Lab 03: Tensile Testing

Introduction

The Tensile Sample (see Figure 1) is held by its two threaded ends and pulled apart while both the extension and load are recorded. From the data collected, several different properties of the material can be calculated. These properties are the same ones found in materials handbooks and databases, and are used by engineers to design bridges, buildings, and machines.

Quantities measured include Young’s Modulus, Yield Strength, Tensile Strength, Ductility, and Modulus of Resilience.

This lab is written for the brass tensile sample, but any of the samples can be used.

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<th>Items</th>
<th>Part #</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td>Materials Testing Apparatus</td>
<td>ME-8236</td>
</tr>
<tr>
<td>1</td>
<td>Tensile Samples (Brass)</td>
<td>ME-8232</td>
</tr>
<tr>
<td>1</td>
<td>Calipers</td>
<td>SE-8710</td>
</tr>
</tbody>
</table>

Written by Jon Hanks

Figure 1. Tensile Testing Brass Sample
Stress

It is important to distinguish between the strength of a component, such as a bolt, and the strength of the material that the bolt is made of. A large diameter bolt, for instance, will be stronger than a small diameter bolt when both are made of the same material. The only difference is the cross-sectional area of the bolts.

The strength of a material tested in tension is expressed in terms of the stress, \( s \), and is given by

\[
    s = \frac{F}{A}
\]

Eqn. (1)

where \( F \) is the tensile force applied and \( A \) is the cross-sectional area of the sample. The strength of the bolt is given in terms of how much force it can withstand, while the strength of the material is given in terms of how much force a given amount of material can withstand.

When loaded in tension the sample will stretch, but at the same time it will also become thinner. To measure the "true stress" one would have to monitor the change in \( A \) while the specimen is stretched, but that is not easy to do and in typical engineering situations the error involved is small. Instead, the initial value of \( A \) is used in the calculation, and the result is called the "engineering stress".

Strain

Where the strength of a material is a measure of its resistance to stress, strain is its give, and like stress, strain is not dependent on the size of the specimen. A long bolt loaded in tension may elongate several millimeters before it breaks while a small only half as long will elongate only half as much. In both cases the strains were equal because strain is the amount of elongation relative to the length of the bolt. The equation for strain, \( e \), is

\[
    e = \frac{\Delta L}{L}
\]

Eqn. (2)

where \( L \) is the initial length and \( \Delta L \) is the change in length of the sample.

Behavior of Metals in Tension

When an item such as a rod or wire sample is loaded in tension it will elongate. If pulled far enough the sample will fail, breaking into two pieces. Between the point where it was initially loaded and it failed, it will generally exhibit three types of behavior:

**Elastic Deformation** - This deformation is temporary and is recovered as soon as the load is removed. The sample returns to its original size.

**Uniform Plastic Deformation** - When deformed beyond its Yield Strength (see Figure 2), further deformation is permanent. When the load is removed, the specimen will be longer than it was originally.

**Non-uniform Plastic Deformation** - When deformed past the point where the maximum load is observed (Tensile Strength) the deformation becomes localized. A thinner "necked" region will form and most of the deformation from this point on will take place there.

![Figure 2. A typical stress-strain curve, with points of interest labeled.](image)
Speed Control

1. Click on Record and then turn the crank. Note that the Meter display at right shows you the rate that you are raising (+) or lowering (-) the cross-head beam, in millimeters / minute.

2. Practice turning the crank to raise the cross-head at a smooth, constant rate between 10 and 20 mm/Min.

Tensile Samples

3. Use calipers (or a micrometer) to measure the diameter of the machined portion of the tensile sample. Edit the value for diameter in line #2 of the calculator.

4. Note that the calculator also has a value for the length of the sample. If you measure the complete machined portion, you should get about 38 mm. However, since there is a radius, the length of the thinner part that is actually stretching, is less. A good average value to use for the length is 35 ± 1 mm.

5. Install the test sample as shown in Figure 3. The end of the bar with the longer threads should be screwed directly into the knurled cap nut.

6. Lower the sample through the hole in the cross-head, and screw the other end of the sample into the top of the load cell, as shown in Figure 4. You will need to use the hand crank to adjust the height of the cross-head.

