PASCO Materials Testing System Experiments

Table of Contents

Introduction to the Materials Tester

Equipment

Qty	Description	Part Number
1	Materials Testing Apparatus	ME-8236

Introduction

The PASCO Materials Testing Machine is a device for measuring force and displacement for various materials as they are stretched, compressed, sheared, or bent. The Materials Tester has a built-in load cell (strain gauge transducer) capable of measuring up to 7100 N (1600 lb) of force, and an optical encoder that measures displacement of the cross-head load bar. A crank-and-gear system (see Fig. 1) raises or lowers the cross-head on two leadscrews. Force data from the load cell and displacement data from the encoder can be recorded, displayed, and analyzed using a PASCO Interface with PASCO Capstone Software.

The ME-8236 includes the Materials Testing Machine, knurled cap nut, safety shields (which should be used at all times when testing samples), and the Calibration Rod used to create a compliance calibration. This calibration automatically adjusts for the unwanted stretching of the Materials Tester and is easily performed using the Calibration Wizard in the Tools Palette.

Figure 1: PASCO Materials Tester

Optional accessories include metal and plastic Tensile Samples, ME-8237 Three-Point Bending Accessory, ME-8249 Four-point Load Anvil, ME-8247 Compression Accessory, ME-8239 Shear Accessory, and the ME-8241 Photoelasticity Accessory.

Setup

1. Connect the tester to the interface. Open the Hardware Setup window in the Tools Palette at left and click on Properties. Note that the "Zero Sensor at Start" box is checked.

2. In PASCO Capstone, create a graph display of Force vs. Time, Position vs. Time, and Speed vs. Time.

Procedure: Making Measurements

1. Click on Record. Push down several times on the Load Cell. Turn the crank counter-clockwise, then clockwise. Click on Stop.

2. Examine your graph data. What is the sign convention for pushing down on the load cell? This corresponds to compressing a sample. Turning the crank counter-clockwise lowers the cross-head and gives a positive displacement.

3. Open the Hardware Setup window and click on Properties. If you check the Change Sign box, the sign convention will be switched for both force and displacement. To have only positive data, leave the box un-checked for compression, and check the box when doing a tensile experiment.

4. Was the force and position data zero at the start? You can un-check the "Zero Sensor at Start" box, and you can manually zero the system (both position and force) by clicking on the "Zero Sensor Now" icon in the Controls Palette.

5. Note that the Materials Tester also measures the cross-head speed in millimeters of displacement per minute. In some experiments, you are directed to change the length of the sample at a specific rate. Try moving the cross-head at a steady 50 mm/min.

6. The default sample rate is 20 Hz, but you can change this as needed. In general, slower rates give smoother data (less noise) due to oversampling (averaging) of data.

Procedure: Using Accessories

1. Some of the accessories (such as the Tensile Samples shown in Figure 2) thread directly into the top of the Load Cell. The end with the longer threads should be screwed into the knurled cap nut, as shown in Figure 3. 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.

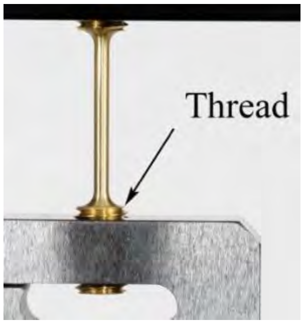


Figure 2: Center Threads

Figure 3: Installing Sample

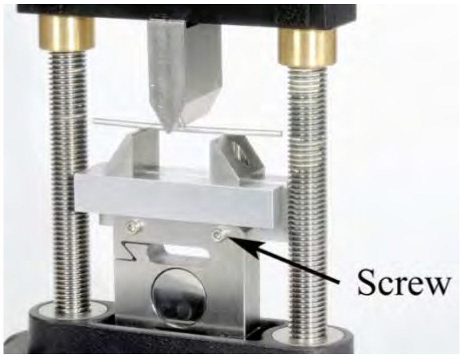


Figure 4: Three-point Bending

2. Other accessories, such as Three-point Bending Accessory use the through-holes in the Load Cell, as shown in Figure 4. The upper load Anvil attaches to the Cross-head using the knurled cap nut, as before.

3. When you are actually testing a 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!

4. Use the PS-2343 USB Camera Microscope (as shown in Figure 6) to take close-up video (synched to data) and photos.

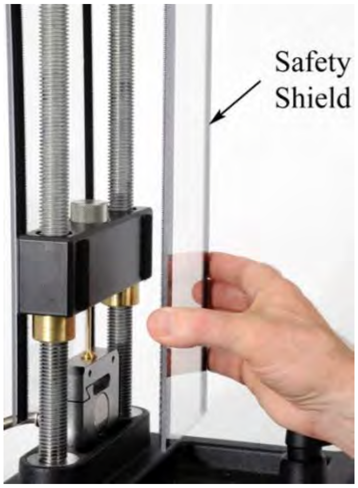


Figure 5: Always use Safety Shields!

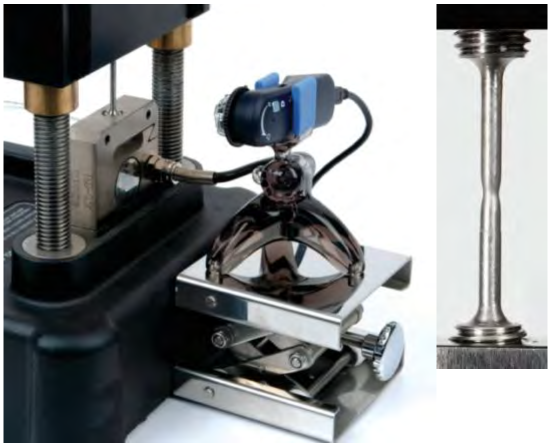


Figure 6: USB Camera Microscope

Compliance Calibration Tutorial

Equipment

Qty	Description	Part Number
1	Materials Testing Apparatus	ME-8236

Introduction

The Calibration Wizard (in the Tools Palette at left) is used to create a compliance calibration for the Materials Testing System (MTS). To keep the procedure short and easy to perform, the instructions in the wizard have been kept to a minimum. Thus, a beginner will find it useful to first run through the tutorial in this workbook which contains more detailed explanations.

Information covered in this tutorial includes how a compliance calibration works, how to create, save, and delete calibrations, and hints and practice in making an accurate calibration.

Setup

1. Install the Calibration Rod as shown in Figure 1. The end of the rod, with the shorter threads, screws directly into the top of the Load Cell.
2. Turn the crank to lower the cross-head, and then fasten with the knurled cap nut.
3. Note: The Calibration Rod also includes a thin hex nut. This nut is only used for compression tests and should ***not*** be installed now.
4. Connect the Materials Tester to a computer using a USB interface. In PASCO Capstone, create a graph display of Position vs. Force and a Digits display of Force. Set the sample rate to 20 Hz.

Figure 1: Using the Calibration Rod to make a Compliance Calibration

Theory

When a material like the Tensile Sample is stretched, precise measurements of force and position are recorded. If the Materials Tester was absolutely rigid, the measured movement of the tester crosshead would equal the distance the test sample was stretched. Obviously, this is not the case. To correct for this, the stiffness of the tester is characterized, and a calculation is performed to adjust the raw position data and compute the movement due only to the test sample.

Figure 2 shows a position vs. force compliance calibration graph recorded using the very stiff Calibration Rod. This shows that even when there is no test sample present, the tester itself still flexes. For example, you can see that for a load force of 3500 N, there is a "flex" of 0.2 mm in the system. If you stretched a more flexible test sample with a force of 3500 N, you would know to ignore (or subtract off) 0.2 mm of motion.

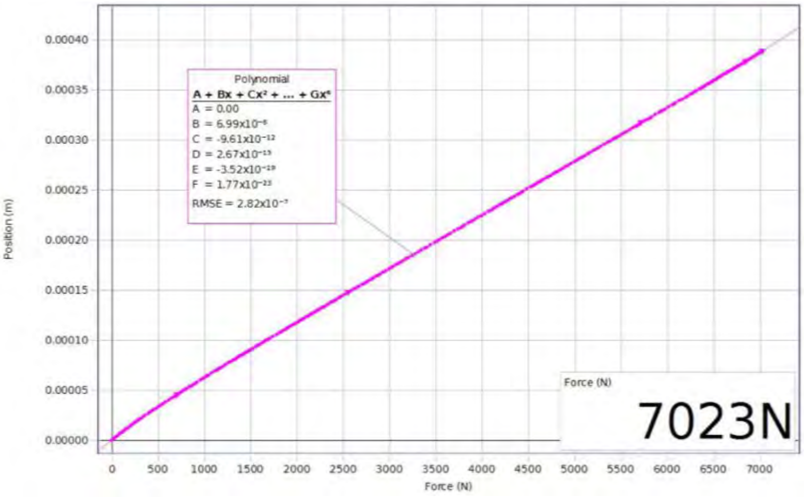


Figure 2: Sample Compliance Calibration Graph

Once you have created an active compliance calibration, this subtraction is automatically performed on the raw position data and cannot be undone or redone at a later time. If you make a new calibration, then subsequent runs of data will be modified based on that new calibration.

The compliance calibration can be saved in two ways:

1. Saved with the program file
2. Stored in the sensor (in the MTS unit)

Any compliance calibration saved with the program file can be used with any MTS unit. A compliance calibration stored in the MTS unit stays with that unit (even when unplugged) and can be used with any file in the future.

Note that the Calibration Graph is Position vs. Force, which is reversed from the normal Force vs. Position graphs used when taking data on actual samples. A polynomial curve fit is applied to the Calibration Graph, and the coefficients are saved as a calibration. When a new data run is collected, the polynomial equation is used to modify each position value by a Δx based on the force measured at that point.

Procedure: Calibration Wizard

You can run the Calibration Wizard (in the Tools Palette) to perform a compliance calibration at any time. It is helpful, however, to first look at the detailed explanations on the following pages. The figures are static screen shots of the actual Calibration Wizard and are only for clarification.

Open the Calibration Wizard by clicking Calibration in the left-hand tool panel.

Step 1: Choose the measurement to calibrate. There are two types of calibrations possible on the Materials Tester. One is a simple calibration of the force measured by the Load Cell. The other is explained in the following steps. It is a calibration that allows the program to automatically make compliance corrections on position data.

Step 2: Choose the calibration action. There are five activities (see Fig. 3) that allow you to create, select, save, modify and delete calibrations.

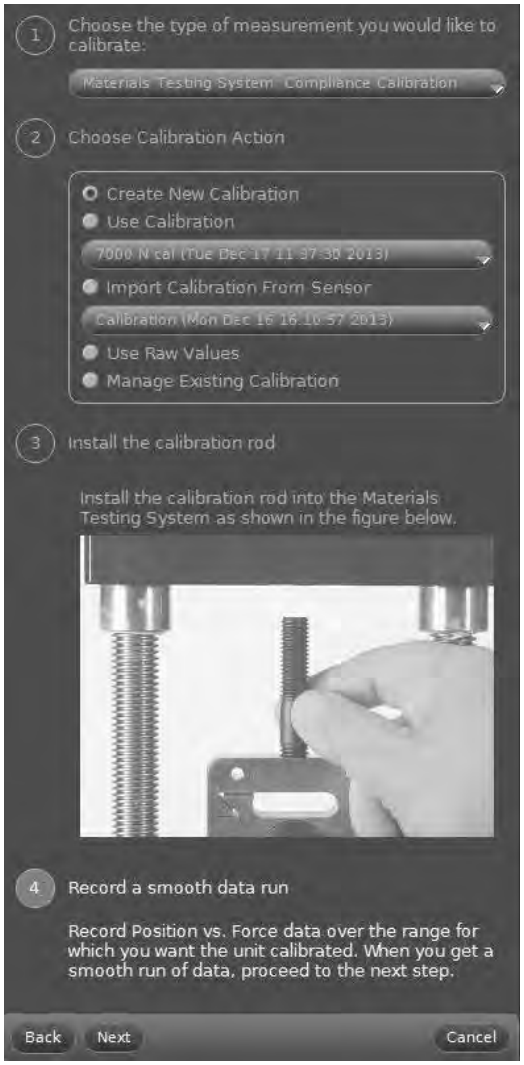
- **Create New Calibration**

If you choose the **Create New Calibration** selection, the wizard will take you through all the steps needed to create and save a new compliance calibration. This includes prompting you to **Install the Calibration Rod (Step 3)**, **Record a Smooth Data Run (Step 4)** on the graph provided, and **Creating a Polynomial Curve Fit (Step 5)** that will be stored as your compliance calibration. The default number of terms in the poly fit is six, but you can change this if needed. Once completed, you will have a calibration graph similar to the sample shown in Figure 2.

Note: You can have any number of calibrations saved with the file, and when you re-open the saved file, these calibrations will still be available. When you save your calibration, create a name that includes the maximum force used, and record that value in the lab as well. It is also helpful to record any preload that is used.

- **Use Calibration**

If the "Use Calibration" window is blank (see Fig. 4), that means there is no "active" calibration being used. If any compliance calibrations have been saved with the file, they can be displayed in the pull-down window. Click on the calibration you want to use. The one displayed in the window is the "active" calibration, and once you click on Finish it will be used to make a compliance correction to any ***future*** data collected.



1 Choose the type of measurement you would like to calibrate:

Materials Testing System Compliance Calibration

2 Choose Calibration Action

○ Create New Calibration
● Use Calibration
7000 N cal (Tue Dec 17 11:37:30 2013)
● Import Calibration From Sensor
Calibration (Mon Dec 16 16:16:57 2013)
● Use Raw Values
● Manage Existing Calibration

3 Install the calibration rod

Install the calibration rod into the Materials Testing System as shown in the figure below.

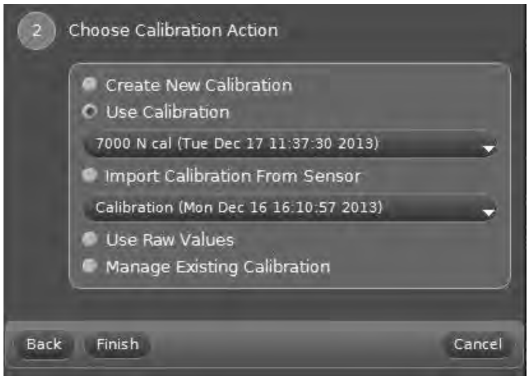
4 Record a smooth data run

Record Position vs. Force data over the range for which you want the unit calibrated. When you get a smooth run of data, proceed to the next step.

Figure 3: Calibration Wizard screen shot

- **Import Calibration from Sensor**

If any compliance calibrations have been stored in the sensor (the MTS unit), they will be displayed in this "Import Calibration" pull-down window. Click on the calibration you want to import. When you click on Finish, that stored calibration will be imported and added to the list for use and will become the "active" calibration. Calibrations stored in the sensor cannot be used or renamed until they are imported.



2 Choose Calibration Action

● Create New Calibration
○ Use Calibration
7000 N cal (Tue Dec 17 11:37:30 2013)
● Import Calibration From Sensor
Calibration (Mon Dec 16 16:10:57 2013)
● Use Raw Values
● Manage Existing Calibration

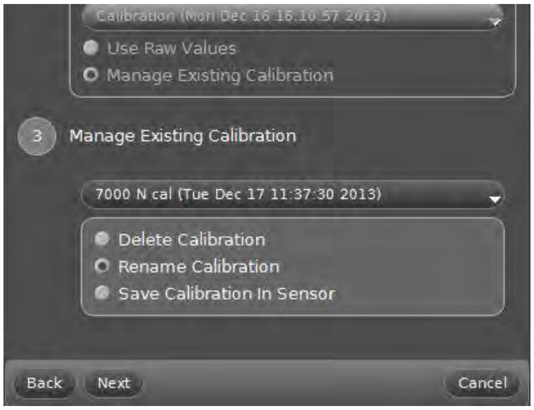
Figure 4: Choosing Use Calibration

- **Use Raw Values**

When you select "Use Raw Values" and click on Finish, the compliance correction is disabled, and any ***future*** data collected will not be adjusted. All calibrations, of course, are still saved.

- **Managing Existing Calibration**

When you select "Manage Existing Calibration" and click Next, step 3 is created and a new window is displayed as shown in Figure 5. The default, shown in the pull-down window, is the "active" calibration but you can select any of the saved files. You can then delete the calibration, change its name, or store it to the sensor (MTS unit). Note that only four calibrations can be stored in the MTS unit, and you will be prompted for which file you want to replace.



Calibration (Mon Dec 16 16:10:57 2013)
● Use Raw Values
○ Manage Existing Calibration

3 Manage Existing Calibration

7000 N cal (Tue Dec 17 11:37:30 2013)
● Delete Calibration
○ Rename Calibration
● Save Calibration In Sensor

Figure 5: Manage Existing Calibrations

Note: To ensure that a calibration will accurately correct for compliance, it is necessary to calibrate the Materials Tester over the same range and conditions you expect to use in testing samples. Your data will also look better if you use a small preload, but the preload must be the same value used in the compliance calibration. The steps below are a guide to taking good repeatable data. When you can get a good smooth graph, you are ready to use the Calibration Wizard to make your own compliance calibration. The actual Wizard will create its own temporary graph that will overlay any PASCO Capstone workbook page. For now, "Use Raw Values" should be selected so that any compliance calculation will be disabled, showing you the actual position data.

Procedure: "Seating" the Test Sample and Setting a Pre-Load

1. Make sure that the knurled cap is loose, not creating a force on the load cell. Set the sample rate to 20 Hz. This should be a good value to use, but you can change this if needed. Slower sample rates give more oversampling and thus smoother data.

2. Click on Record. If the force and position data is not zero, check the properties in Hardware Setup. The sensor should be set to zero on start. Tighten the knurled cap. Note that the digits display shows the force on the Load Cell.

3. Slowly turn the crank clockwise, about a quarter of a turn. Note that the position and force data are being plotted on the graph. 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 N. Try not to let the force go completely to zero.

4. 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. This has been accomplished when two subsequent curves track on top of each other. Click on Stop.

5. Repeat ***all*** the above steps, this time increasing the force up to about 6000 N, and then reduce the force back to between 5 and 10 N as before.

6. 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.

