Law and represents elastic deformation. If the stress is removed in this region of the test, the sample will return to its original shape without permanent deformation. The slope of the curve, E, is the modulus of elasticity or Young's Modulus, which is analogous to a spring constant. The stronger the bonds, the higher the modulus. Unlike other mechanical properties, a material's modulus of elasticity is not affected by microstructure but is only affected by the bond strength between the atoms.

When the stress level is increased beyond the elastic limit, the stress exceeds the yield stress ($\sigma_Y$) and permanent deformation takes place. This permanent deformation is also called plastic deformation owing to this type of behavior in many polymers. Now if the stress is removed, the sample will be measurable longer. It's difficult to determine exactly where this change from elastic to plastic behavior occurs. A method called the 0.2% offset method is often used to estimate $\sigma_Y$. A line parallel with the elastic curve is drawn through 0.002 (m/m) strain and its intersection with the stress strain curve defines the yield stress.

An ultimate tensile stress ($\sigma_{UTS}$) is defined as the maximum stress in the engineering stress strain diagram. Materials, which experience extensive plastic deformation often, undergo localized deformation called necking before final failure. The necked region is caused by deformation instability and after it forms, all further deformation is restricted to this region. It should be realized that the true stress required to pull the sample to failure constantly increases until fracture.
But, since the engineering stress is calculated by using the original cross-section, after necking occurs the engineering stress decreases.

A material's ductility is characterized either by the strain to failure, the percent elongation at fracture or by the percent reduction in area at fracture. Ductile materials exhibit large fracture strains ($E_f$). Percent elongation at fracture is equal to the difference between the final length ($l_f$) and the initial length ($l_o$) divided by the initial length times 100%:

\[
\% \text{Elongation at fracture} = \frac{(l_f - l_o)}{l_o} \times 100\%
\]

If significant necking has occurred before fracture, the percent reduction in area at fracture may provide a more meaningful measurement of ductility. The percent reduction of area at fracture is equal to the difference between the original cross sectional area ($A_o$) and the final area ($A_f$) divided by the original area times 100%:

\[
\% \text{Reduction in area at fracture} = \frac{(A_o - A_f)}{A_o} \times 100\%
\]

**Experimental Procedure**

1) Measured and sketched your specimen

2) Used the marking jig and hammer to place two indentations in the narrow section of the specimen, centered, spaced exactly two inches apart

3) Took three Rockwell-B hardness tests at each wide end of specimen

4) Loaded specimen into Instron Universal Testing Machine, tightened grips

5) Mounted extensometer to center of specimen

6) Started machine, noted graph of elastic range until extensometer would go no further

7) Stopped machine, detached extensometer, set chart speed: 1 inch/min

8) Reset extensometer, continued experiment until fracture

9) After fracture, removed specimen

10) Measured final length and cross sectional area of fractured specimen

11) Took several Rockwell-B hardness tests very close to fracture
Report Requirements and Questions

Each section will divide into four groups. Each group is responsible for analyzing the data from one of the four samples. These data will be used to complete an EXCEL spreadsheet that will be available on the network drive class library. The data from all of the sections will be used to generate a database for statistical analysis (mean and standard deviations).

From the data, you should be able to determine the following material properties

- Proportional limit
- Yield point
- Ultimate stress
- Young's Modulus
- Modulus of Resilience
- Ductility
- Toughness
- Determine the percent increase in hardness along the gage length.

To get these properties from this data, it is essential know how to use EXCEL or similar software. From the load, you can compute the stress and knowing the deflection, you can compute the strain. This data defines the stress-strain history from which a stress-strain diagram can be plotted. This is a very useful way to describe a material.
Figure 2.2 Stress-Strain Diagrams

Figure 2.3 Strength and ductility comparison of two materials

A is stronger. Because it withstands a higher stress before failure than material B. (Compare the peak stress levels of the two curves)

A is ductile, because the strain under curve A is greater than B. This indicates that A shows more elongation than B before failure.

Definitions (*)
Common Errors:

- Young's modulus is best computed by linear regression. Although you could draw a 'best fit' straight line, a computer will give far better results and is actually easier. The problem with this is that many people don't think about the range of data to include when performing the regression (insert trend line in Excel). **Do not include the entire data series!** The modulus is the slope of the line before the proportional limit so you must include data only up to this point.

- Modulus of Resilience and Toughness **cannot be negative numbers**. They are areas under the curve and you should be able to check your results with quick approximations to see if your values are roughly correct.

Definitions

**Stress**

Stress is defined as force per unit area. This is one of the most basic engineering quantities.

**Shear Stress**

Shear stress has the same units as normal stress (force / area) but represents a stress that acts parallel to the surface (cross section). This is different from normal stress, which acts perpendicular (normal) to the cross section. Torsion is a force that causes shear stress but this is not the only force that can cause shear stress. For example, a beam that supports a shear force also has a shear stress over the section (even without torsion).