7. When you are testing the sample, it is important that you use the plastic safety shields as shown in Figure 5. They attach with Velcro directly to the cross-head, and are easily installed and removed. Never touch the test sample when it is under load!
"Seating" the Test Sample and Setting Pre-Load

1. Make sure that the knurled cap is loose, not creating a force on the load cell. The default sample rate is set at 20 Hz. This should be a good value to use, but you can change this if needed.

2. Click on Record. If the force and position data is not zero, check the properties in Hardware Setup. Sensor should be set to zero on start.

3. Tighten the knurled cap. Note that the digits display shows the force on the load cell.

4. Slowly turn the crank clockwise, increasing the force about 100 N. Note that the position and force data are being plotted on the graph. If the data is not positive, check the properes in Hardware Setup. The "Change Sign" feature should be checked.

5. With data still being recorded, slowly turn the crank back **counter-clockwise**. Watch the digits display, and reduce the force to between 10 and 20 Newtons. Try not to let the force go completely to zero.

6. Increase the force as before. You will probably notice that the second curve does not track on top of the first. It is necessary to load and unload the system several times to remove all the slack and properly "seat" the test sample. When two subsequent curves track on top of each other, you are ready to proceed.

7. With data still being recorded, slowly increase the force back up to 100 N. Click on Stop, and do NOT change the crank position. Since the sensor will auto-zero the next time you start recording data, this puts a 100 N pre-load on the sample which results in better data. You should use this same method when performing any calibration of the Materials Tester.

8. You can use the Delete Run menu (Controls tool bar, below) to delete your practice runs. Proceed to the next page to collect your actual data run.
Breaking the Sample

In this next section, you will deform the tensile sample, pulling it apart until it breaks. Try to turn the crank at a slow and steady rate, about 10 to 20 mm/Min.

1. Make sure the safety shield is in place.

2. Click on Record. The initial force and position data should be zero.

3. Turn the crank clockwise, stretching the sample. Continue cranking until the sample breaks.

4. Click on Stop.
Force Graph

1. Note the overall shape of the curve. Was this what you expected?

2. What was the maximum load exerted on the sample? How does this compare to the equipment's maximum?

3. What was the total extension (elongation) of the sample?

4. Is the data linear at the beginning of the run? Use the Highlight Range tool and a Linear curve fit to find the slope of this linear region. This is called the "stiffness" of the sample, and is similar to the spring constant (k) of a spring.

5. Measure the area under the entire graph. What are the units? This is the total work done to deform and break the sample.

6. Where does this energy go?

7. Use the Highlight Range tool to find the energy stored in the elongation of the sample during the linear portion of the curve only. If all that stored energy was converted into kinetic energy, how high would it shoot the broken piece captured in the knurled cap nut, when the sample broke? Did you notice how high it jumped?

Answers:

Max load of 4200 N well below max of 7000 N
Max elongation = 4.5 mm
slope of linear portion = 1.7 x 10^-3 \text{N/m} "spring constant"
18 J of work done deforming sample, breaking bonds. Some energy into heat, raising temperature
0.2 J potential energy = mgh, 200g for holder and sample
Assuming half of energy, gives a height of
h = \frac{1}{2} (2kg \times 9.8) = 5 \text{cm}
Only jumped one or two cm.
**Young's Modulus**

When tested in tension or compression, **Young's Modulus** (E) is the property that describes the stiffness of a material. It is measured as the slope of the linear portion of the stress-strain curve.

1. Use Eqns. #1 and #2 to confirm that the calculations for Stress and Strain are being done correctly. Note that the calculator line 1 includes the 100 N pre-load.

2. Measure the slope in the linear portion of the graph to find Young's Modulus for the material. What is the uncertainty in your measurement?

3. How does your value compare to those listed in reference data tables for the material? Compare the value found for this material to other materials tested.

4. Young's Modulus tells you the stiffness of the material. Why is that different than the stiffness you calculated using the Force vs. Position graph?

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**Answers.**

slope = E = 70,000 MPa = 70 ± 5 GPa

uncertainty based on slope in different regions, and uncertainty in sample length

Most data tables list brass around 100 GPa, but this material always gives a value around 80 GPa.

slope of Force vs. elongation gives stiffness of the entire sample.

slope of Stress vs. Strain gives stiffness of the material.
Yield Strength

Different materials yield in different ways. Some yield gradually while for others yielding is abrupt. In the latter case it is easy to find this point on the stress-strain curve but for the case of gradual yielding there is no such clear yield point, making determining the yield strength difficult. The solution is to find an offset stress, one obtained by drawing a line parallel to the linear portion of the stress-strain curve, but shifted to the right a small amount, such as 0.2% strain. The stress where this line and the stress-strain curve cross defines the offset yield strength.

