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Young's Modulus

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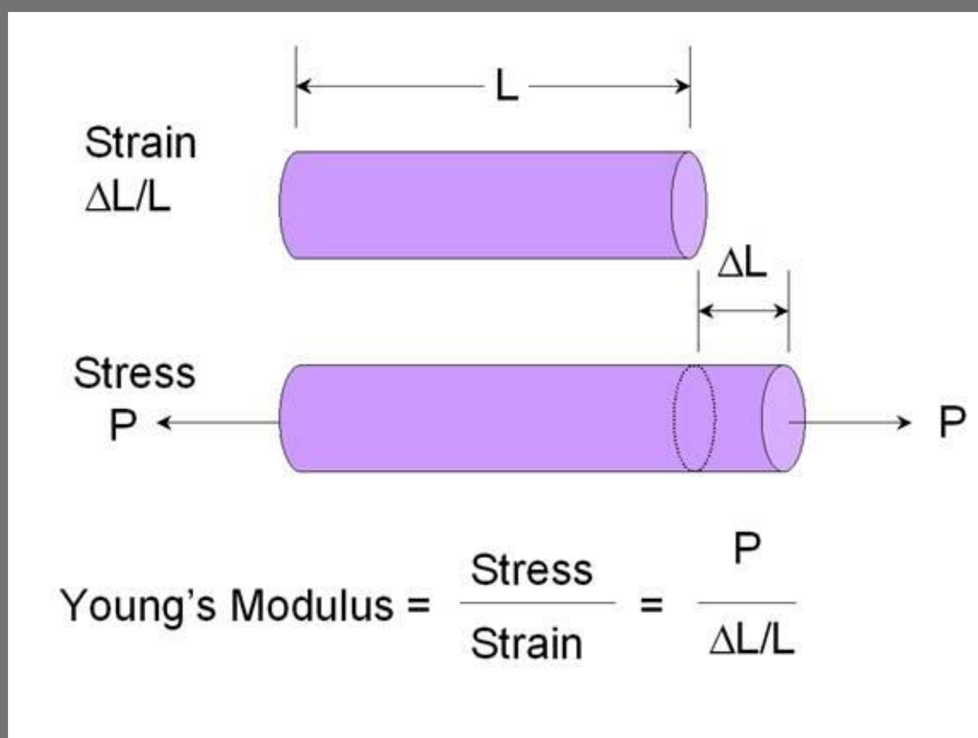
PHYS 107



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Abstract

The purpose of this lab is to determine the value of Young's Modulus for a known coupon (strip) of substance using a stress/strain apparatus and Data Studio. By using the apparatus (see figure 1) with the Data Studio software, we find the displacement due to the rotation of the rotary wheel, and the force that is put onto the force sensor. With these variables, a stress vs. strain graph can be shown to be linear. The slope of this line is our Young's Modulus value (see Appendix C for sample calculations).If this experiment is done correctly; the result should be within a 5% error of the theoretical value. This is seen valid because our result with the plastic substance was found to be 2.21 GPa, and the theoretical value is 2.3 GPa (see works cited). The percent error (see Appendix C) was found to be ±3.9%. This is within the 5% error range and thus validates the process.

Introduction & Discussion

In most applications and example problems used in physics courses, objects are assumed to be rigid for the purpose of simplification. Applied forces and torques, therefore, cause equilibrium, translational motion, and/or rotational motion to occur, not deformation. Personal experience, however, tells us differently. When rigid materials have great forces acting on them, permanent deformation takes place. Car crashes are a common example. Stories of buildings and bridges collapsing under pressure are less common, but they do occur.

Engineers need to be extremely aware of the properties of the materials that they use in their designs. When subject to a particular *stress*, or force per unit area, materials will respond with a particular *strain*, or deformation. If the stress is small enough, the material will return to its original shape after the stress is removed, exhibiting its elasticity. If the stress is greater, the material may be incapable of returning to its original shape, causing it to be permanently deformed. At some even greater value of stress, the material will break or fracture. The particular values of stress that cause these three situations differ for every material. Knowing these values, however, is very important.

The quantity for stress can be defined as follows:

Equation 1

$$\text{stress} = \frac{F}{A}$$

where *F* is the force applied and *A* is the cross-sectional area of the material (See Figure 1). Notice that the standard units of stress are [N/m^2].

The quantity strain can be defined as follows:

Equation 2

$$\text{strain} = \frac{\Delta L}{L}$$

where *L* is the original length of the material, and ΔL is the change in length that results after the stress is applied (See Figure 1). Notice that strain is a unitless quantity.

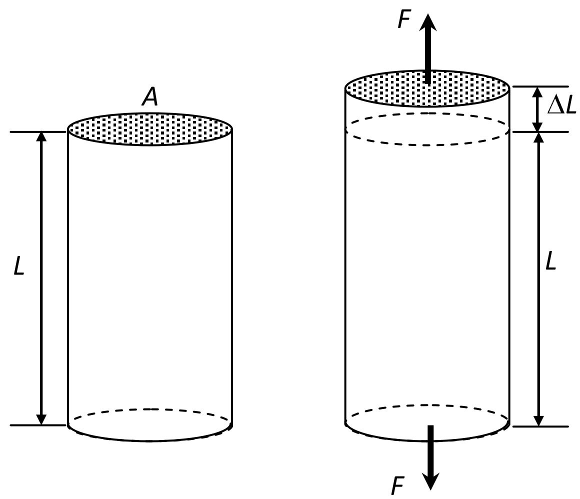
Young's Modulus, *E*, is a constant that describes the ratio of stress to strain for a material experiencing either tensile or compressive stress.