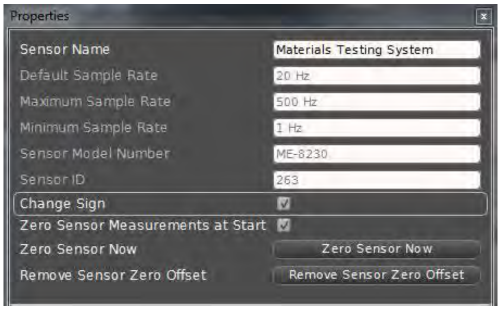
7. Take a final run of data, increasing the force up to 7000 N. Compare your graph to the sample shown in Figure 2.

Procedure: Materials Tester Sign Convention

1. Open the Hardware Setup in the Tools Palette and click on Properties. You should see a screen similar to that shown in Figure 6.

2. Note that the "Change Sign" box is checked. The default (un-checked) sign convention for the MTS is a positive value (for both position and force) when the crosshead is moving ***down***, compressing a sample. With the "Change Sign" box checked, a positive value (for both position and force) is measured when the crosshead is moving ***up***, putting the sample in tension, as you have seen so far in this lab.

3. Although it is possible to use the MTS with negative values, it is easier to change the sign convention to be positive for your application. For tension experiments, the box should be checked. For compression experiments, the box should be un-checked. If you plan to use the Calibration Wizard to make a compression compliance calibration, you should leave the box un-checked.



Sensor Name: Materials Testing System
Default Sample Rate: 20 Hz
Maximum Sample Rate: 500 Hz
Minimum Sample Rate: 1 Hz
Sensor Model Number: ME-8230
Sensor ID: 263
Change Sign ☑
Zero Sensor Measurements at Start ☑
Zero Sensor Now
Remove Sensor Zero Offset

Figure 6: Reversing Sign Convention

4. The Calibration Rod can be used to make a compression compliance calibration, using the thin hex nut. Install the Calibration Rod with the hex nut as shown in Figure 7, then turn the crank to lower the cross-head.

5. Position the cross-head so that it is ***almost*** touching the nut. Remember that you want to have zero force on the Force Sensor when you start because it automatically performs a tare. If this causes problems, note that you can disable this feature (see Fig. 6) and zero the sensor if and when you want.

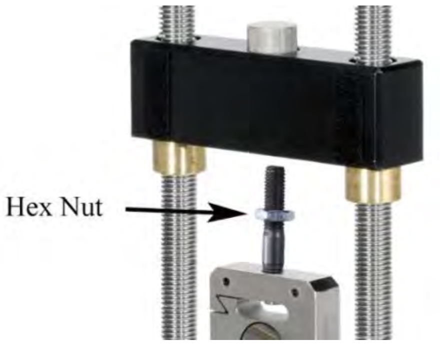


Figure 7: Compression Calibration

6. The knurled cap nut can be left (as shown) although it does not have any real effect since the cross-head will be moving down to compress the rod.

7. Practice making a compression graph.

8. Note: If you are making both a compression and tension calibration in the same workbook, choose names for your saved compliance files that reflect this!

Tensile Testing

Equipment

Qty	Description	Part Number
1	Materials Testing Apparatus	ME-8236
1	Tensile Samples (Brass)	ME-8232
1	Calipers	SE-8710

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.

Figure 1: Tensile Testing Brass Sample

Theory

Stress

It is important to distinguish between the strength of a component, such as a bolt, and the strength of the material from which the bolt is made. 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

$$s = F/A \qquad (1)$$

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

While 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 bolt 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

$$e = \Delta L/L \qquad (2)$$

where L is the initial length and ΔL 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.

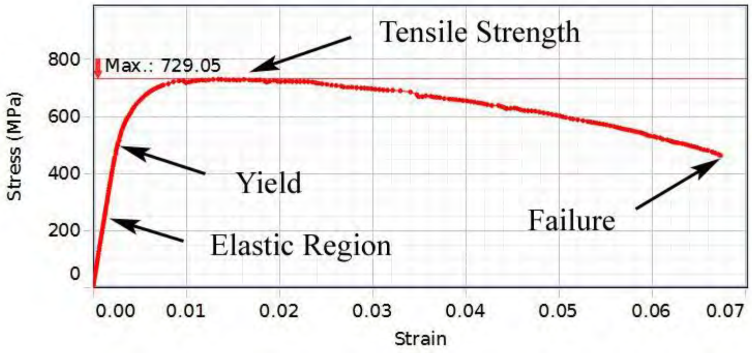


Figure 2: A typical stress-strain curve, with points of interest labeled

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.

Setup: Speed Control

1. In the PASCO Capstone calculator, create the following calculations:

   Stress=10^{-6} *([Force (N)]+100)/(π*(Dia/2)^2) with units of MPa
   Dia= with units of m
   Strain=[Position (m)]/L unitless
   L= with units of mm
   speed=60000*derivative(2,[Position (m)],[Time (s)]) with units of mm/min
   E=70000 with units of MPa

2. In PASCO Capstone, create a Meter display of Speed, a graph display of Force vs. Position, and a Digits display of Force.

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

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

Setup: Tensile Samples

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

6. 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.

7. 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.

8. 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.

9. 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!

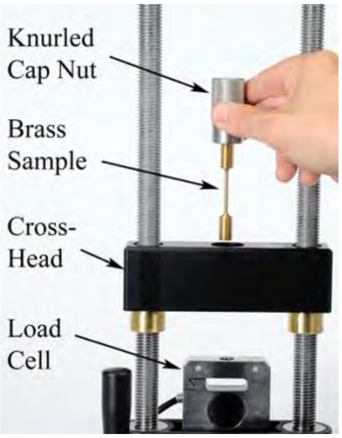


Figure 3: Installing Sample

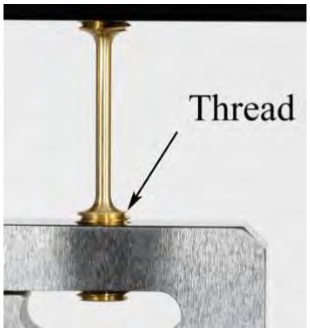


Figure 4: Center Threads in Load Cell

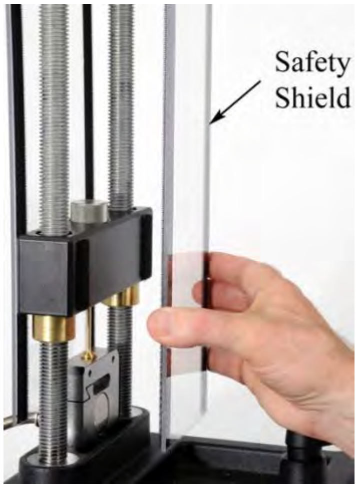


Figure 5: Always use Safety Shields!

Procedure: "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 are 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 100N. Note that the position and force data are being plotted on the graph. If the data is not positive, check the properties 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 to delete your practice runs.

Procedure: 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.

Analysis: 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?

Analysis: 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. In PASCO Capstone, create a graph display of Stress vs. Strain.

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

3. 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?

4. 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.

5. 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?

Analysis: 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. Edit the value in the calculator for your value of Young's Modulus (E). Add a second y-axis to the stress vs strain graph and add the offset yield calculation. Make sure the scaling of both y-axes is 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.

Analysis: 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.

Analysis: 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

   $$\text{modulus of resilience} = (\text{yield strength})^2/2E$$

   where E is Young's Modulus. Calculate the modulus of resilience, and compare to the value from the graph.

Summary

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

   Elastic, Uniform Plastic Deformation, Non-uniform Plastic Deformation, Tensile Strength, Necking, and Fracture.

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?

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?

Young's Modulus

Equipment

Qty	Description	Part Number
1	Materials Testing Apparatus	ME-8236
1	Tensile Samples (Steel)	ME-8243
1	Calipers	SE-8710

Introduction

In this lab, you will collect stress vs. strain data for the test sample in the elastic region. Several runs will be taken for the same sample, and an average value of Young's Modulus for the material will be determined. It is important that you never exceed the yield strength of the material: For the ME-8243 Steel Tensile Sample, a safe maximum force is 3000 N.

Figure 1: Tensile Testing Steel Sample

Setup

1. In the PASCO Capstone calculator, create the following calculations, add your values for the constants as you determine their values:

Stress=10^{-9} *[Force (N), ▼]/(π*(Dia/2)^2)	with units of MPa
Dia=	with units of m
Strain=[Position (m)]/L	unitless
L=	with units of mm

2. 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.

3. 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.

4. In PASCO Capstone, create a graph display of Force vs. Position, a Digits display of Force, and a graph display of Stress vs. Strain.

5. Set the sample rate to 50 Hz.

Procedure: "Seating" the Test Sample and Setting Pre-Load

1. Note: The following is written for using a test sample (see Figure 1), but you should also use this method when performing a compliance calibration of the Materials Tester using the Calibration Rod. In the following procedure, you will load and unload the system several times to remove all the slack and properly "seat" the test sample, in addition to introducing a small pre-load to the system.

2. Make sure that the knurled cap is loose, not creating a force on the load cell. Click on Record. Note that the Digits display shows the force on the load cell.

3. Turn the crank clockwise about a quarter of a turn. Note that the position and force data are being plotted on the graph. With data still being recorded, continue turning the crank clockwise until the force has reached the desired maximum, based on the yield strength of the material.

4. 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.

5. 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.

6. With data still being recorded, slowly turn the crank counter-clockwise. Watch the digits display, and reduce the force to between 10 and 20 Newtons, then carefully increase the force to 100 N. Click on Stop, and do NOT change the crank position. Since the sensor will auto-zero next time you record 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 compliance calibration of the Materials Tester.

Procedure: Taking Data

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

2. Turn the crank clockwise, stretching the sample, until you have reached the max force. Do not exceed the Yield Strength of the material!

3. Click on Stop.

4. The data should be fairly linear. It is ok if there is a slight curvature at the beginning or end, but if there is not a straight section in the middle, you probably have something wrong. Try doing a new compliance calibration using the Calibration Rod.

5. Look at the Stress vs. Strain graph to check how you are doing.

6. To take another run of data, turn the crank counter-clockwise to remove the tension.
7. Repeat **all** the steps in the "Seating" the Test Sample and Setting Pre-Load section to properly re-seat the sample, then take another run of data.
8. Rename the good runs of data you wish to keep, and delete the unwanted runs and data taken when you are seating the sample.
9. Get at least five good runs.

Analysis

1. Young’s Modulus is the slope of the linear portion of the stress-strain curve. Confirm that the equations for Stress and Strain in the calculator are being done correctly.
2. For each of your runs, measure the slope in the linear portion of the graph to find Young's Modulus for the material. What is the uncertainty? Use the Highlight tool to select only a portion of the graph.
3. What is your average value for Young's Modulus? What is the uncertainty in your answer? How did you estimate this uncertainty?
4. How does your value compare to those listed in reference data tables for the material?

Tensile Testing Annealed Steel

Equipment

Qty	Description	Part Number
1	Materials Testing Apparatus	ME-8236
1	Tensile Samples (Steel)	ME-8243
1	Tensile Samples (Annealed)	ME-8233
1	Calipers	SE-8710

Introduction

The two steel tensile samples are made from the same (1018) material, but the ME-8233 samples are annealed after the machining process. This involves heating the sample, holding the sample at a critical temperature for a fixed time, and then allowing the sample to cool in a controlled environment. This lab investigates what effect annealing has on the properties of the material. Properties measured for both samples include Young's Modulus, Yield Strength, Tensile Strength, Ductility, and Modulus of Toughness.

Figure 1: Tensile Testing Steel Samples

Setup

1. In the PASCO Capstone calculator, create the following calculations:

Stress=10^{-6} *([Force (N)]+100)/(π*(Dia/2)^{2})	with units of MPa
Dia=	with units of m
Strain=[Position (m)]/L	unitless
L=	with units of mm
speed=60000*derivative(2,[Position (m)],[Time (s)])	with units of mm/min
offset yield=E*([Strain]-.002)	unitless
E=190000	with units of MPa

2. Connect the Materials Testing Machine to a PASPORT interface or AirLink. In PASCO Capstone, set the sample rate to 50 Hz, create a Meter display of Speed, a graph display of Force vs. Position, and a Digits display of Force.

3. Use calipers (or a micrometer) to measure the diameter of the machined portion of the tensile sample. Enter it as 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 enter in line #4 of the calculator for the length is 35 ± 1 mm.

Procedure: "Seating" the Test Sample and Setting Pre-Load

Note: The following is written for using a test sample (see Figure 1), but you should also use this method when performing a compliance calibration of the Materials Tester using the Calibration Rod. In the following procedure, you will load and unload the system several times to remove all the slack and properly "seat" the test sample, in addition to introducing a small pre-load to the system.

1. Install the steel test sample as shown in Figure 1. Make sure that the knurled cap is loose, not creating a force on the load cell.

2. Click on Record. Tighten the knurled cap. Note that the digits display shows the force on the load cell.

3. Slowly turn the crank clockwise, increasing the force to about 100 N. Note that the position and force data are being plotted on the graph.

4. 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.

5. 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.

6. 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 compliance calibration of the Material Tester.

7. You can use the Delete Run menu on the Controls tool bar to delete your practice runs.

Procedure: Breaking the Samples

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. Turn the crank clockwise, stretching the sample. Continue cranking until the sample breaks. Click on Stop.

3. Replace the broken sample with your second sample. Repeat **all** the steps from the previous page to properly seat the sample.

4. Click on Record. Turn the crank clockwise, stretching the sample. Continue cranking until the sample breaks. Click on Stop.

Analysis: Young's Modulus

Young’s Modulus is the slope of the linear portion of the stress-strain curve. Confirm that the equations for Stress and Strain in the calculator are being done correctly.

1. In PASCO Capstone, create a graph display of Stress vs. Strain.

2. For both of your runs, 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 do your two values compare? Are they about the same? Should they be?

4. How does your value compare to those listed in reference data tables for the material?

Analysis: 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, which makes 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. Select the data for the steel sample.

2. 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 is the same and then note where this new line crosses the stress-strain curve.

3. Compare your value for the Yield Strength (or Offset Yield Strength) to those listed in reference data tables for the material.

Analysis: Upper and Lower Yield Strength

Some materials (such as mild steel) exhibit a sharp yield (called the upper yield strength) followed immediately by a rapid drop in stress (down to the lower yield strength). Only after additional added strain does the stress start to rise again.

For a material with this behavior, the "Yield Strength" used is the **lower** yield strength. The reason for this is that the upper yield strength is very sensitive to the alignment of the specimen in the tensile tester and defects in the specimen such as those caused by machining. The lower yield strength is more repeatable.

1. Measure the Yield Strength for Annealed Steel.

2. Compare your value for the Yield Strength to those listed in reference data tables for the material. Compare the value found for this material to the other sample.

Analysis: 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.

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.

Analysis: Area

The area under the Stress vs. Strain graph 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.

1. Measure the area under the entire graph for both samples. What are the units?

2. How do the two compare?

Summary

1. Summarize the values you got for both samples.

2. What effect did annealing have on each of the measured quantities?

   a. Young's Modulus
   b. Yield Strength
   c. Tensile Strength
   d. Ductility
   e. Toughness

Tensile Testing Metals

Equipment

Qty	Description	Part Number
1	Materials Testing Apparatus	ME-8236
1	Tensile Sample (Aluminum)	ME-8231
1	Tensile Sample (Brass)	ME-8232
1	Tensile Sample (Steel)	ME-8243
1	Calipers	SE-8710

Introduction

The three metal tensile samples are made from 1018 Steel, 360 Brass and 2024-T3 Aluminum. The properties measured for these samples include Young's Modulus, Yield Strength, Tensile Strength, Ductility, and Modulus of Toughness. These properties are the same ones found in materials handbooks and databases, and are used by engineers to design bridges, buildings, and machines.

Figure 1: Tensile Testing Metals

Setup

1. Connect the Materials Testing Machine to a computer using a USB interface. In the PASCO Capstone calculator, create the following calculations:

   ```
   Stress=10⁻⁶ *([Force (N)]+100)/(π*(Dia/2)²) with units of MPa
   Dia=0.0033 with units of m
   Strain=[Position (m)]/L   (unitless)
   L=0.036 with units of mm
   ```

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

3. 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.

4. In PASCO Capstone, create a graph of Force vs. Position and a digits display for the Force. On another page, create a graph of Stress vs. Strain. Also create a meter and select speed in mm/min.

Procedure

"Seating" the Test Sample and Setting Pre-Load

Note: The following is written for using a test sample (see Figure 1), but you should also use this method when performing a compliance calibration of the Materials Tester using the Calibration Rod. In the following procedure, you will load and unload the system several times to remove all the slack and properly "seat" the test sample, in addition to introducing a small pre-load to the system.

1. Install the Steel test sample as shown in Figure 1. Make sure that the knurled cap is loose, not creating a force on the load cell.

2. Click on Record. Tighten the knurled cap. Note that the digits display shows the force on the load cell.

3. Slowly turn the crank clockwise, increasing the force to about 100 N. Note that the position and force data are being plotted on the graph.

4. 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.

5. 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.

6. 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 compliance calibration of the Material Tester.

7. You can use the Delete Run menu (Controls tool bar, below) to delete your practice runs.

Breaking the Samples

In this 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. Go to the page with the Stress vs. Strain graph. Start recording. Turn the crank clockwise, stretching the sample. Continue cranking until the sample breaks. Click on Stop.

3. Replace the broken sample with your second sample. Repeat **all** the steps to properly seat the sample.

4. Start recording. Turn the crank clockwise, stretching the sample. Continue cranking until the sample breaks. Click on Stop.

5. Repeat for your third sample.

Analysis

1. If you have not already done so, open the Data Summary and rename your runs Steel, Brass and Aluminum.

2. Confirm that the equations for Stress and Strain in the calculator are being done correctly.

3. For each of your runs, measure the slope in the linear portion of the graph to find Young's Modulus for the material, and record the values.

4. Where does the linear part of the curve end? Is it a gradual or abrupt change? For each sample, estimate the Yield Strength, and record the values.

5. The Tensile Strength is the maximum stress on the graph. Measure and record this quantity for each sample.

6. The Ductility of the material is the maximum strain just before it broke. Measure and record this quantity for each sample. Note that this is usually expressed as a percentage.

7. The Modulus of Toughness for the material is the area under the Stress vs. Strain graph. Measure and record this quantity for each sample.