1. The calculation for an offset line has been entered in the calculator. Edit the value for your value of Young’s Modulus (E). Make sure the scaling of both y-axes are the same and then note where this new line crosses the stress-strain curve.

2. Compare your value for the Yield Strength (or Offset Yield Strength) to those listed in reference data tables for the material. Compare the value found for this material to other materials tested.

Answers.
First part of graph that is very straight ends about 200 MPa
Most common range in data tables is 150 - 300
Offset yield from graph is 400 MPa
Maximum Values

1. Measure and record the **Tensile Strength** of the material. This is the maximum stress on the graph. Compare your value to those listed in reference data tables for the material. Compare the value found for this material to other materials tested.

2. Measure and record the maximum strain on the material just before it broke. This quantity is called the **Ductility** of the material. Compare your value to those listed in reference data tables for the material. Note that this number is often reported in terms of percent strain. Compare the value found for this material to other materials tested.

**Tensile Strength = 500 MPa**  
**Data Table values 250 - 500 MPa**  
**Ductility = 13%**  
**Data Table values 5 - 40%**
Area

1. The area under the Force vs. Position graph (as shown earlier) is the total work done to break the sample. The area under the Stress vs. Strain graph is the energy capacity, and is called the **Modulus of Toughness**. The units for this area will be the units for stress, (pressure) but this works out to be the same as energy per volume, making this measurement independent of the specimen size and therefore a material property. Measure the area under the entire graph. What are the units? Compare the value found for this material to other materials tested.

2. Another quantity often measured is the **Modulus of Resilience**, which is the area under only the linear (elastic) portion of the curve. Measure this area, using the yield point calculated earlier.

3. The modulus of resilience can also be calculated using

   \[
   \text{modulus of resilience} = \frac{(\text{yield strength})^2}{2E}
   \]

   where \( E \) is Young’s Modulus. Calculate the modulus of resilience, and compare to the value from the graph.

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Modulus of Toughness = 600 M J/m³
Area under linear = .3 M J/m³
Modulus of Resilience = \( (200 \text{ MPa})^2 / 2(70 \text{ GPa}) = .29 \text{ M J/m}³ \)
Summary

1. Use Text annotations to mark the following regions of your graph.


2. What important quantities did you measure? How did your values compare to those listed in reference data tables for the material? How did the values found for this material compare to other materials tested.

<table>
<thead>
<tr>
<th>Material</th>
<th>E</th>
<th>Yield</th>
<th>Tensile</th>
<th>Ductility</th>
<th>Toughness</th>
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<td>200</td>
<td>400</td>
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<tr>
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<td>Brass</td>
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<td>250</td>
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Questions

1. Your data tells you how long your sample was just before it broke. How long would it be if, after the test, you put the two pieces back together and measured it. Would they be the same, within measurement errors, or be different? Explain.

2. As a mechanical engineer designing a component to be used in an automobile, which would you use, the yield strength or tensile strength, in your efforts to determine a safe working load? Explain.

3. If you had tensile tested a specimen to about half way between where it yielded and when you expected the tensile stress to be reached, then stopped the test, removed the sample, and later decided to test it again, what would the yield strength be during the second test?

4. During a forming operation a material may be bent or pulled to the new dimensions. If the material you just tested was to be as close to 10% longer as possible after this operation, how much longer than this does it have to pulled during this operation?

5. In some designs a bolt may be declared one that you install once and torque to specification, but only once. During a repair you must use a new bolt. Why?

Answers:

1. The sample was still under tension (stretched) when it broke. Thus the two pieces would be shorter than the stretched length.

2. Yield strength In normal working conditions, the stress should never exceed the yield strength because the part would then be permanently deformed. However, if you wanted to study what would happen during catastrophic failure, you might want to look at tensile strength, along with ductility, resilience and toughness.

3. It would still be the same.

4. By the amount of Stain there was at the yield point. For the brass sample used in this lab, that would only be about 1/4%.

5. Bolts often have a torque specification very close to the yield point. If there has been some permanent deformation, that would change the bolt.