Equation 3

$$E = \frac{stress}{strain}$$

Young's modulus is named after Thomas Young, the 19th century British scientist. However, the concept was developed in 1727 by Leonhard Euler, and the first experiments that used the concept of Young's modulus in its current form were performed by the Italian scientist Giordano Riccati in 1782 who predated Young's work by 25 years.

Figure 1: *For the case of tensile stress on a cylinder or wire, the following diagram illustrates the above variables. For the case of compressive stress, the forces act in the opposite direction, causing the cylinder to compress by a length ΔL.*



Given the fact that ΔL is generally a very small length for most materials, measuring Young's Modulus accurately can be difficult. In this lab we use a Stress/Strain Apparatus, a Rotary Motion Sensor, a Force Sensor, and Data Studio™ Software in order to test a material for Young's Modulus. By putting all the components together (see Figure 1) properly when you turn the rotary wheel, the coupon will undergo strain. Data studio will record the displacement and the force that is applied. Using these variables, we can find young's modulus using a plotted stress vs. strain graph and the linear best fit line (see Appendix C for sample calculation).The slope of this line is the value for Young's Modulus, assuming that the calibration curve was done correctly and that the coupon does not slip while stretching it.

Procedure

Materials: Stress Strain Apparatus, Calibration Bar, Various Coupons of different substances, Rotary Motion Sensor, Force Sensor, and Data Studio Software. All equipment was provided by PASCO.

<u>Equipment and Software Setup:</u>

1. Make sure that the Stress/Strain Apparatus has been set up as shown in the (figure 1). The pulley belt should be placed in the middle groove on the crankshaft. The Force Sensor and Rotary Motion Sensor should be attached to the base.
2. Connect the Force Sensor to Channel A of GLX interface. Then the GLX should be connected to the computer with the Data Studio Software.
3. Test the orientation of the Rotary Motion sensor by turning the crank clockwise while monitoring data in DataStudio. The displacement should increase. If the displacement is observed to decrease then simply switch the yellow and black plugs in channels 1 and 2.

<u>Calibration:</u>

The following calibration instructions were found using the stress strain apparatus manual (see Works Cited).

During the experiment, as you turn the crank, force will be applied to the test coupon, causing it to stretch. The applied force will also cause the apparatus platform and the Force Sensor to bend. Thus, the displacement measures by the rotary motion sensor will be a combination of the stretching of the coupon and the bending of the apparatus.

The bending of the apparatus is constant for any given force. The deformation can be measured directly by using the calibration bar in place of the test coupon. The calibration bar does not stretch significantly compared with the bending of the apparatus. The goal will be to make a plot of the Displacement versus Force for the calibration bar, in which the displacement is due to the bending of the apparatus. Later, you will subtract this plot from a similar plot made with a test coupon. The resulting plot will be a plot in which the displacement is due only to the stretching of the coupon.

Use the following procedure to acquire Displacement versus Force data for the calibration bar:

- **Mount the calibration bar.** Remove the nuts and clips from the apparatus platform (Figure 2). Turn the crank to adjust the position of the bolts and slip the bolts through the holes in the calibration bar. ***Do NOT replace the nuts when using the calibration bar.***

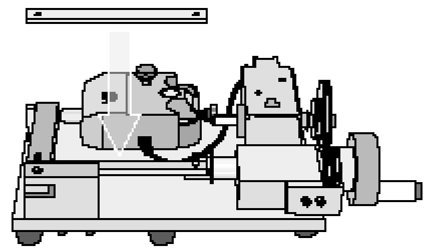


Figure 2

- **Place the lever arm in the starting position.** Turn the crank counter-clockwise and pull the lever arm away from the Force Sensor. (Figure 3)

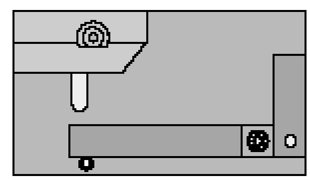


Figure 3

- Plot Position versus Force. Press the Tare button on the Force Sensor. Click the Start button to begin to collect data. Wait until the digits of the experiment clock turn yellow. Turn the crank clockwise. Starting just before the lever arms comes into contact with the Force Sensor, turn the crank very slowly. DataStudio will start recording when the force applied reaches 2.5 N, or 1% of the maximum force to be applied. This can be monitored in the “% Max Force” digits display. Continue to turn the crank until the force reaches 100% of the maximum. At this point, DataStudio will stop recording automatically. ***DO NOT overstrain the force sensor by continuing to turn the crank once data collection has stopped***. Change the name of the data run containing the calibration data to “Cal”.