Summary

What did you discover about the properties of the three materials you tested? When would one be better than the others?

Testing Plastic Tensile Samples

Equipment

Qty	Description	Part Number
1	Materials Testing Apparatus	ME-8236
2	Tensile Sample (Acrylic)	ME-8234
1	Tensile Sample (Polyethylene)	ME-8235
1	Calipers	SE-8710

Introduction

The behavior of plastics when deformed in tension is generally like that of metals. We see elastic and plastic deformation, yielding, and strain hardening, but the differences are notable. Often, we might not see a linear-elastic behavior at the start of the test and so Young's Modulus would not represent the plastic's stiffness. Yielding is defined differently, and it may coincide with the tensile strength. Plastics also tend to be more sensitive to the strain rate than metals and this must be considered when conducting the test and when reporting the results. In this lab you will tensile test two types of plastic and measure the stiffness of the materials using several different methods.

Figure 1: Testing Plastic Tensile Samples

Theory

When a plastic sample is loaded in tension it will elongate. If pulled far enough it will fail, breaking into two pieces. Between the point where it was initially loaded and it failed, it will generally exhibit the following types of behavior, as shown in Figure 2.

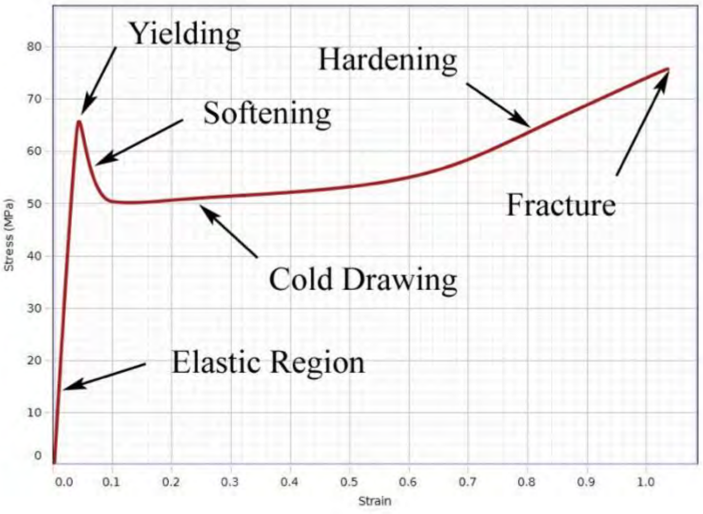


Figure 2: Typical stress-strain curve for plastic

Elastic Deformation – This deformation is temporary and is recovered as soon as the load is removed. The sample returns to its original size. Depending on the type of plastic, some time-dependent elastic and plastic deformation (anelasticity and creep) may accompany the initial elastic deformation of the specimen.

Yielding – This marks the end of the initial elastic region and the start of plastic deformation and in some cases the onset of necking.

Strain Softening – Following yielding some materials will appear to soften (load decreases) as a neck forms (see Fig. 3) and the structure begins the transformation from one of randomly oriented chains and crystallites into a more aligned structure.

Cold Drawing – The crystallites are rotating and being reoriented. Most of this is happening in the zone where the neck is forming.

Strain Hardening – Once the specimen's structure is fully drawn the stress increases again. This new structure is now resisting deformation.

Fracture – The specimen finally breaks.

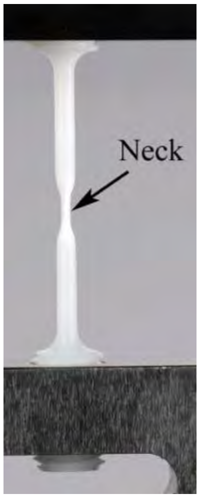


Figure 3: Necking

Setup

1. Connect the Materials Testing Machine to a PASPORT interface or AirLink. In the PASCO Capstone calculator, create the following calculations, add your values for the constants as you determine their values:

Stress=10^{-9} *[Force (N)]/(π*(Dia/2)^2)	with units of MPa
Dia=	with units of m
Strain=[Position (m)]/L	unitless
L=	with units of mm
speed=60000*derivative(2,[Position (m)],[Time (s)])	mm/Min
poly fit=A + B*[Strain]+C*[Strain]^2 + D*[Strain]^3	MPa
A=0	MPa
B=1	MPa
C=1	MPa
D=1	MPa

2. 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.

3. 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.

4. In PASCO Capstone, create a Meter display of Speed, a graph display of Force vs. Position, a Digits display of Force, and a graph display of Stress vs. Strain.

5. Set the sample rate to 20 Hz.

Procedure: "Seating" the Test Sample and Setting Pre-Load

1. Note: The following is written for using a test sample (see Figure 1), but you should also use this method when performing a compliance calibration of the Materials Tester using the Calibration Rod. In the following procedure, you will load the system to introduce a small pre-load.

2. Install the acrylic test sample as shown in Figure 1. Make sure that the knurled cap is loose, not creating a force on the load cell.

3. Click on Record. 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 to about 10 N. Note that the position and force data are being plotted on the graph.

5. 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 10 N pre-load on the sample which results in better data. You should use this same method when performing any compliance calibration of the Material Tester.

6. You can use the Delete Run menu (Controls tool bar) to delete your practice runs. Proceed to the next page to collect your actual data runs.

7. You can use the Calibration routine (in the Tools Palette) to perform a compliance calibration at any time. You should calibrate the Materials Tester over the same range you expect to use in testing samples. In this lab, for example, a max range of 1000 N is sufficient. When you store your calibration, create a name that includes the max force used, and record that value in the lab as well. Compliance calibration called "Calibration 1000" was over a range of 1000 N and used a pre-load of 10 N.

Procedure: Breaking the Sample

1. You will deform the acrylic tensile sample, pulling it apart until it breaks. Try to turn the crank at a steady rate of about 20 to 30 mm/Min. Make sure the safety shield is in place.

2. Click on Record. Turn the crank clockwise, stretching the sample. Continue cranking until the sample breaks. Click on Stop.

3. Replace the broken sample with your second acrylic sample. Repeat the steps from the previous page to properly seat the sample.

4. For this run, turn the crank very slowly, less than 5 mm/Min. Click on Record. Turn the crank until the sample breaks. Click on Stop.

5. Repeat using the polyethylene sample. This material will stretch a **long** way, so it is best to use a fast rate. Continue cranking at least until the necked region that forms is 2 cm long. You probably will not be able to break the sample.

6. Rename your runs Acrylic fast, Acrylic slow, and Polyethylene.

Analysis: Linear Elastic Behavior

1. For plastics that exhibit linear-elastic behavior, **Young's Modulus** (E) is the property that describes the stiffness of the material. It is measured as the slope of the linear portion of the stress-strain curve.

2. Confirm that the equations for Stress and Strain in the calculator are being done correctly.

3. For your two **acrylic** samples, Measure the slope in the linear portion of the Stress vs. Strain graph to find Young's Modulus for the material. What is the uncertainty in your measurements?

4. How do the two values compare? What effect did the strain rate have on the modulus and on the tensile strength?

5. How do your values compare to those listed in reference data tables for the material?

Analysis: Nonlinear Elastic Behavior

1. For plastics that do **not** exhibit linear-elastic behavior, the following moduli can be used to describe the stiffness of the material: **Initial Modulus** is the slope of the stress-strain curve at the very start of the test. **Secant Modulus** is the slope in the stress-strain curve from the origin to a specified strain. **Tangent Modulus** is slope in the stress-strain curve at a specified strain: For example, 2% of strain can be used. **Chord Modulus** is the slope in the stress-strain curve measured between two specified strains. Since the actual data tends to be fairly noisy, the general approach is to fit a polynomial curve to the data, and then make all measurements from that fit.

2. Use the highlighter to select only the data up to about 5% strain.

3. Fit a 4-term polynomial to your polyethylene test sample data. Use the Curve Fit Editor in the Tools Palette. You can change the number of terms, and lock A=0.

4. Open the Calculator window and edit the coefficients for the poly fit. You will make your remaining measurements on this curve fit model, not on your actual data.

5. In PASCO Capstone, create a graph display of Poly fit vs. Strain.

6. Lock the scale to only show the curve up to 5% strain.

7. Use the Slope tool to measure Initial Modulus.
8. Use the Slope tool to measure Tangent Modulus at 2% strain.
9. Use rise over run to measure the Secant Modulus at 2% strain.
10. How do your values compare to those listed in reference data tables for the material?
11. Measure and record the Tensile Strength of the polyethylene material. Compare your value to those listed in reference data tables for the material. Compare the value found for this material to other materials tested.
12. Use Text annotations to mark the following regions of your polyethylene graph: Yielding, Softening, Cold Drawing, Necking.
13. What are the differences in the two plastics?

Tensile Testing Plastic Coupons

Equipment

Qty	Description	Part Number
1	Materials Testing Apparatus	ME-8236
1	Plastic Test Coupons	AP-8222
1	Material Coupon Adapter	ME-8238
1	Calipers	SE-8710

Introduction

The ME-8238 Coupon Adapter allows you to tensile test the AP-8222 Plastic Coupons, which includes four different types of plastics. In this lab you will measure the stiffness of the materials using several different methods, in addition to determining the tensile strength. Plastics tested are ABS, Nylon, Polypropylene (PP) and High-Impact Polystyrene (HIPS).

Figure 1: Testing Plastic Coupons

Theory

When a plastic sample is loaded in tension it will elongate. If pulled far enough it will fail, breaking into two pieces. Between the point where it was initially loaded and it failed, it will generally exhibit the following types of behavior, as shown in Figure 2. The behavior of plastics when deformed in tension is generally like that of metals. We see elastic and plastic deformation, yielding, and strain hardening, but the differences are notable. Often, we might not see a linear-elastic behavior at the start of the test and so Young’s Modulus would not represent the plastic’s stiffness. Yielding is defined differently, and it may coincide with the tensile strength. Plastics also tend to be more sensitive to the strain rate than metals and this must be considered when conducting the test and when reporting the results.

Elastic Deformation – This deformation is temporary and is recovered as soon as the load is removed. The sample returns to its original size. Depending on the type of plastic, some time-dependent elastic and plastic deformation (anelasticity and creep) may accompany the initial elastic deformation of the specimen.

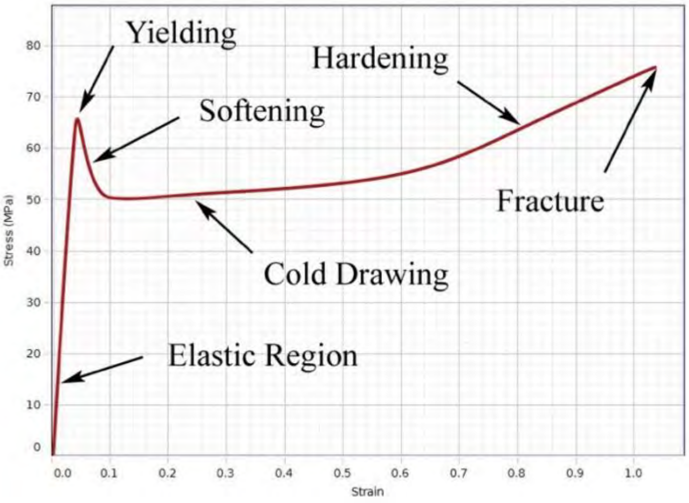


Figure 2: Typical stress-strain curve for plastic

Yielding – This marks the end of the initial elastic region and the start of plastic deformation and in some cases the onset of necking.

Strain Softening – Following yielding some materials will appear to soften (load decreases) as a neck forms (see Fig. 3) and the structure begins the transformation from one of randomly oriented chains and crystallites into a more aligned structure.

Cold Drawing – The crystallites are rotating and being reoriented. Most of this is happening in the zone where the neck is forming.

Strain Hardening – Once the specimen's structure is fully drawn the stress increases again. This new structure is now resisting deformation.

Fracture – The specimen finally breaks.

Setup

Note: Installing the Coupon Adapter

Notice that the two parts of the Coupon Adapter are NOT identical. The one with the shorter threads goes on the bottom, and screws directly into the load cell as shown in Figure 1. Screw it most of the way in, but you want the clamp assembly to face forward so that you can use the wrench. The other adapter, with the longer threads, sticks up through the cross-head and is held by the knurled cap nut.

1. Connect the Materials Testing Machine to a PASPORT interface or AirLink. In the PASCO Capstone calculator, create the following calculations, add your values for the constants as you determine their values:

Stress=10^{-9} *[Force (N)]/(π*(Dia/2)^2)	with units of MPa
Dia=	with units of m
Strain=[Position (m)]/L	unitless
L=	with units of mm
speed=60000*derivative(2,[Position (m)],[Time (s)])	mm/Min
poly fit=A + B*[Strain]+C*[Strain]^2 + D*[Strain]^3	MPa
A=0	MPa
B=1	MPa
C=1	MPa
D=1	MPa

2. Use calipers (or a micrometer) to measure the diameter of the thin round portion of the coupons. Edit the value for diameter in line #2 of the calculator.

3. Note that the calculator also has a value for the length of the sample. If you measure the thin, round portion, you should get about 20 mm. However, since there is a taper, the length that is actually stretching is longer. A good average value to use for the length is 22 ± 2 mm.

4. There is a ridge on one side of the coupon that fits under the black clamp on the adapter, as shown in Figure 3.

5. Use the socket wrench to tighten the hex nuts, as shown in Figure 4.

6. You can use the Calibration routine (in the Tools Palette at left) to perform a compliance calibration at any time. You should calibrate the Materials Tester over the same range you expect to use in testing samples. In this lab, the max force is under 200 N, and the compliance calibration is not really even needed. Note that one of the choices in the calibration is to just use "RawValues" with no corrections. As always, keep a record of what you used.

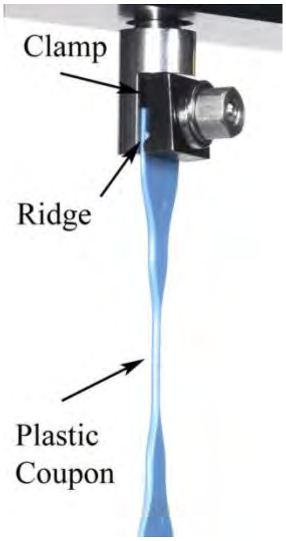


Figure 3: Installing Coupons


Figure 4: Tighten hex nuts

7. In PASCO Capstone, create a Meter display of Speed, a Graph display of Force vs. Position, a Digits display of Force, and a Graph display of Stress vs. Strain.

8. Set the sample rate to 20 Hz.

Procedure: Breaking the Sample

1. You will deform the coupon, pulling it apart until it breaks. Try to turn the crank at a steady rate of about 20 to 30 mm/Min.

2. Click on Record. Turn the crank clockwise, stretching the sample. Continue cranking until the sample breaks. Click on Stop.

3. Replace the broken sample with another coupon and repeat.

4. Repeat for the other coupons.

5. Rename your runs to indicate the material used.

Analysis: Linear Elastic Behavior

1. For plastics that exhibit linear-elastic behavior, **Young's Modulus** (E) is the property that describes the stiffness of the material. It is measured as the slope of the linear portion of the stress-strain curve.
2. Confirm that the equations for Stress and Strain in the calculator are being done correctly.
3. For your ABS sample, 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?
4. How does your value compare to that listed in reference data tables for the material?

Analysis: Nonlinear Elastic Behavior

1. For plastics that do **not** exhibit linear-elastic behavior, the following moduli can be used to describe the stiffness of the material: **Initial Modulus** is the slope of the stress-strain curve at the very start of the test. **Secant Modulus** is the slope in the stress-strain curve from the origin to a specified strain. **Tangent Modulus** is slope in the stress-strain curve at a specified strain: For example, 2% of strain can be used. **Chord Modulus** is the slope in the stress-strain curve measured between two specified strains. Since the actual data tends to be fairly noisy, the general approach is to fit a polynomial curve to the data, and then make all measurements from that fit.
2. For your nylon data, use the highlighter to select only the data up to about 5% strain.
3. Fit a 4-term polynomial to your nylon test sample data. Use the Curve Fit Editor in the Tools Palette. You can change the number of terms, and lock A = 0.
4. Open the Calculator window and edit the coefficients for the poly fit. You will make your remaining measurements on this curve fit model, not on your actual data.
5. In PASCO Capstone, create a graph display of Poly fit vs. Strain.
6. Lock the scale to only show the curve up to 5% strain.
7. Use the Slope tool to measure Initial Modulus.
8. Use the Slope tool to measure Tangent Modulus at 2% strain.
9. Use rise over run to measure the Secant Modulus at 2% strain.
10. How do your values compare to those listed in reference data tables for the material?
11. Measure and record the "stiffness" of the other two plastics. List the method you used and compare to values listed in reference data tables.

12. The Tensile Strength is the maximum stress on the graph. Measure and record this quantity for each sample. You should also note if this occurs at yield or at fracture.

13. Compare your measurement to values listed in reference data tables.

Analysis: Material Comparison

1. Which material has a stress-strain graph that most closely resembles the "typical" curve for plastics shown in the theory section of this lab.

2. For that data, use the Text Annotations to mark the following regions of your graph: Elastic, Yielding, Softening, Hardening, Cold Drawing, and Necking.

3. What are the major differences in the four plastics tested?

Three-Point Bending

Introduction

A Three-Point Bend test is performed on a round rod as shown in Figure 1. As a downward force (F) is applied in the middle of the rod, the flex (Δx) is recorded. The ratio (F/Δx) is the effective stiffness of the length of rod being tested.

The distance between the anvils (see inset) is varied, and the resulting effect on the stiffness of the beam is measured. A graph of the resulting data yields the Flexural Elastic Modulus for the material.

Equipment

Qty	Description	Part #
1	Materials Testing Apparatus	ME-8236
1	Bending Accessory	ME-8237
1	Shear Sample (Steel)	ME-8240
1	Calipers	SE-8710

This experiment uses the round rod from the ME-8240 Shear Samples. The lab is written for the steel samples, but any could be used, including samples of your own.

You will need to cut the rod to a length of about 10 cm, so that it will fit between the drive screws.