**Strain**

Strain is the change in length per unit length. It is normally computed as \((L_f - L_0) / L_0\) where \(L_f\) is the final length and \(L_0\) is the initial length. When testing materials, a gage length is normally specified known; this represents \(L_0\).

**Strain Rate**

When testing a material, it is normally important to know how quickly (or slowly) it is being deformed or loaded. One way to report this is the amount of strain that occurs in a unit of time, which is termed the strain rate. Because strain is dimension-less, units for this quantity are \(1/time\) but sometimes it will be seen with the non-dimensional part attached e.g., \(in/in/sec\).
Young's Modulus
This is the constant of proportionality between stress and strain. Units of this quantity are the same as stress (i.e., force per unit area) and the most commonly used are psi, Pa (pascal), and MPa (mega-pascal). This is one of the most fundamental material properties. A typical value for steel is $29 \times 10^6$ psi (200 GPa).

Deflection Equation
A prismatic bar loaded uniaxially made from a material that obeys Hooke's law deflects when loaded by an amount $d = \frac{PL}{AE}$ where

d = Deflection,
P = Applied Force,
L = Length,
A = Area,
E = Young's Modulus,

Poisson's Ratio
This is the ratio of lateral strain to longitudinal strain. The typical range of values for this quantity is between zero and 0.5.

Hooke's Law
When the applied force is proportional to the deflection, a material is said to obey Hooke's law. There is a linear relationship between the force and displacement and thus, linear elastic materials obey this law. When steel is below the proportional limit it shows this linear behavior.

Material Properties
These are properties specific to the material used. These are different from section properties, which do not depend on what an object is made of. Examples of material properties are Young's modulus and yield point. Typical values of these for steel are $29 \times 10^6$ psi and 36 ksi respectively. In general, different materials will have different material properties.

Section Properties
These are properties specific to the geometry (dimensions) of the section used. These are different from material properties, which depend on what an object is made of. Examples of section properties are area, diameter, and section modulus.

Stress - Strain Diagram
The stress-strain diagram is a plot of the stress on the ordinate (y-axis) versus the strain on the (x-axis). The data is often obtained from a uniaxial tension test although this is not the only test possible. The axes must be labeled with the appropriate units for stress (strain is dimensionless). This link will show a sample diagram in a new browser window with this and other terms.

Proportional Limit
The proportional limit is the greatest stress that one can still see a linear relation between stress and strain. Beyond this point, the stress is no longer proportional to the strain. A sample stress-strain diagram (in a new browser) will show this and other terms.

**Precision**

The precision of a measuring instrument is its least count (i.e., the smallest directly readable value). The precision of a data set is the closeness of agreement of results, often measured by standard deviation. When a value varies within statistical limits, the variations stem from numerous chances causes due to unknown factors, individually small, that are not readily identifiable or detectable. Within statistical limits, the average can be used as a good representation of the data set. Precision does not ensure accuracy.

**Accuracy**

Accuracy is the agreement between the test result and the "actual" value. For example, if the actual length of a rod is 230.0000 mm, a measurement of 231 mm is accurate to 0.4%. A different measurement of 232.15 mm is less accurate even though more precise. Accuracy does not ensure precision.

**Linear Elastic Material**

This is a material that responds both linearly and elastically when loaded and unloaded. Linear indicates that the stress is proportional to the strain and the material obeys Hooke's law. Elastic indicates that it follows the same path on the stress-strain diagram for both loading and unloading (i.e., no permanent deformation when load is released).

Most materials have a **linear elastic range** which means that the above is valid for a certain load (stress) range but beyond this, the material may yield, become nonlinear, or both.

**Modulus of Resilience**

This is a material property and a measure of the energy a material can contain. It is the area under the stress-strain diagram up to the proportional limit.

**Toughness**

This is a material property and a measure of the energy a material can contain. It is the area under the entire stress-strain diagram (up to the point of failure).

**Yield Point**

This is a material property that indicates when permanent deformation will occur. If a material is loaded below its yield point, there will theoretically be no permanent deformation. This link will show a sample diagram in a new browser window with this and other terms.

**Ultimate Stress**
This is a material property that indicates the maximum stress the material has been observed to sustain. This link will show a sample diagram in a new browser window with this and other terms.

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**Gage Length**

This is the initial distance between two points that a measurement is being taken. As the test proceeds, this distance will change but the original distance will always be the same and this is what is used when computing strain.

**Euler Buckling Load**

When a column is loaded axially in compression, it is possible for it to become unstable before the material reaches its yield point. This load is termed the 'buckling load' or often the 'Euler buckling load' and is described by $P_{cr} = \pi^2 \frac{E}{I} \frac{1}{L^2}$. 