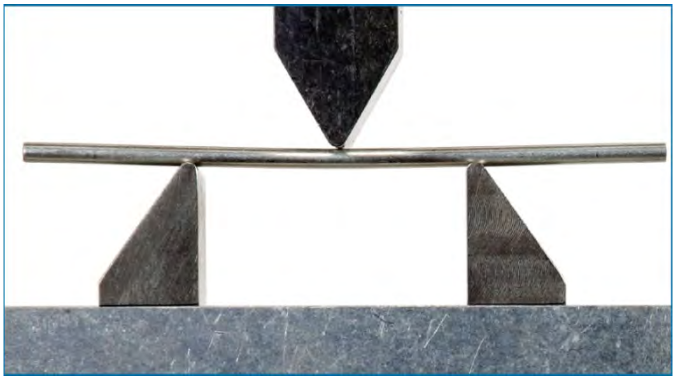


Figure 1: Three-Point Bending

Three-Point Bending Test

A test sample is supported by two anvils separated by a length, L, as shown in Figure 2. A load, F, is applied in the middle, an equal distance from each anvil, and the resulting flexure (Δx) is measured.

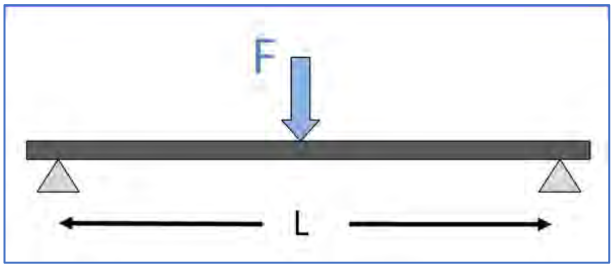


Figure 2: 3-Point Bending Test

The ratio of F/Δx is the stiffness of the sample, and depends on the length, L. It also depends on the cross-section shape and area of the sample, as well as the material.

If "E" is the Flexural Elastic Modulus for the material, and "**I**" is the Area Moment of Inertia for the sample, then

$$\frac{F}{\Delta x} = \frac{48\,IE}{L^3} \qquad (1)$$

The Area Moment of Inertia depends on the shape of the cross section of the sample. For a round rod of radius, r,

$$I_{rod} = \frac{1}{4}\pi r^4 \qquad (2)$$

Thus, we see from Eqn. (1) that the stiffness (F/Δx) is inversely proportional to the cube of the anvil separation, L, and a graph F/Δx vs. $1/L^3$, yields a straight line with a slope = 48**I**E. Finally, solving for E yields

$$E = \frac{\text{slope}}{48\,I} \qquad (3)$$

Note. The Flexural Modulus is technically not the same as Young's Modulus. Bend testing involves both tensile and compressive stresses, and for some materials these moduli are different.

Installing Bending Accessory

Note: The ME-8237 Bending Accessory consists of two major parts: The upper load anvil and the lower base with the two support anvils. In this lab, you will vary the support anvil spacing using the hex wrench as shown in Figure 2. Start with the anvils spaced as far apart as possible: If you want, you can reverse the anvils to increase this maximum length.

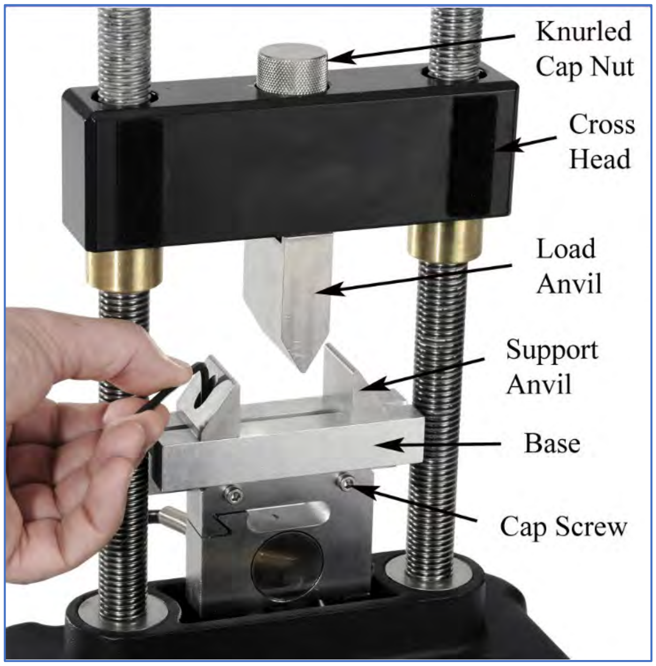


Figure 3: Changing Anvil Spacing

1. The load anvil sticks up through the cross-head and is held in place by the knurled cap nut, as shown in Figure 3.

2. The base (for the support anvils) fastens directly to the load cell using the two cap screws. Each anvil is captured by the T-slot in the base, and their separation should always be adjusted so that the Load Anvil is centered between them. Use calipers to make this alignment as accurate as possible.

3. Start with the anvils spaced as far as possible, and measure their separation. This length, L, is to the top of the camber on each anvil. You can also just measure between the vertical surfaces, and calculate L by including the 1.5 mm radius on each anvil.

Compliance Calibration

Note: Before you can test the sample, you must complete the following steps to seat the test sample and set a pre-load. The procedure is written for using a test sample (see Fig. 1), but you should also use this method when performing a compliance calibration of the Materials Tester using the Calibration Rod. In this procedure, you load and unload the system several times to remove all the slack and properly "seat" the test sample, in addition to introducing a small pre-load to the system.

"Seating" the Test Sample and Setting Pre-Load

1. Connect the Materials Testing Machine to a computer using a USB interface. In PASCO Capstone, create a graph of Force vs. Position. Also create a Digits display and select Force.

2. Place the steel test sample across the support anvils. Turn the crank counter-clockwise until the load anvil is almost touching the sample.

3. Click on Record. Continue cranking counter-clockwise, watching the graph and digits display. Run the applied force up to about 50 N, and then decrease it back to about 10 to 20 N. Try not to let the force go completely to zero.

4. While still recording data, run the force up and down again. 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.

5. With data still being recorded, reduce the force back down to about 20 N, and then Click on Stop. Do NOT change the crank position. Since the sensor will auto-zero next time you record data, this puts a 20 N pre-load on the sample which results in better data. You should use this same method when performing any compliance calibration of the Materials Tester.

6. Note: Do not exceed the Yield Strength of the material! If the sample is permanently bent, you went too far. For these samples, you only need to apply a max force of 100 to 200 N.

Taking Data

1. In PASCO Capstone, create a table and create two user-entered data sets: The first set is called L and has units of m; the second set is called F/Δx and has units of N/m.

2. Click on Record. Turn the crank counter-clockwise, bending the sample. Increase the force to about 100 N.

3. Click on Stop. The data should be fairly linear. It is ok if there is a slight curvature at the beginning or end, but if there is not a straight section in the middle, you probably have something wrong.

4. To take another run of data, turn the crank clockwise to completely remove the tension. Repeat **all** the steps to properly re-seat the sample, then take another run of data.

5. Use a linear curve fit to find the slope. This is the stiffness (F/Δx) of the length of beam you are testing. Record these values in the table.

6. Decrease the anvil spacing, L, by about 1 cm and repeat.

7. Measure the stiffness for lengths down to about 3 cm.

Beam Stiffness and Anvil Separation

1. In Capstone, create a graph of F/Δx vs. L.

2. How does the stiffness of the beam depend on the length being tested? Does it increase or decrease with length?

3. Try a QuikCalc on the vertical axis to graph $(F/\Delta x)^{-1}$.

4. Is this linear? Try a QuikCalc on the horizontal axis to graph the square root of length ($L^{1/2}$).

5. Is this linear? Did it make it more or less linear? Try a QuikCalc on horizontal axis to graph the length squared (L^2).

6. Is this linear? Try a QuikCalc on horizontal axis to graph the length cubed (L^3).

7. What do you conclude?

Calculating Moment of Inertia

1. Measure the radius of the test sample.

2. Use Eqn. (2) to calculate the Area Moment of Inertia.

Flexural Modulus

1. In the Capstone Calculator, create the calculation:
   Inverse L^3=1/[L (m)]^3 with units of m^{-3}

2. Create a graph of $F/\Delta x$ vs. Inverse L^3.

3. Use a linear curve fit to find slope of the graph.

4. Use Eqn. (3) to calculate the Flexural Modulus for your steel sample.

5. For your sample, how does the Flexural Modulus compare to Young's Modulus?

Bend Testing a Round Rod

Equipment

Qty	Description	Part Number
1	Materials Testing Apparatus	ME-8236
1	Bending Accessory	ME-8237
1	Shear Samples	ME-8240
1	Calipers	SE-8710

Introduction

1. A Three-Point Bend test is performed on a round rod as shown in Figure 1. As a downward force (F) is applied in the middle of the rod, the flex (Δx) is recorded. The ratio (F/Δx) is the effective stiffness of the length of rod being tested and is measured directly from the slope of the F vs. Δx graph. The Flexural Elastic Modulus for that material is then calculated.

2. This experiment uses the round rod from the ME-8240 Shear Samples. For each material, you will need to cut a rod to a length of about 10 cm, so that it will fit between the drive screws. Materials tested include Aluminum, Brass and Steel.

Figure 1: Three-Point Bending

Theory

A test sample is supported by two anvils separated by a length, L, as shown in Figure 2. A load, F, is applied in the middle, an equal distance from each anvil, and the resulting flexure (Δx) is measured. The ratio of F/Δx is the stiffness of the sample, and depends on the length, L. It also depends on the cross-section shape and area of the sample, as well as the material.

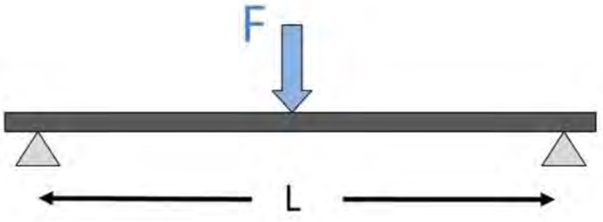


Figure 2: Three-Point Bending Test

If "E" is the Flexural Elastic Modulus for the material, and "I" is the Area Moment of Inertia for the sample, then

$$\frac{\mathrm{F}}{\Delta \mathrm{x}} = \frac{48\ \mathrm{IE}}{\mathrm{L}^3} \qquad (1)$$

Solving for E, yields

$$\mathrm{E} = \frac{\mathrm{F\ L}^3}{\Delta \mathrm{x}\ 48\ \mathrm{I}} \qquad (2)$$

where the ratio F/Δx is determined from the slope of the force vs. flexure graph. The Area Moment of Inertia depends on the shape of the cross section of the sample. For a round rod of radius, r,

$$\mathrm{I}_{\mathrm{rod}} = \frac{1}{4}\pi \mathrm{r}^4 \qquad (3)$$

Note: The Flexural Modulus is technically not the same as Young's Modulus. Bend testing involves both tensile and compressive stresses, and for some materials these moduli are different.

Setup: Installing Bending Accessory

1. Connect the Materials Testing Machine to a computer using a USB interface. In the PASCO Capstone calculator, create the following calculation:

   E=(10^-9)*[F/Δx (N/m)]*[L (m)]³/(48*[I (m⁴)]) with units of GPa

2. ME-8237 Bending Accessory consists of two major parts: The upper load anvil and the lower base with the two support anvils. The load anvil sticks up through the cross-head and is held in place by the knurled cap nut.

3. The base (for the support anvils) fastens directly to the load cell using the two cap screws as shown in Figure 3.

4. In PASCO Capstone, create a table and create two user-entered data sets: The first set is called L and has units of m; the second set is called I and has units of m^4.

Figure 3: Setting Anvil Spacing

5. Each anvil is captured by the T-slot in the base, and their separation should always be adjusted so that the Load Anvil is centered between them. Use calipers to make this alignment as accurate as possible. Set the anvil spacing (see Fig. 3) between 4 and 5 cm. Carefully measure the length, L, from the top of the camber on each anvil. You can also just measure between the vertical surfaces, and calculate L by including the 1.5 mm radius on each anvil. Record this value in the table. What is the uncertainty?

6. Measure the diameter of the three rod samples. Use Eqn. (3) to calculate the Area Moment of Inertia, and record in the table.

Procedure: "Seating" the Test Sample and Setting Pre-Load

1. Note: Before you can test the sample, you must complete the steps below. The procedure is written for using a test sample (see Fig. 1), but you should also use this method when performing a compliance calibration of the Materials Tester using the Calibration Rod. In this procedure, you load and unload the system several times to remove all the slack and properly "seat" the test sample, in addition to introducing a small pre-load to the system.

2. In PASCO Capstone, create a graph of Force vs. Position. Also create a Digits display and select Force.

3. Place the aluminum test sample across the support anvils. Turn the crank counter-clockwise until the load anvil is almost touching the sample.

4. Click on Record. Continue cranking counter-clockwise, watching the graph and digits display. Run the applied force up to about 50 N, and then decrease it back to about 10 to 20 N. Try not to let the force go completely to zero.

   Note: Do not exceed the Yield Strength of the material! If the sample is permanently bent, you went too far. For these samples, you only need to apply a max force of 100 to 200 N.

5. While still recording data, run the force up and down again. 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.

6. With data still being recorded, reduce the force back down to about 20 N, and then Click on Stop. Do NOT change the crank position. Since the sensor will auto-zero next time you record data, this puts a 20 N pre-load on the sample which results in better data. You should use this same method when performing any compliance calibration of the Materials Tester.

Procedure: Taking Data

1. In PASCO Capstone, create a table and create two user-entered data sets: The first set is called L and has units of m; the second set is called F/Δx and has units of N/m.

2. Click on Record. Turn the crank counter-clockwise, bending the sample. Increase the force to about 100 N.

3. Click on Stop. The data should be fairly linear. It is ok if there is a slight curvature at the beginning or end, but if there is not a straight section in the middle, you probably have something wrong.

4. To take another run of data, turn the crank clockwise to completely remove the tension. Repeat **all** the steps from the previous page to properly re-seat the sample, then take another run of data.

5. In PASCO Capstone, create a table and create a user-entered data set called slope and has units of N/m.

6. Use a linear curve fit to find the slope. This is the stiffness (F/Δx) of the length of beam you are testing. Take multiple runs and record your values in the slope table to get a good average value. Enter your final average value for F/Δx in the table.

7. Repeat for the brass and steel samples. Rename your runs to reflect which material you were using.

Analysis: Elastic Modulus

1. Add a column to the table to the right of the F/Δx column for the calculation for "E", the Flexural Elastic Modulus. Open the calculator window to view this calculation, and use Equation (3) to confirm that the calculation was done correctly. Note the units.

2. Estimate the uncertainty in your values for E.

3. For your samples, how does the Flexural Modulus compare to Young's Modulus?

4. Increase the Support Anvil spacing to the maximum possible and repeat the process on the previous page for the **steel** rod. Don't forget to measure and record the new value for L.

5. How does changing L affect the stiffness of the sample being tested?

6. How does changing L affect the final value for E?

Questions

1. In theory, if you shorten the length of the test sample by a factor of 2, what happens to the stiffness of that section?

2. In theory, if you increase the radius of the test sample by a factor of 2, what happens to the stiffness of that section.

3. For both these cases, what would happen to E?

Bend Testing Beams

Equipment

Qty	Description	Part Number
1	Materials Testing Apparatus	ME-8236
1	Bending Accessory	ME-8237
1	Structures Flat Beam	ME-6987
1	Structures Thin I Beam	ME-7012
1	Calipers	SE-8710

Introduction

A Three-Point Bend Test is performed on plastic beams as shown in Figure 1. As a downward force (F) is applied in the middle of the beam, the flex (Δx) is recorded. The ratio (F/Δx) is the effective stiffness of the length of beam being tested, and is measured directly from the slope of the F vs. Δx graph. The Flexural Elastic Modulus for the material is then calculated.

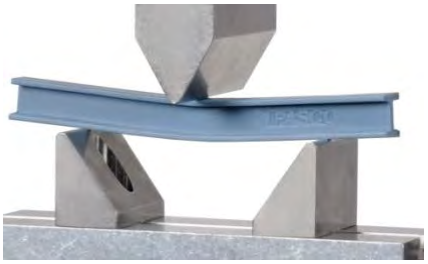


Figure 1: Three-Point Bend Test

This experiment uses the ABS plastic beams from the PASCO Structures System. You will need to cut each beam to a length of about 10 cm, so that it will fit between the drive screws.

Theory

A test sample is supported by two anvils separated by a length, L, as shown in Figure 2. A load, F, is applied in the middle, an equal distance from each anvil, and the resulting flexure (Δx) is measured. The ratio of F/Δx is the stiffness of the sample, and depends on the length, L. It also depends on the cross-section shape and area of the sample, as well as the material.

If "E" is the Flexural Elastic Modulus for the material, and "I" is the Area Moment of Inertia for the sample, then

$$\frac{F}{\Delta x} = \frac{48\,IE}{L^3} \qquad (1)$$

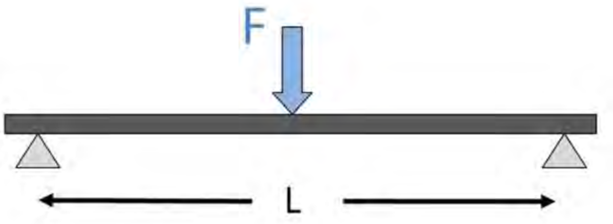


Figure 2: Three-Point Bending Test

Solving for E, yields

$$E = \frac{F\,L^3}{\Delta x\;48\,I} \qquad (2)$$

where the ratio F/Δx is determined from the slope of the force vs. flexure graph. The Area Moment of Inertia depends on the shape of the cross section of the sample. For a beam with a rectangular cross-section

$$I_{\text{rectangle}} = \frac{1}{12} bh^3 \qquad (3)$$

Figure 3: Beam with rectangular cross-section

where A is the cross-sectional area, and the height, h, is the dimension that is parallel to the applied force. The base, b, is the dimension perpendicular to the applied force, as shown in Figure 4, and since A=bh, Eqn. (3) can be written as

$$I_{\text{rectangle}} = \frac{1}{12} bh^3 \qquad (4)$$

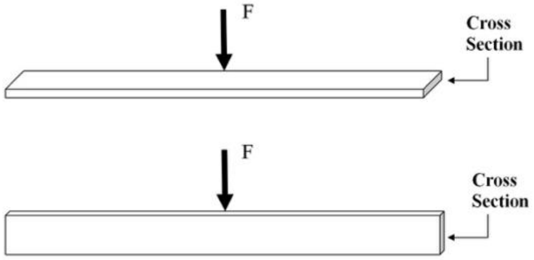


Figure 4: Two ways to bend a beam

Thus, in Figure 3, b > h for the upper picture with the beam being bent in the "weak" direction, and b < h in the lower picture with the beam being bent in the "strong" direction.

Note. The Flexural Modulus is technically not the same as Young's Modulus. Bend testing involves both tensile and compressive stresses, and for some materials these moduli are different.

Setup: Installing Bending Accessory

Note: You will probably want to make a Compliance Calibration (using the Calibration Rod) before attaching the Bending Accessory! A max force of 500 N is adequate for this experiment.

1. Connect the Materials Testing Machine to a computer using a USB interface. In the PASCO Capstone calculator, create the following calculation:

   `E=(10^-9)*[F/Δx (N/m)]*[L (m)]³/(48*[I (m⁴)])` with units of GPa

2. The ME-8237 Bending Accessory consists of two major parts: The upper load anvil and the lower base with the two support anvils. The load anvil sticks up through the cross-head and is held in place by the knurled cap nut.

3. The base (for the support anvils) fastens directly to the load cell using the two cap screws as shown in Figure 5.

4. Each anvil is captured by the T-slot in the base, and their separation should always be adjusted so that the Load Anvil is centered between them. Use calipers to make this alignment as accurate as possible. Set the anvil spacing between 5 and 6 cm.

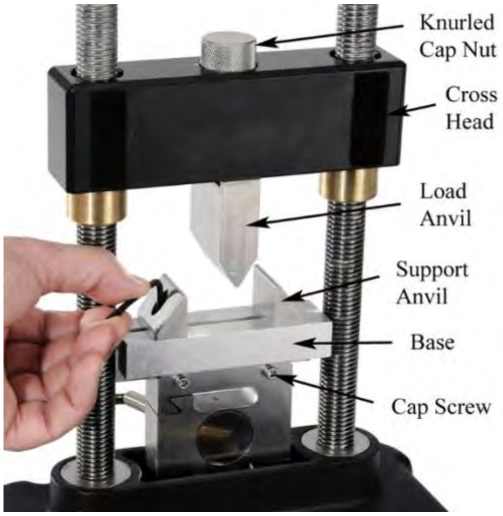


Figure 5: Setting Anvil Spacing

Procedure: Rectangular Beam

1. In PASCO Capstone, create a table and create two user-entered data sets: The first set is called I and has units of m^4; the second set is called Graph Slope and has units of N/m.

2. Carefully measure the length, L, from the top of the camber on each anvil. You can also just measure between the vertical surfaces and calculate L by including the 1.5 mm radius on each anvil. Record this value. What is the uncertainty?

3. Cut a 10 cm length of rectangular cross-section beam from the ME-6987 Structures Flat Beam set. You can use either the F4 or 3X4 beams from that set. The shorter 2X3 beam (also in that set) has a smaller cross-section and should be saved for further investigations later.

4. Measure the cross-sectional dimensions of the beam and record them.

5. Use Eqn. (4) to calculate the Area Moment of Inertia, for the beam being bent in both the strong and weak directions. Record these in the table.

6. Place the beam across the support anvils as shown in Figure 6. This will bend the beam in the strong direction. Turn the crank counter-clockwise until the load anvil is just touching the sample.

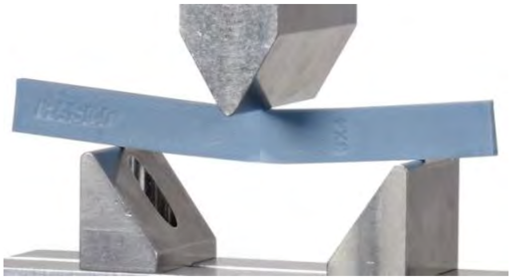


Figure 6: Bending Rectangular Beam

Procedure: "Seating" the Test Sample and Setting Pre-Load

1. Your data will look better if you use the normal procedure to "seat" the test sample. If you use a pre-load, do not go over 5 N, as the forces required to bend the beams in this lab are quite low. Remember that you should use the same method for testing your sample, as you used when performing a compliance calibration with the Calibration Rod.

2. Do not exceed the Yield Strength of the material! If the sample is permanently bent, you went too far. For these samples, you only need to apply a maximum force of 100 to 200 N.

3. In PASCO Capstone, create a graph of Force vs. Position. Also create a Digits display and select Force.

Procedure: Taking Data

1. The sample rate is set to 5 Hz, but you can change this if needed. In general, a slower rate gives smoother (less noisy) data.

2. Click on Record. Turn the crank counter-clockwise, bending the sample. Increase the force to about 100 N.

3. Click on Stop. The data should be fairly linear. It is OK if there is a slight curvature at the beginning or end, but if there is not a straight section in the middle, you probably have something wrong.

4. To take another run of data, turn the crank clockwise to completely remove the tension.

5. In PASCO Capstone, create a table and create a user-entered data set called slope and has units of N/m.

6. Use a linear curve fit to find the slope. This is the stiffness (F/Δx) of the length of beam you are testing. Take multiple runs and record your values in the slope table to get a good average value. Enter your final average value for F/Δx (Graph Slope) in the table.

Analysis: Elastic Modulus

1. Use Eqn. (2) or the PASCO Capstone calculator to calculate "E", the Flexural Elastic Modulus. What are the units?

2. Estimate the uncertainty in your values for E.

3. How does the Flexural Modulus compare to the value found in reference data tables for Young's Modulus for ABS plastic?

4. Use Eqn. (1) and your value for the modulus to predict the stiffness of the beam bent in the "weak" direction.

5. Repeat the Procedure to test the beam in the “weak” direction. Compare to your predicted value.

6. For this beam, what is the stiffness ratio for strong/weak?

7. In theory, if you shorten the length of the test sample by a factor of 2, what happens to the stiffness of that section?

8. For this case, what would happen to the calculated value for E?

Procedure: Testing the I Beam

1. In PASCO Capstone, create a table and create two user-entered data sets: The first set is called Beam Moment and has units of m^4; the second set is called $F/\Delta x$ and has units of N/m.

2. The **I** Beam can also be bent in two directions, as shown in Figure 7. Measure the cross-sectional dimensions of your beam and use Eqn. (3) to calculate the Area Moment of Inertia for the beam bending in the weak direction. You can assume that the cross-section is composed of three rectangles.

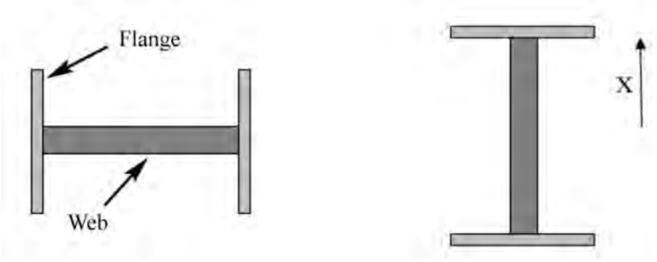


Figure 7: Weak and Strong Directions

3. Calculate the Area Moment of Inertia for the beam bending in the "strong" direction. You can once again assume that the cross-section is composed of three rectangles, but you must include an additional term for the flanges. Eqn. (3) gives the Moment of Inertia (I_{cm}) of the area about its own centroidal axis, but you must calculate the moment about the center of the entire beam. Using the parallel axis theorem,

$$I = I_{cm} + A\text{x}^2 \qquad (5)$$

   where x is measured from the center of the I Beam, to the center of the flange as shown in Figure 7. Record your values for the Area Moment of Inertias in the table.

4. Use Eqn. (1) and your value for the modulus to predict the stiffness of the beam bent in both directions. Record in the table.

5. Follow the same procedure as before to record Force vs. Position data for the I beam bent in both the strong and weak directions.

6. Use a linear curve fit to find the slope (stiffness) of the beam and compare to the predicted (calculated) values.

7. For this beam, what is the stiffness ratio for strong/weak?

8. Which beam is stronger, your rectangular beam or the I beam? Calculate the cross-sectional area for each. What do you conclude?

9. For further study, there are other beams you can measure. The ME-7011 polycarbonate beams have the same cross-section as the ME-7012, and the other I-beams in the Structures System are made of ABS but have a bigger cross-section.

Tensile Testing Beams

Equipment

Qty	Description	Part Number
1	Materials Testing Apparatus	ME-8236
1	Structures Beam Adapter	ME-8242
1	Structures Flat Beam	ME-6987
1	Structures Thin I-Beam	ME-7012
1	Calipers	SE-8710

Introduction

A Tensile Test is performed on plastic beams as shown in Figure 1. Young's Modulus for the material is measured using the dimensions of the beam and the slope of the Force vs. Elongation graph. By testing beams with different cross-sectional shapes, the student investigates the effect (if any) of shape on the outcome of the experiment.

For this lab, you will need an F4 (rectangular cross-section beam) from the ME-6987 Structures Flat Beam Set, and a T4 (I-Beam) from the ME-7012 Structures Thin I-Beam Set. Other beams that can be used in this lab include the shorter T3 (included in the ME-7012) and the ME-7011 Polycarbonate Thin I-Beams.

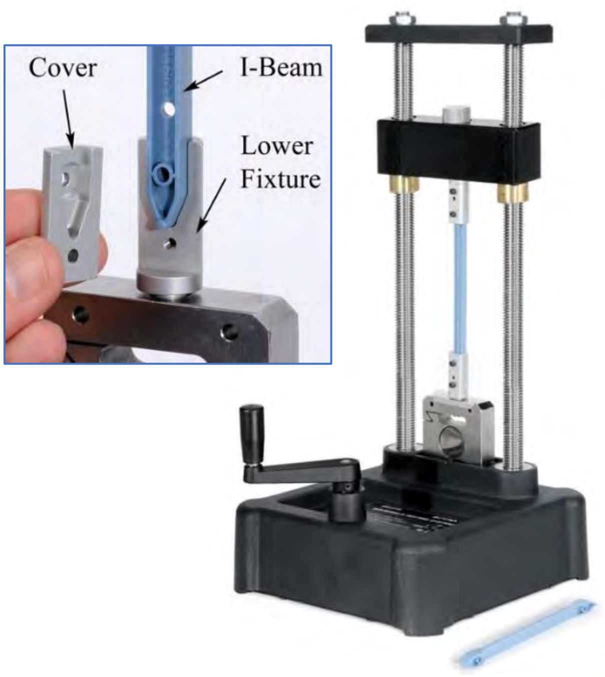


Figure 1: Tensile testing plastic beams

Theory

A force (F) is applied to a beam of length (L) and cross-sectional area (A), causing an elongation of Δx. The stress (F/A), is related to the strain ($\Delta x/L$), by

$$\text{Stress} = \text{E} * \text{Strain}$$

where "E" is the Young's Modulus for the beam material. Combining the above and solving for the force yields

$$F = (AE/L)\,\Delta x \qquad (1)$$

Thus, the slope of a graph of F vs. Δx is AE/L, and

$$E = L(\text{slope})/A \qquad (2)$$

Setup

Note: You will probably want to make a Compliance Calibration (using the Calibration Rod) before attaching the Structures Beam Adapter! A max force of 1000 N is adequate for this experiment. Do not use a preload over 20 N.

1. Connect the Materials Testing Machine to a computer using a USB interface. In the PASCO Capstone calculator, create the following calculation, add your values for the constants as you determine their values:

   E=(10⁻⁹)*[Slope (F/Δx) (N/m)]*[Length (m)]/[Area (m²)] with units of GPa

2. In PASCO Capstone, create a table and create two user-entered data sets: The first set is called Area and has units of m^2; the second set is called Length and has units of m.

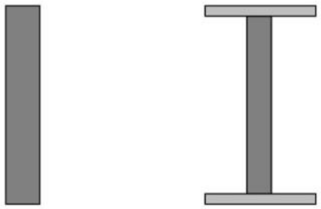


Figure 2: Cross-section of beams

3. For both your beams (see Fig. 2), calculate the cross-sectional area. The beams were designed to have about the same area, so if the values are not close, check your calculations! Enter your values into the table.

4. Measure the effective length (L) of your beams. Note that "L" should only be the part of the beam that is actually stretching. For the rectangular (F4) beam, this would be only the thinner portion, not the thicker ends. The **I**-beam (T4) stretches mostly in the area between the two bolt holes. Enter your values into the table. What is the uncertainty in your measurement?

5. The ME-8242 Structures Beam Adapter consists of two major parts: The upper fixture with the longer thread sticks up through the cross-head and is held in place by the knurled cap nut. The lower fixture screws directly into the Load Cell as shown in the inset to Figure 1.

6. Install the T4 I-beam and secure the covers on both fixtures using the cap screws.

7. In PASCO Capstone, create a graph display of Force vs. Position, a Digits display of Force, and a Meter display of Speed.

Procedure: Taking Data

1. Note: Your data will look better if you use the normal procedure to "seat" the test sample. If you use a pre-load, do not go over 20 N, as the forces required in this lab are quite low. Remember that you should use the same method for testing your sample, as you used when performing a Compliance Calibration with the Calibration Rod. Note the cross-head speed display. Try and use about the same speed for both your samples.

2. Click on Record. Turn the crank clockwise, stretching the sample. Increase the force to between 200 N to 300 N. You are interested in the linear portion of the graph: You do not need to destroy the sample!

3. Click on Stop. The data should be fairly linear. It is all right if there is a slight curvature at the beginning or end, but if there is not a straight section in the middle, you probably have something wrong.

4. Once you have a good run of data, replace the beam with the rectangular cross-section (F4) beam, and repeat.

Analysis: Young's Modulus

1. In PASCO Capstone, add two user-entered data sets to the table: The first set is called Slope (F/Δx) and has units of N/m; the second set is called E and has units of GPa.

2. Use a linear curve fit to find the slope (F/Δx) for both your beams and record in the table.

3. The calculation for "E" is being done automatically. Use Eqn. (2) to verify that this is calculated correctly. What are the units?

4. Use your uncertainty in the measurement of "L" to estimate the uncertainty in your final answer. Do you get about the same value of "E" for both beams? Why might one beam be better than the other?

5. For further study, there are other beams that can be used in this lab, including the shorter T3 (included in the ME-7012) and the ME-7011 Polycarbonate Thin **I**-Beams. You can also test the beams to destruction, but you will probably need to make a new Compliance Calibration.

Column Buckling and Slenderness Ratio

Equipment

Qty	Description	Part #
1	Materials Testing Machine	ME-8236
1	Structures Beam Adapter	ME-8242
1	Structures Truss Set	ME-6993
1	Calipers	SE-8710

Introduction

Three different length plastic I-beams are tested under compression to investigate their method of failure. The way in which a member fails (buckling or not) is determined by its Slenderness Ratio, and this ratio is calculated for each beam. Topics covered also include the Radius of Gyration and the Area Moment of Inertia.

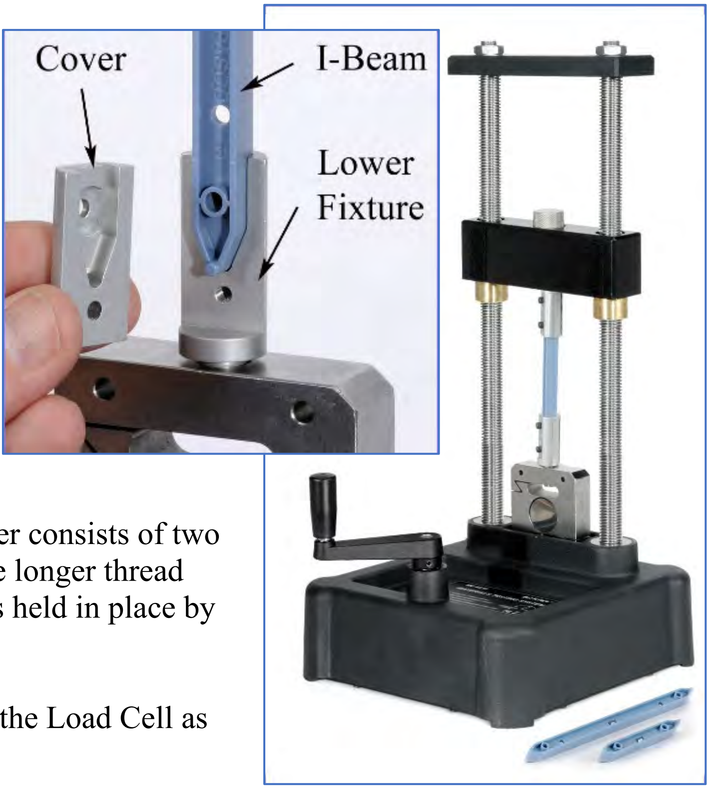


Figure 1: Compressing I-beams

This experiment uses the #2, #3 and #4 ABS plastic beams from the PASCO Structures System.

Setup

1. Note: A Compliance Calibration is NOT needed for this experiment.

2. The ME-8242 Structures Beam Adapter consists of two major parts: The upper fixture with the longer thread sticks up through the cross-head and is held in place by the knurled cap nut.

3. The lower fixture screws directly into the Load Cell as shown in the inset to Figure 1.

4. Install the shortest beam (#2) and secure the covers on both fixtures using the cap screws.

Theory of Columns

If a very short bar is compressed, it will shorten. If it is compressed even more, past the elastic limit of the material, it bulges until it is deformed into a flat disk. However, if the bar being compressed is sufficiently long (and straight), something different can happen. At first, as the load is increased, the bar shortens as before. But as the force increases, a critical value is reached, and the beam suddenly buckles. In general, if a compression member is long enough to fail by buckling, it is called a column; otherwise it is simply a compression member.

For a given material, the way in which a member fails (buckling or not) is determined by its Slenderness Ratio; the length (L) of the member divided by the Radius of Gyration (k) of the members cross-sectional area.

$$k = \frac{I}{A} \qquad (1)$$

where **I** is the Moment of Inertia, and A is the area of the cross-section.

For a beam member with a rectangular cross-section

$$I_{\text{rectangle}} = \left(\frac{1}{12}\right) Ah^2 \qquad (2)$$

where the height, h, is the dimension that is parallel to the direction in which the beam will buckle. The base, b, is the dimension perpendicular to this direction (see Fig. 2), and since A=bh, Eqn. (2) can be written as

$$I_{\text{rectangle}} = \left(\frac{1}{12}\right) bh^3 \qquad (3)$$

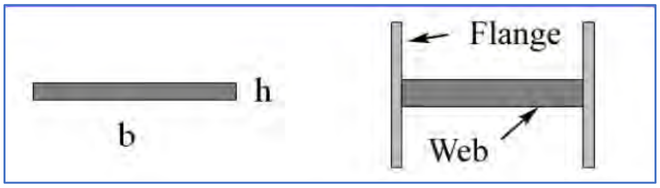


Figure 2: Beam Cross-section

Calculating Radius of Gyration, k:

1. Measure the cross-sectional dimensions of your beam, and use Eqn. (3) to calculate the Moment of Inertia. You can assume that the cross-section is composed of three rectangles, and that all the beams are the same.

2. Calculate the cross-sectional area of the beam.

3. Use Eqn. (1) to calculate Radius of Gyration of the beam.

Taking Data

1. Connect the Materials Testing Machine to a computer using a USB interface. In PASCO Capstone, create a graph of Force vs. Position.

2. With the #2 beam installed, measure the distance between the top of the lower fixture to the bottom of the upper fixture. This is the effective length, L, of the beam: The amount that is free to bend.

3. Click on Record and turn the crank counter-clockwise, compressing the beam. Continue until the beam fails, and click on Stop.

4. Observe the manner in which the beam fails. Does it buckle in the "weaker" direction for the beam? Note that because of the holes in the beam, it will fail no matter what its length is. But does it fail in compression along the sides of the hole, or does it suddenly buckle sideways and fail as a column?

5. Repeat the above procedure for the #3 and then #4 beams.

Analysis

1. For each beam, calculate the Slenderness Ratio, the effective length (L) of the member divided by its Radius of Gyration (k).

   Slenderness Ratio = L / k

2. What was the mode of failure for each beam? Which beam is truly a column?

Column Buckling and the Euler Column Equation

Equipment

Qty	Description	Part #
1	Materials Testing Machine	ME-8236
1	Structures Beam Adapter	ME-8242
1	Structures Flat Beam	ME-6987
1	Structures Thin I-Beam	ME-7012
1	Calipers	SE-8710

For this lab, you will need an F4 (rectangular cross-section beam) from the ME-6987 Structures Flat Beam Set, and a T4 (I-Beam) from the ME-7012 Structures Thin I-Beam Set. Other beams that can be used in this lab include the shorter T3 (included in the ME-7012) and the ME-7011 Polycarbonate Thin I-Beams.

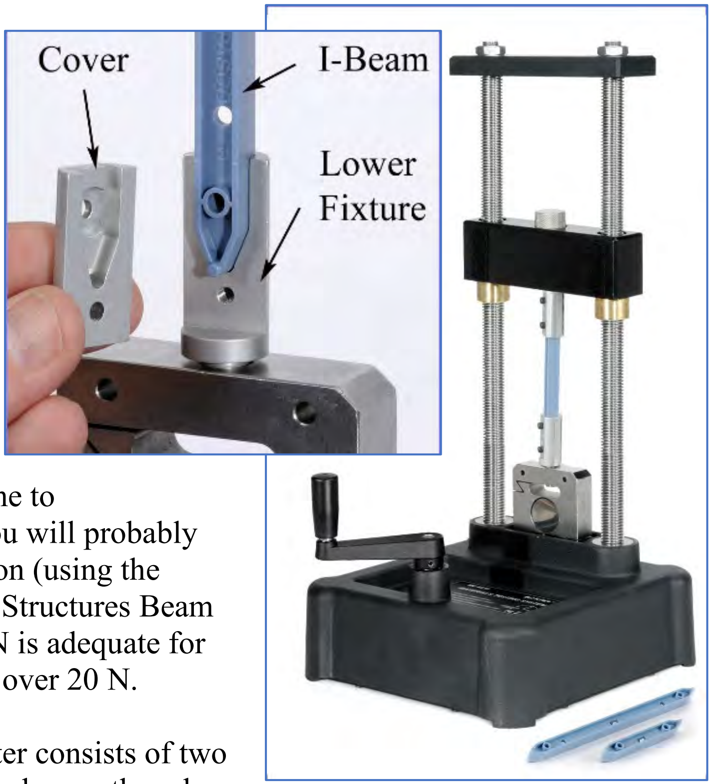


Figure 1: Compressing I-beams

Introduction

The Euler Column Equation predicts the maximum compressional force applied to a column before it buckles. This value depends on the length of the column, its Area Moment of Inertia, and Young's Modulus for the material.

Setup

1. Connect the Materials Testing Machine to a computer using a USB interface. You will probably want to make a Compliance Calibration (using the Calibration Rod) before attaching the Structures Beam Adapter! A maximum force of 1000 N is adequate for this experiment. Do not use a preload over 20 N.

2. The ME-8242 Structures Beam Adapter consists of two major parts: The upper fixture with the longer thread sticks up through the cross-head and is held in place by the knurled cap nut. The lower fixture screws directly into the load cell as shown in the inset to Figure 1. Do NOT install a beam at this time!

Theory

Euler Column Equation

When a compressive force is applied to a long straight column, it will elastically compress until a critical force (F_{crit}) is reached, and at this point the column will suddenly buckle. The relationship between this critical load and the column material and geometry is called the Euler Column Equation.

$$F_{crit} = \frac{4\pi^2 EI}{L^2} \qquad (1)$$

where "E" is Young's Modulus for the material, "I" is the Area Moment of Inertia of the cross-section, and "L" is the effective length of the column. The constant in front is dependent on the end conditions for the column: For the case where both ends are fixed (as in this lab), the constant is 4.

Area Moment of Inertia

For a beam member with a rectangular cross-section

$$I_{rectangle} = \frac{1}{12} A h^2 \qquad (2)$$

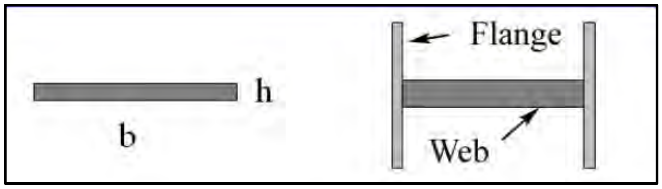


Figure 2: I-beam Cross-section

where the height (h) is the dimension that is parallel to the direction in which the beam will buckle. The base (b) is the dimension perpendicular to this direction (see Fig. 2), and since A=bh, Eqn. (2) can be written as

$$I_{rectangle} = \frac{1}{12} b h^3 \qquad (3)$$

Procedure

1. Measure the cross-sectional dimensions of both your beams.

2. For both beams, use Eqn. (3) to calculate the Moment of Inertia for the direction in which the beam will buckle. For the I-beam, you can assume that the cross-section is composed of three rectangles.

3. Install the T4 I-beam, and secure the covers on both fixtures using the cap screws as shown in Figure 1.

4. With the beam installed, measure the distance between the top of the lower fixture to the bottom of the upper fixture. This is the effective length (L) of the beam: The amount that is free to bend.

Taking Data

Note. Your data will look better if you use the normal procedure to "seat" the test sample. If you use a pre-load, do not go over 20 N, as the forces required in this lab are quite low. Remember that you should use the same method for testing your sample, as you used when performing a Compliance Calibration with the Calibration Rod. Note the cross-head speed display below. Try and use about the same speed for both your samples.

1. In PASCO Capstone, create a graph of Force vs. Position and select the speed on a meter.

2. Click on Record. Turn the crank counter-clockwise, compressing the sample. Continue until the beam buckles.

3. Click on Stop. There should be a fairly linear section of data before suddenly buckling. It is OK if there is a slight curvature at the beginning, but if there is not a straight section in the middle, you probably have something wrong.

4. Once you have a good run of data, replace the beam with the rectangular cross-section (F4) beam, and repeat.

Young's Modulus

You can use a standard known value for Young's Modulus (E), but you can also measure this directly from the linear portion of your data. When a column of cross-sectional area (A) is being elastically compressed (before buckling), there is a linear relationship between the applied force (F) and the resulting compression (Δx). The stress (F/A), is related to the strain ($\Delta x/x$), by Stress = E * Strain. Combining, and solving for the force yields

$$F = (AE/x)\,\Delta x$$

Thus, the slope of a graph of F vs. Δx is AE/x, and

$$E = x*(\text{slope})/A \qquad (4)$$

1. For at least one of your beams calculate the cross-sectional area, and measure "x", the length of the beam that is being compressed. For the rectangular (F4) beam, this would be only the thinner portion, not the thicker ends. The **I**-beam (T4) compresses mostly in the area between the two bolt holes. Note that "x" is not necessarily the same as "L".

2. Measure the slope from your graph and calculate "E" using Eqn. (4).

Critical Load

1. Use Eqn. (1) to calculate the theoretical maximum load for both your beams.

2. How do your measured values compare? Would you expect the measured (actual) values to be above or below the theoretical?

3. Both beams have the same Young's Modulus and about the same cross-sectional area. Do they have the same strength?

4. For further study, there are other beams that can be used in this lab, including the shorter T3 (included in the ME-7012) and the ME-7011 Polycarbonate Thin I-Beams.

Column Buckling Tensile Samples

Equipment

Qty	Description	Part Number
1	Materials Testing Apparatus	ME-8236
1	Brass Tensile Sample	ME-8232
1	Aluminum Tensile Sample	ME-8231
1	Calipers	SE-8710

Introduction

The Euler Column Equation predicts the maximum compressional force applied to a column before it buckles. This value depends on the length of the column, its Area Moment of Inertia, and Young's Modulus for the material. In this lab, you will column buckle the machined metal samples that are normally tested in tension. The predicted value for the critical buckling force is compared to the actual values.

Theory

Euler Column Equation

When a compressive force is applied to a long straight column, it will elastically compress until a critical force (F_{crit}) is reached, and at this point the column will suddenly buckle. The relationship between this critical load and the column material and geometry is called the Euler Column Equation.

$$F_{crit} = 4\frac{\pi^2 EI}{L^2} \qquad (1)$$

where "E" is Young's Modulus for the material, "I" is the Area Moment of Inertia of the cross-section, and "L" is the effective length of the column. The constant in front is dependent on the end conditions for the column: For the case where both ends are fixed (as in this lab), the constant is 4.

Area Moment of Inertia

For a round beam member with radius (r), the Area Moment of Inertia is

$$I_{rod} = (1/4)\pi r^4 \qquad (2)$$

Written by Jon Hanks

Young's Modulus

When a column of cross-sectional area (A) is being elastically compressed (before buckling), there is a linear relationship between the applied force (F) and the resulting compression (Δx). The stress (F/A), is related to the strain ($\Delta x/L$), by Stress = E * Strain. Combining, and solving for the force yields

$$F = (AE/L)\Delta x$$

Thus, the slope of a graph of F vs. Δx is AE/L, and

$$E = L * (\text{slope})/A \qquad (3)$$

Setup

Note: You will probably want to make a Compliance Calibration (using the Calibration Rod (with compression nut) before attaching the Tensile Sample! A maximum force of 5000 N is adequate for this experiment.

1. Connect the Materials Testing Machine to a computer using a USB interface. In PASCO Capstone, create a graph of Force vs. Position. Also create a Digits display and select Force.
2. Measure the diameter of the thin part of the sample and calculate the cross-sectional area (A).
3. Measure the effective length (L) of the sample. This is the amount that is free to bend.
4. Use Eqn. (2) to calculate the Area Moment of Inertia for the sample.
5. Install the Brass Tensile Sample as shown in Figure 1. Note the use of the compression nut from the Calibration Rod.
6. Note: Your data will look better if you use the normal procedure to "seat" the test sample. Remember that you should use the same method for testing your sample as you used when performing a Compliance Calibration with the Calibration Rod.

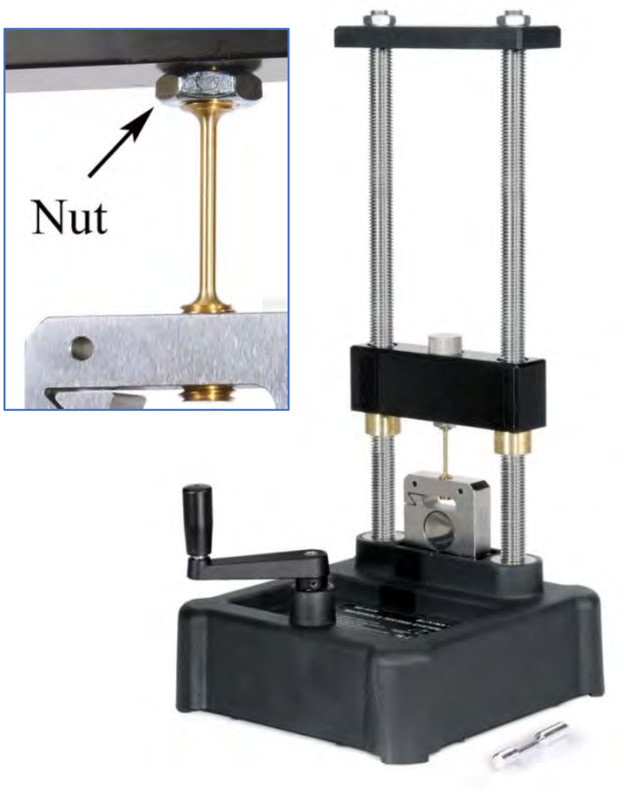


Figure 1: Column Buckling "Tensile" Samples

Procedure: Force vs. Position

1. Click on Record. Turn the crank counter-clockwise, compressing the sample. Continue until the beam buckles.

2. Click on Stop. There should be a fairly linear section of data before suddenly buckling. It is all right if there is a slight curvature at the beginning, but if there is not a straight section in the middle, you probably have something wrong.

3. Measure the slope from your graph and calculate "E" using Eqn. (3).

4. Replace the brass beam with the aluminum beam, and repeat.

Analysis: Critical Load

1. Use Eqn. (1) to calculate the theoretical maximum load for both your samples.

2. How do your measured values compare? Would you expect the measured (actual) values to be above or below the theoretical?

Compression Testing Cast Beams

Equipment

Qty	Description	Part Number
1	Materials Testing Apparatus	ME-8236
1	Structures Beam Adapter	ME-8242
1	Structures Cast Beams Set	ME-6983
1	Calipers	SE-8710

Introduction

Plaster of Paris (hydrated calcium sulphate) is a brittle solid with fracture properties similar to cement, and can be used to model the load behavior of concrete beams. In this lab, cast beams are tested to destruction under compression. Quantities measured include Young's Modulus and the Compressive Strength for the material.

You will need Plaster of Paris, and utensils like cups and spoons to mix the plaster. The beams need to be made before lab to allow them to cure. Typical cure times are from several hours to several days.

Setup

Note: You will probably want to make a Compliance Calibration (using the Calibration Rod) before attaching the Beam Accessory! A maximum force of 3000 N is adequate for this experiment.

1. Snap the rebar into the mold (see Figure 1). Pour all of the beams from the same batch. Tap the sides to remove bubbles.

2. Make several beams so that you can see how much the beams vary in strength. You can also allow some of the beams to dry for a longer time, to observe the effect of curing time on strength.

3. Do not remove the beam from the mold until the plaster is dry. Allow a cure time of at least a few hours.

4. Connect the Materials Testing Machine to a computer using a USB interface. In the PASCO Capstone calculator, create the following calculations, add your values for the constants as you determine values:

Stress=(10^{-6})*[Force (N)]/A	with units of MPa
A=	with units of m^2
Strain=[Position (m)]/L	unitless
L=	with units of m

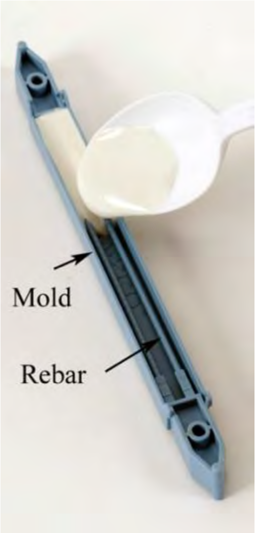


Figure 1: Making Cast Beams

5. In PASCO Capstone, create a graph of Force vs. Position. Also create a Digits display and select Force.

6. Measure the cross-sectional dimensions of the cast beam and calculate the area. Edit the value for the area in line #2 of the calculator.

7. Confirm that the calculation for stress is correct. What are the units?

8. Measure the length of the cast portion of the beam and edit the value for the length in line #4 of the calculator.

9. Confirm that the calculation for strain is correct. What are the units?

10. The ME-8242 Structures Beam Adapter consists of two major parts: The upper fixture with the longer thread sticks up through the cross-head and is held in place by the knurled cap nut. The lower fixture screws directly into the Load Cell as shown in Figure 2.

Figure 2: Compression Testing Cast Beams

11. Install one of your cast beams and secure the covers on both fixtures using the cap screws.

12. When you are testing the beam, it is important that you use the plastic safety shields as shown in Figure 3. They attach with Velcro® directly to the cross-head and are easily installed and removed. *Caution: Never touch the test sample when it is under load!*

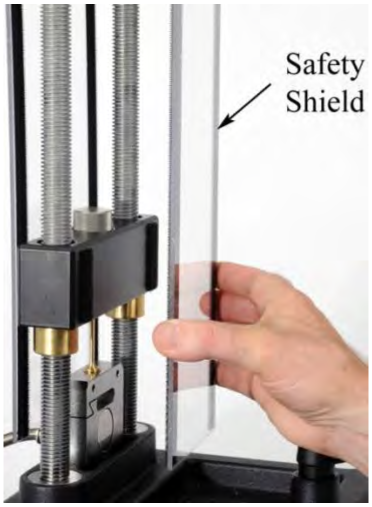


Figure 3: Use Safety Shields!

Procedure: Taking Data

1. Note: Your data will look better if you use the normal procedure to "seat" the test sample. Remember that you should use the same method for testing your sample, as you used when performing a Compliance Calibration with the Calibration Rod.

2. Make sure the plastic Safety Shields are in place.

3. Click on Record. Turn the crank counter-clockwise, compressing the sample. Continue until the beam fails, then click on Stop.

4. Repeat the procedure for the other beams to be tested.

Analysis: Stress and Strain

1. In PASCO Capstone, create a graph of Stress vs. Strain.

2. Use a linear Curve Fit to find the slope (Young's Modulus) for the beam material and compare to values listed in reference data tables.

3. Measure the Compressive Strength (Max Stress) for the beam material and compare to values listed in reference data tables.

4. If you measured more than one beam, discuss the variations you found.

5. For Further Study: Test beams from the same batch over a period of several days to see the effect of curing time. Also try making beams with a fairly dry mixture and compare to beams made with a very wet mixture. Try testing one of your beams under tension!

Bend Testing Cast Beams

Equipment

Qty	Description	Part Number
1	Materials Testing Apparatus	ME-8236
1	Bending Accessory	ME-8237
1	Structures Cast Beam	ME-6983
1	Calipers	SE-8710

Introduction

A Three-Point Bend Test is performed on Plaster of Paris cast beams as shown in Figure 1. As a downward force (F) is applied in the middle of the beam, the flex (Δx) is recorded. The ratio (F/Δx) is measured directly from the slope of the F vs. Δx graph, and is used to calculate the Flexural Elastic Modulus for the material. The maximum load force at fracture is measured, and is used to calculate the Modulus of Rupture.

This experiment uses the Cast Beams from the PASCO Structures System. You will need Plaster of Paris, and utensils like cups and spoons to mix the plaster. The beams need to be made before lab to allow them to cure. Typical cure times are from several hours to several days. You will also need a hacksaw to cut each beam to a length of about 10 cm, so they will fit between the drive screws.

Figure 1: Three-point Bend Test

Theory

Flexural Elastic Modulus

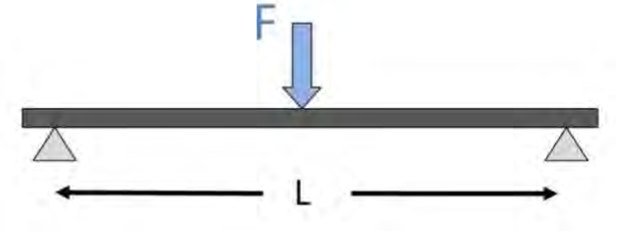


Figure 2: Three-Point Bending Test

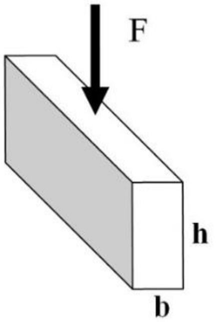
A test sample is supported by two anvils separated by a length (L) as shown in Figure 2. A load (F) is applied in the middle, an equal distance from each anvil, and the resulting flexure (Δx) is measured. The ratio ($F/\Delta x$) is the stiffness of the sample, and depends on the length. It also depends on the shape and area of the sample cross-section, as well as the material.

If "E" is the Flexural Elastic Modulus for the material, and "I" is the Area Moment of Inertia for the sample, then

$$\frac{F}{\Delta x} = \frac{48\,IE}{L^3} \qquad (1)$$

The Area Moment of Inertia depends on the cross-sectional shape and area of the sample. For a beam with a rectangular cross-section

$$I_{\text{rectangle}} = \frac{1}{12} bh^3 \qquad (2)$$



where the height (h) is the dimension that is parallel to the applied force, and the base (b) is the dimension perpendicular to the applied force, as shown in Figure 3. Combining, yields

$$\frac{F}{\Delta x} = \frac{4bh^3E}{L^3} \qquad (3)$$

Modulus of Rupture

The bending stress at a perpendicular distance (y) from the neutral axis is given by the Flexure Formula,

$$\text{Bending Stress} = \frac{My}{I} \qquad (4)$$

For a rectangular beam the bending moment (M) at mid-span is 1/4 FL, and the perpendicular distance (y) is h/2. Combining with Eqn. (4) and Eqn. (2), yields

$$\text{Bending Stress} = \frac{3FL}{2bh^2} \qquad (5)$$

When the applied force (F) is the load force at fracture, then Eqn. (5) calculates the Maximum Bending Stress, which is also called the Modulus of Rupture.

Setup: Making Cast Beams

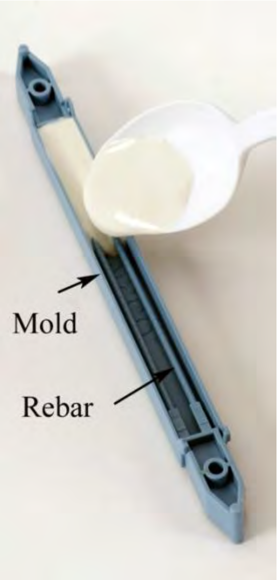


Figure 3: Making Cast Beams

1. Snap the rebar into the mold (see Figure 3). Pour all of the beams from the same batch. Tap the sides to remove bubbles.

2. Make several beams so that you can see how much the beams vary in strength. You can also allow some of the beams to dry for a longer time, to observe the effect of curing time on strength.

3. Do not remove the beam from the mold until the plaster is dry. Allow a cure time of at least a few hours.

Setup: Installing Bending Accessory

You will probably want to make a Compliance Calibration (using the Calibration Rod) before attaching the Bending Accessory! A max force of 500 N is adequate for this experiment.

1. The ME-8237 Bending Accessory consists of two major parts: The upper load anvil and the lower base with the two support anvils. The load anvil sticks up through the cross-head and is held in place by the knurled cap nut. The base (for the support anvils) fastens directly to the load cell using the two cap screws as shown in Figure 1.

2. Each anvil is captured by the T-slot in the base, and their separation should always be adjusted so that the Load Anvil is centered between them. Use calipers to make this alignment as accurate as possible. Set the anvil spacing between 5 and 6 cm. Carefully measure the length (L) from the top of the camber on each anvil. You can also just measure between the vertical surfaces, and calculate L by including the 1.5 mm radius on each anvil. Record this value.

3. Cut the plastic ends from your cast beam, leaving a 9 to 10 cm length.

4. Measure the cross-sectional dimensions of the beam and record.

5. Place the beam across the support anvils as shown in Figure 1. Turn the crank counter-clockwise until the load anvil is ***almost*** touching the sample.

Procedure: Taking Data

1. Connect the Materials Testing Machine to a computer using a USB interface. In PASCO Capstone, create a table and create two user-entered data sets: The first set is called Slope and has units of N/m; the second set is called Max Force and has units of N.

2. In PASCO Capstone, create a graph of Force vs. Position. Also create a Digits display and select Force.

3. Note: Your data will look better if you use the normal procedure to "seat" the test sample, but do NOT use a preload over 5 N: The force needed to fracture the beams can be less than 100 N!

4. Make sure the plastic Safety Shields are in place.

5. Click on Record and turn the crank counter-clockwise. Continue until the beam fractures, then click on Stop. It is not necessary to completely destroy the beam.

6. Repeat the procedure for the other beams to be tested.

7. For each of your beams, use a linear curve fit to find the slope. This is the stiffness ($F/\Delta x$) of the length of beam you are testing. Record your values in the table.

8. For each of your beams, measure and record the maximum load force at fracture.

Analysis: Flexural Elastic Modulus

1. In PASCO Capstone, add two user-entered data sets to the table: The first set is called E and has units of GPa; the second set is called Rupture Mod and has units of MPa.

2. For each of your beams, use Eqn. (3) to calculate the Flexural Elastic Modulus (E) and record in the table.

3. For each of your beams, use Eqn. (5) to calculate the Modulus of Rupture and record in the table.

4. How much variation is there in your beams? Compare your average values to those listed in reference data tables.

Procedure: Further Study

1. Re-test a fractured beam, this time taking it to destruction. What differences do you see?

2. Make a new set of beams, but do not test all your beams at the same time. Perform the testing over several hours, or even over several days, to observe the effect cure time has on the strength.

3. Test new beams using a different anvil spacing. What effect would you expect this to have on your calculations of the Flexural Elastic Modulus and the Modulus of Rupture.

4. Test new beams bending them in the "weak" direction. What effect would you expect this to have on your calculations of the Flexural Elastic Modulus and the Modulus of Rupture.

5. Remove one or both of the rebar before casting the beam.

Shear Testing Round Rod

Equipment

Qty	Description	Part Number
1	Materials Testing Apparatus	ME-8236
1	Materials Shear Accessory	ME-8239
1	Materials Shear Samples	ME-8240
1	Calipers	SE-8710

Introduction

A single-shear test is performed on 1/8 inch diameter metal rods. The maximum force needed to shear the rod is measured, and this is used to calculate the Shear Strength of the material. Tested materials include 1018 steel, 360 brass, and 2024-T4 aluminum.

The Materials Shear Accessory consists of two hardened metal blocks, held together permanently by two screws. The back piece (with the label) fastens directly to the load cell, and the front piece slides vertically to provide the shearing action. The shearing force is applied by the cross-head, which is in direct contact with the front block. Note that the knurled cap nut is not needed for this experiment.

Note: A Compliance Calibration is NOT needed for this experiment.

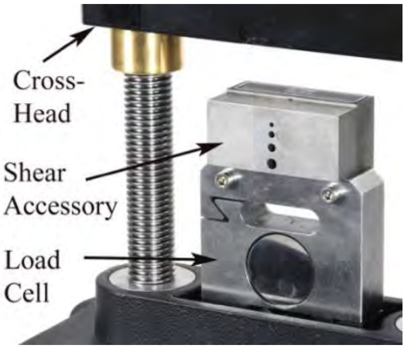


Figure 1: Shear Accessory

Setup

1. Connect the Materials Testing Machine to a computer using a USB interface. In the PASCO Capstone calculator, create the following calculations, add your values for the constant as you determine its value:

   Stress=10^{-6} *([Force (N)]+100)/(π*(Dia/2)^2) with units of MPa
   Dia= with units of m

2. In PASCO Capstone, create a graph of Force vs. Position. Also create a Digits display and select Force.

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

4. Fasten the Shear Accessory to the load cell using the two silver cap screws as shown in Figure 1.

Figure 2: Lift Shear

5. Lift the front block to the top of its travel as shown in Figure 2.

6. Slide the rod into the appropriately sized hole as shown in Figure 3. You may have to slightly lower the shear block for the holes to line up.

7. Slide the rod completely through, leaving only a small amount sticking out the front, as shown in Figure 4. The small tab sticking out makes it easier to remove once it is sheared, but you don't want to use any more material than you have too!

8. Note. When the rod is properly inserted, the front shear block will be higher than the back. When the cross-head is lowered, it should press on the front block that is free to move, NOT the back block that is fastened to the load cell.

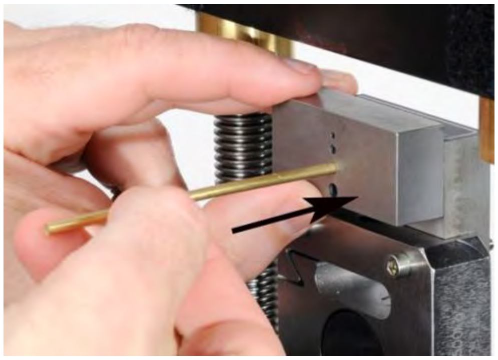


Figure 3: Insert Rod

Procedure: Taking Data

1. Note: Your data will look better if you use the normal procedure to "seat" the test sample. A Compliance Calibration on position is NOT needed for this experiment: Only the force data is used.

2. Make sure the plastic Safety Shield is in place on the front of the tester.

3. Turn the crank counter-clockwise, moving the cross-head downward until it is just touching the front shear block.

4. Click on Record and turn the crank counter-clockwise.

5. Continue cranking until the rod shears, then click on Stop.

6. Repeat the procedure for the other rods.

7. Open the Data Summary and re-name your runs with the type of material.

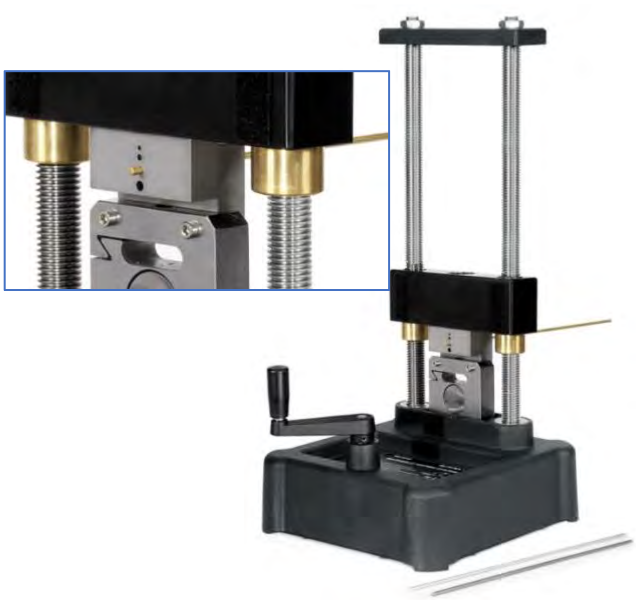


Figure 4: Shear Testing Round Rod

Analysis: Stress and Strain

1. In PASCO Capstone, create a graph of Stress vs. Strain.
2. Confirm that the equation for Stress in the calculator is correct. What are the units?
3. Measure the Shear Strength (max stress) for each of your materials, and record.
4. How do your values compare to those listed in reference data tables for the materials?

Strength of Materials

Equipment

Qty	Description	Part Number
1	Materials Testing Apparatus	ME-8236
1	Materials Shear Accessory	ME-8239
1	Aluminum Tensile Sample	ME-8231
1	Brass Tensile Sample	ME-8232
1	Annealed Steel Sample	ME-8233
1	Steel Tensile Sample	ME-8243
1	Calipers	SE-8710

Introduction

This lab investigates two ways in which a member can fail: In Tension and in Shear. The strength of a material is often expressed in terms of the maximum stress needed to cause failure. A standard tensile test is performed using the Tensile Samples, and the Tensile Strength (maximum axial stress) is measured. A shear test is then performed (on the same sample), and the Shear Strength (maximum shear stress) is measured. Four metal samples are measured, and the shear/tensile strength ratio is calculated for each.

Tested materials include 1018 steel, annealed 1018 steel, 360 brass, and 2024-T3 aluminum.

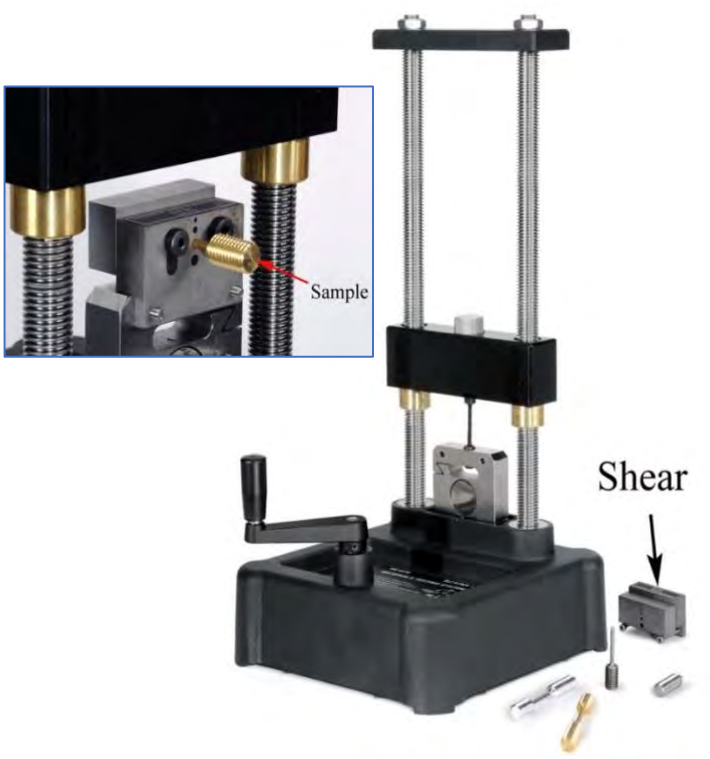


Figure 1: Shear and Tensile Testing

Four different metal Tensile Samples are broken under tension, and the Tensile Strength for each material is measured. A shear test is then performed (see inset to Figure 1) on the broken sample using the Shear Accessory, and the Shear Strength for each material is measured.

Note: A Compliance Calibration is NOT needed for this experiment.

Procedure: Tensile Test

1. Connect the Materials Testing Machine to a computer using a USB interface. In the PASCO Capstone calculator, create the following calculations, add your values for the constant as you determine its value:

Stress=10^{-6} *([Force (N)])/(π*(Dia/2)^2)	with units of MPa
Dia=	with units of m
Ratio=[Shear (MPa)]/[Tensile (MPa)]	unitless

2. In PASCO Capstone, create a graph of Force vs. Position. Also create a Digits display and select Force.

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. Install the first test sample. The end with the shorter threads should be screwed directly into the load cell. Secure the top with the knurled cap nut.

5. Your data will look better if you use the normal procedure to "seat" the test sample. A Compliance Calibration on position is NOT needed for this experiment: Only the force data is used.

6. Click on Record, and turn the crank clockwise, stretching the sample.

7. Continue cranking until the sample beaks, then click on Stop.

8. Open the Data Summary to rename your run.

9. Repeat the above procedure for your other samples.

10. Note: In this lab, both tension and compression are used. To make the data positive for this graph, use a QuickCalc on both axes to change the sign. In the second half of the lab, the data is already positive, and the sign change is not needed.

11. In PASCO Capstone, create a graph of Stress vs. Position. Use QuickCalc to make the data positive.

12. Confirm that the equation for Stress in the calculator is correct. What are the units?

13. In PASCO Capstone, create a table with user-entered data set called Tensile Strength that has units of MPa.

14. For each sample measure the Tensile Strength (maximum Stress). Use the Coordinates Tool or the Statistics feature in the graph tool palette.

15. Record your values in the table.

16. Is the Tensile Strength a property of the specific sample, or of the ***material*** being tested?

Setup: Shear Test

Note: When testing the samples under tension, they usually break in two uneven lengths. You will want to use the longer of the two pieces to test in shear. However, if your sample broke in the middle of the machined part, both pieces may be too short to use. A minimum of about 20 mm is needed to reach through the shear. If needed, break another sample before installing the Shear Accessory. You can also force the sample to break at a specific point by making a small notch with a file.

1. Check the diameter of the sample to see if it has changed.

2. The Materials Shear Accessory consists of two hardened metal blocks, held together permanently by the two black screws (see Fig. 3). The stationary block (with the label) fastens directly to the load cell using the two silver cap screws as shown in Figure 2.

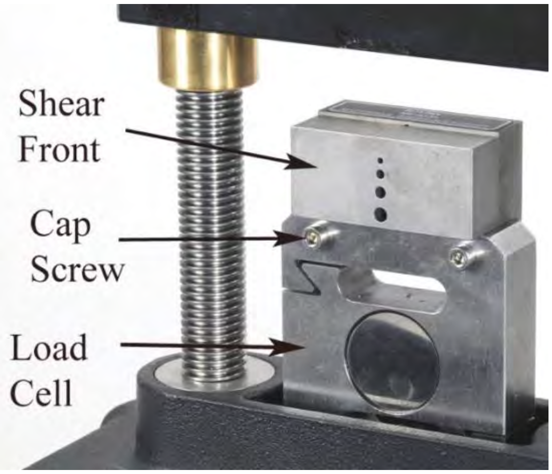


Figure 2: Front view of Shear Accessory

3. The movable block slides vertically to provide the shearing action. Lift this block to the top of its travel as shown in Figure 3 and insert the sample into the appropriately sized hole from the ***BACK*** of the Shear as shown. If you insert the sample from the front, it can get in the way as you turn the crank!

   Note: When the rod is properly inserted, the front (movable) shear block will be higher than the back. When the cross-head is lowered, it should press on the front block that is free to move, NOT the back block that is fastened to the load-cell.

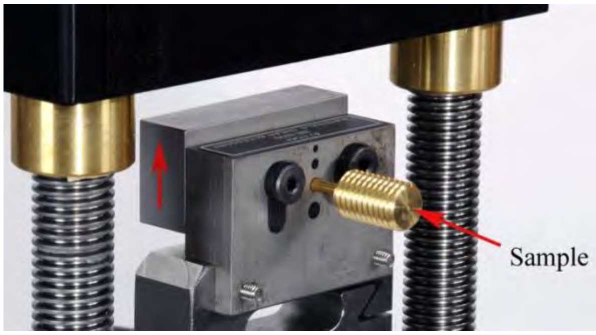


Figure 3: Back view of Shear Accessory

4. Turn the crank counter-clockwise, moving the cross-head downward until it is almost touching the front shear block. The shearing force is applied by the cross-head, which is in direct contact with the front block. Note that the knurled cap nut is not needed for this part of the experiment.

5. Make sure the plastic Safety Shield is in place on the front of the tester.

Procedure: Shear Test

Note: Your data will look better if you use the normal procedure to "seat" the test sample. A Compliance Calibration on position is NOT needed for this experiment: Only the force data is used.

1. Turn the crank counter-clockwise, moving the cross-head downward until it is just touching the front shear block.

2. Click on Record and turn the crank counter-clockwise.

3. Continue cranking until the rod shears, then click on Stop.

4. Repeat the procedure for the other samples.

5. Open the Data Summary and re-name your runs to show the material used.

6. In PASCO Capstone, add a user-entered data set called Shear Strength that has units of MPa to the table.

7. Measure the Shear Strength (max stress) for each of your materials, and record in the table.

8. How do your values for Tensile Strength and Shear Strength compare to those listed in reference data tables for the materials?

Analysis: Tensile and Shear Strength

1. Confirm that the Shear Strength / Tensile Strength ratio is being calculated correctly for your data.
2. There is much written on the theoretical relationship between the Shear Strength and Tensile Strength for a material. For example, the von Mises criterion predicts this ratio to be $1/\sqrt{3} \approx 0.6$. Compare your values to that predicted by theory.

Analysis: For Further Study

1. This lab focused on the ultimate breaking strength of the material, but a similar lab can be done looking at the ***yield*** strengths.

2. When investigating strength of materials, a common property often measured is the Young's Modulus. This can be measured directly from a stress/strain graph of the sample in tension, but you would need to perform a Compliance Calibration on position.

3. You can also measure the Young's Modulus of the test sample by performing a Three Point Bend Test. You should do this test first (before the Tensile and Shear tests) and be very careful not to go past the elastic limit of the material.

Photoelasticity

Equipment

Qty	Description	Part Number
1	Materials Testing Apparatus	ME-8236
1	Bending Accessory	ME-8237
1	Four-Point Load Anvil	ME-8249
1	Photoelasticity Accessory	ME-8241
1	Calipers	SE-8710
1	Bright White Light	
1	Webcam	

Introduction

Photoelasticity is used to determine the stress distribution in birefringent plastics, such as polycarbonate. This experiment uses the clear polycarbonate beams from the PASCO Structures System. Two crossed polarizing sheets are placed in front of, and behind, the clear beam. When illuminated from behind (see Fig. 1.) by a bright white light, fringes become visible. A compact fluorescent lamp works well.

Note: You will need to cut each beam to a length of about 10 cm, so that it will fit between the drive screws.

Figure 1: Viewing stress lines

Setup: Installing Bending Accessory

Note: The ME-8237 Bending Accessory consists of the upper (single point) load anvil and the lower base with the two support anvils. In this lab, you will use the ME-8249 Load Anvil instead of the single point anvil supplied with the ME-8237.

1. The Four-Point Load Anvil sticks up through the cross-head and is held in place by the knurled cap nut. The base (for the support anvils) fastens directly to the load cell using the two cap screws. See Figure 2.

Figure 2: Four-Point Load Anvil

2. Adjust the lower anvil spacing to be three times the upper anvil spacing. Use calipers to make this alignment as accurate as possible and center the upper anvil between the lower.

3. Place the beam across the support anvils as shown in Figure 2.

4. The two polarizing sheets Velcro® directly onto the cross-head, as shown in Figure 3. Note that the orientation of the Velcro is such that the two polarizers are crossed.

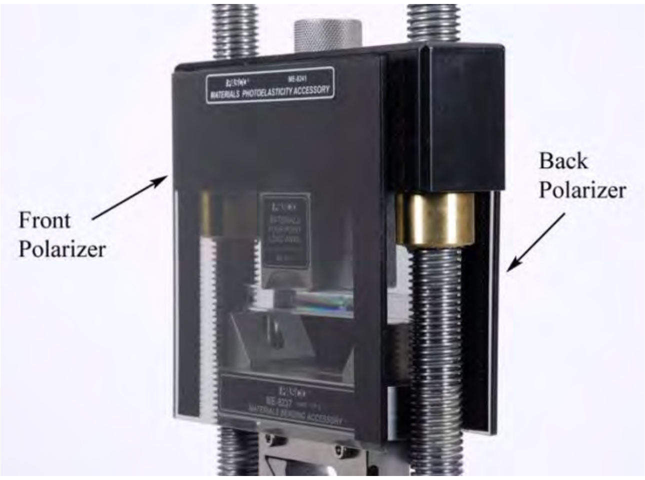


Figure 3: Crossed Polarizers

5. Position the white light source to illuminate the sample. Position the webcam on the opposite side from the light source.

Procedure: Fringes

1. Connect the Materials Testing Machine to a computer using a USB interface. In PASCO Capstone, create a table and create two user-entered data sets: The first set is called n and is unitless; the second set is called F and has units of N.

2. In PASCO Capstone, create a graph of Force vs. Position. Also create a Digits display and select Force. Create a Movie Display and connect the webcam (see Capstone Help for instructions). Also create a graph of the user-entered sets F versus n.

3. Position the anvil so that it is just touching the top of the beam.

4. Start recording, and take data up to 200 N.

5. Play back the video and watch the fringes appear at the point of anvil contact (area of high stress) and move towards the middle (area of low stress). If there are fringes present before loading, this pre-stress is from the molding process, and those fringes should be ignored.

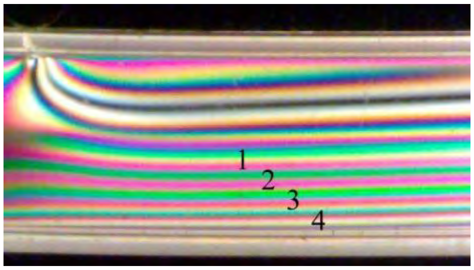


Figure 4: Example Showing Four Fringes

6. Record the force as each new fringe appears.

7. What is the relationship between the applied force and the number of fringes, n?

8. Is it linear?

Procedure: Further Study

1. Try annealing the beam to eliminate the pre-stress lines.

2. Replace the ME-8249 Load Anvil with the single point anvil supplied with the ME-8237 and perform three-point bending.

3. Use only one lower anvil positioned directly below the upper anvil. The fringes formed with this type of diametric compression are easier to analyze.

4. Drill a hole in the beam or cut a notch in the edge.

5. Try rotating the polarizers. Keep them crossed at 90°, and rotate together. Investigate the difference between isochromatic and isoclinic.

Four-Point Bending

Introduction

A Four-Point Bend Test is performed on plastic beams as shown in Figure 1. As a downward force (F) is applied in the middle of the beam, the flex (Δx) is recorded. The ratio (F/Δx) is the effective stiffness of the length of beam being tested, and is measured directly from the slope of the F vs. Δx graph. The Flexural Elastic Modulus for the material is then calculated.

This experiment uses the ABS plastic beams from the PASCO Structures System. You will need to cut each beam to a length of 10 cm, so that it will fit between the drive screws.

Equipment

Qty	Description	Part #
1	Materials Testing Apparatus	ME-8236
1	Bending Accessory	ME-8237
1	Structures Flat Beams	ME-6987
1	Four-Point Load Anvil	ME-8249
1	Calipers	SE-8710

Figure 1: Four-Point Bending Test

Note: The ME-8237 Bending Accessory consists of the upper (single point) load anvil and the lower base with the two support anvils. In this lab, you will use the ME-8249 Four-Point Load Anvil instead of the single point anvil supplied with the ME-8237.

Four-Point Bend Test

A test sample is supported by two anvils separated by a length "L", as shown in Figure 2. A load is applied by two load anvils, each set in an equal distance "a" from the lower load anvils. These distances are measured from the anvils, **NOT** the end of the beam. A total load "F" is applied (½ F by each load anvil) to the test sample, and the resulting **anvil** deflection "Δx" is measured. The ratio "F/Δx" is the stiffness of the sample, and depends on the length "L" and the load anvil spacing "L_o". It also depends on the shape and area of the sample cross-section, as well as the material.

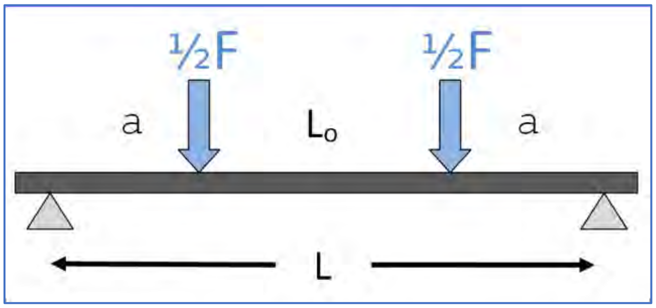


Figure 2: Four-Point Bending Test

If "E" is the Flexural Elastic Modulus for the material, and "**I**" is the Area Moment of Inertia for the sample, then

$$\frac{F}{\Delta x} = \frac{12\ EI}{a^3(3L-4a)} \qquad (1)$$

Since L=2a + L_o, the distance "a" can be eliminated, and Eqn. (1) written as

$$\frac{F}{\Delta x} = \frac{48\ EI}{(L+L_o)(L-L_o)^2} \qquad (2)$$

The spacing for the anvils could be any amount, but two commonly used standards are $L=2L_o$ and $L=3L_o$. For these two special cases, Eqn. (2) becomes

$$\frac{F}{\Delta x} = \frac{16\ EI}{L_o^3} \qquad (3) \qquad \text{for } L=2L_o$$

and

$$\frac{F}{\Delta x} = \frac{3\ EI}{L_o^3} \qquad (4) \qquad \text{for } L=3L_o$$

Note: "Δx" is the deflection of the load anvils, **NOT** the maximum deflection of the test sample at its center.

The Area Moment of Inertia depends on the cross-sectional shape and area of the sample. For a beam with a rectangular cross-section

$$I_{rectangle} = \left(\frac{1}{12}\right) Ah^2 \qquad (5)$$

where "A" is the cross-sectional area, and the height "h" is the dimension that is parallel to the applied force. The base "b" is the dimension perpendicular to the applied force, and since A=bh, Eqn. (5) can be written as

$$I_{rectangle} = \left(\frac{1}{12}\right) bh^3 \qquad (6)$$

Setup

1. Connect the Four-Point Load Anvil to the cross-head using the knurled cap nut as shown in Figure 1.

2. The base (for the support anvils) fastens directly to the load cell using the two cap screws as shown in Figure 3.

Figure 3: Bending Rectangular Beam

3. Carefully measure the spacing, L_o, of the upper fixed anvil. This measurement is from the top of the camber on each anvil, or you can measure between the vertical surfaces, and calculate L_o by including the 1.5 mm radius on each anvil. Record this value below.

4. Adjust the spacing "L" of the lower support anvils so that $L=2L_o$. Make sure that the upper anvil is centered between the two lower anvils. Use calipers to make this alignment as accurate as possible.

5. Cut a 10 cm length of rectangular cross-section beam from the ME-6987 Structures Flat Beam set. You can use either the F4 or 3X4 beams from that set. The shorter 2X3 beam (also in that set) has a smaller cross-section and should be saved for further investigations, later.

6. Measure the cross-sectional dimensions of the beam and record.

7. Use Eqn. (6) to calculate the Area Moment of Inertia for the beam and record.

8. Place the beam across the support anvils as shown in Figure 3. Turn the crank counter-clockwise until the load anvil is just touching the sample.

Taking Data

1. Connect the Materials Testing Machine to a computer using a USB interface. In PASCO Capstone, create a graph of Force vs. Position. Also create a Digits display and select Force. Note: Set the sample rate to 5 Hz, but you can change this if needed. In general, a slower rate gives smoother (less noisy) data.

2. Click on Record. Turn the crank counter-clockwise, bending the sample. Increase the force to about 300 N.

3. Click on Stop. The data should be fairly linear. It is OK if there is a slight curvature at the beginning or end, but if there is not a straight section in the middle, you probably have something wrong.

4. Use a linear curve fit to find the slope. This is the stiffness ($F/\Delta x$) of the length of beam you are testing. Take multiple runs to get a good average value.

Analysis

1. Use Eqn. (4) to calculate "E", the Flexural Elastic Modulus. Estimate the uncertainty in your value for E.

2. How does the Flexural Modulus compare to the value found in reference data tables for Young's Modulus for ABS plastic?

For Further Study

1. Bend the sample in the weak direction. Does this affect the value for E?

2. Try different spacing for the anvils. $L = 3L_o$. Does this affect the value for E?

3. Try a smaller cross-section. Use the 2x3 beam from the ME-6987 Structures Flat Beam set.

4. Try a different shape, such as the ME-7012 Thin I-beam

5. Try a different material, such as the ME-7011 Polycarbonate Beams or the ME-6983 Cast Beams.

Compression Testing

Equipment

Qty	Description	Part Number
1	Materials Testing Apparatus	ME-8236
1	Compression Accessory	ME-8247
1	Calipers	SE-8710

Introduction

A compression test is performed on a polyethylene cylinder. Quantities measured include Young's Modulus and the Yield Strength for the material.

Setup

1. Connect the Materials Testing Machine to a computer using a USB interface. In the PASCO Capstone calculator, create the following calculations, add your values for the constants as you determine their values:

Stress=10^{-9} *[Force (N)]/(π*(Dia/2)^2)	with units of MPa
Dia=	with units of m
Strain=[Position (m)]/L	unitless
L=	with units of mm

2. In PASCO Capstone, create a graph display of Force vs. Position, a Digits display of Force, and a graph display of Stress vs. Strain.
3. Part #1 of the Compression Accessory (with the shorter screw) fastens directly into the load cell as shown in Figure 1.
4. Part #2 fastens to the cross-head using the knurled cap nut.

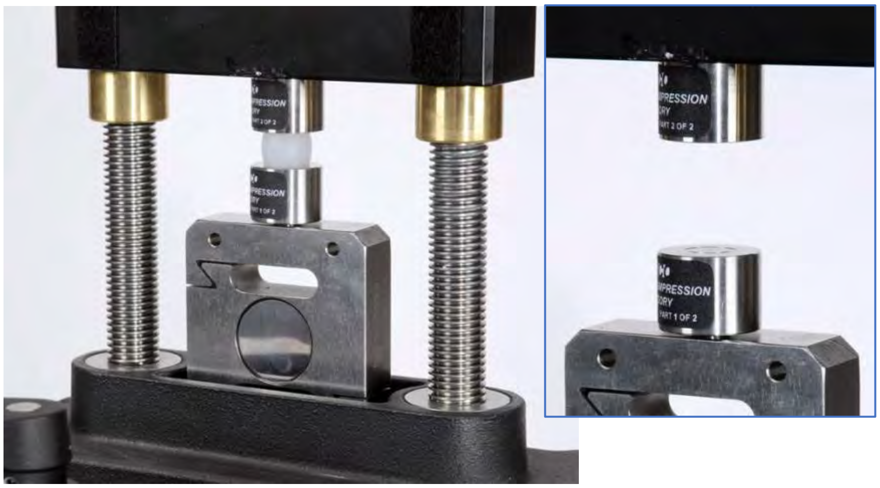


Figure 1: Compression Testing

Procedure

1. Use calipers to measure the diameter of the sample. Edit the value for diameter in line #2 of the calculator.
2. Measure the length of the sample and edit the value in line #4 of the calculator.
3. Place sample on the platform, using the circle to center the sample.
4. Install the safety shield.
5. Turn the crank counter-clockwise until the load anvil is just touching the sample.
6. Click on Record. Turn the crank counter-clockwise, compressing the sample.
7. Continue until the force reaches 5000 N.

Analysis

1. Label the following areas of your graph: Elastic, Yield Point, Non-elastic/Plastic Deformation, Geometric Deformation.
2. Use a curve fit to measure Young's Modulus for your sample and compare to expected values.
3. Measure the Yield Strength for your sample and compare to expected values.
4. For further study: Perform a compression test on some other material. Sidewalk chalk works great!

Figure 2: Sidewalk Chalk