Renaming a data run can be a bit tricky. Please try the following procedure. Click the run name (e.g.”Run#1”) where it appears on the Data List. Wait about 1 second and then click it again. Enter the new name. A dialog box will appear. Select Yes. (If a window titled “Data Properties” appears, you didn’t wait long enough after the first click; close the window and try again.)

Data Collection – Software Setup:

1. Place the lever in the starting position. Turn the crank counter-clockwise and pull the lever arm away from the Force Sensor.
2. Remove the calibration bar and put on a coupon with the clips and nuts. Tighten both nuts with the wrench. With no force applied to the coupon, as little twist as possible should be visible in the coupon.

3. Press the Tare button on the Force Sensor. Click the Start Button. Turn the crank very slowly. When you are finished collecting data, click stop. If the coupon breaks, it should break in the middle. If it breaks near to one end or the other, it was likely slightly twisted when it was mounted, resulting in a point of higher stress where it broke.

Data Analysis:

To Calculate Young's Modulus, select a region of the data and apply a linear fit to the data selected. The slope of the line is Young's Modulus in units of MPa. Simply convert it to GPa to compare to theoretical value.

Troubleshooting:

1. Make sure all equipment is properly installed. i.e. the apparatus and the data studio software.
2. Do NOT over tighten of under tighten the nuts and bolts.
3. Make sure the coupon has no wrinkles prior to experiment.
4. Make sure the calibration is done correctly according to the Pasco operation manual (see above procedure).
5. Do not over turn the wheel to effect the force sensor.

Data & Results

In this lab, we want to use the provided stress/strain apparatus and data studio software to find the value of young's modulus using the stress vs. strain graph that is produced. The slope of the linear best fit line over a selected area is the value of young's modulus for that substance. The following is a table of the known data collected:

Table 1

	Initial length	Width	Thickness	Area	Young's Modulus Obtained	Young's Modulus Theoretical
Plastic	85.3 mm	.01in	.4 cm	157 mm^2	2.21	2.3

Initial Length, width and thickness comprise the measurements of the coupon prior to the applied forced. Area and Young's Modulus Obtained are a calculated value while the theoretical value is a known quantity. The resulting modulus of the experiment came fairly close to the theoretical value of young's modulus.

Summary

The purpose of this lab is to determine the value of Young's Modulus for a known coupon of a certain substance using a stress/strain apparatus and Data Studio. By plotting a linear best fit line and finding the slope of it on a stress/strain graph we can find the value of young's modulus with a 5% error (see Appendix C). This feat was accomplished and was within the 5% error. The experimental value was found to be 2.21 GPa and has a 4% error compared to the theoretical value of 2.3 GPa. This quantity means that plastic needs about a 2.21 GPa pressure to break is after a significant amount of stretching. Different substances will have different values of course as this value depends on characteristics of the material.

The sources of error can be due to an over tightening of screws and/or inconsistent turning of the wheel which would introduce torsion forces and would lower the fracture point and thus Young's Modulus. Other sources of error may due to a non-uniform substance or improper apparatus setup. Such source of error could make the experimental value become greater or lesser depending on the situation.

Appendix A: Works Cited

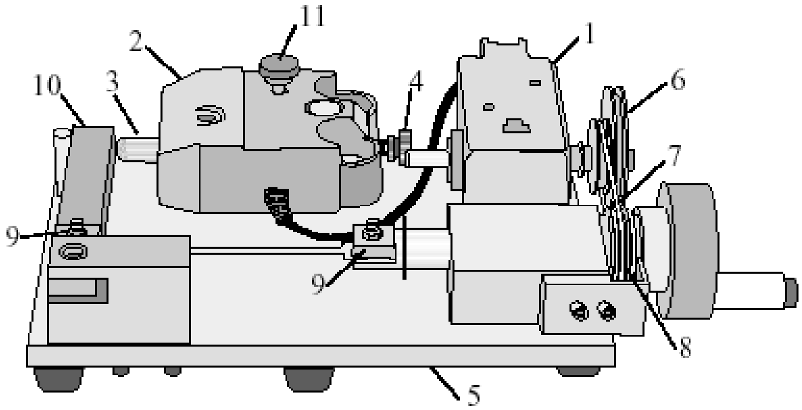
Stress/Strain Apparatus. (2008). Pasco Operation Manual. Retrieved October 13, 2009, from Pasco Online: http://faculty.plattsburgh.edu/kenneth.podolak/phy380/Stress2.pdf

Young’s Modulus. (2009). Young’s Modulus Table. Retrieved October 13, 2009, from Engineeringtoolbox: http://www.engineeringtoolbox.com/young-modulus-d_417.html

Appendix B: Figures

Figure 1

Apparatus Setup



1. Rotary Motion Sensor (RMS)
2. Force Sensor
3. Force Sensor attachment
4. setscrew
5. Stress Strain platform
6. 3-step pulley
7. belt
8. groove
9. coupon clamps
10. lever arm
11. thumbscrew

This is a figure of the stress/strain apparatus and its components. This apparatus is used to help find young's modulus.

Appendix C: Sample Calculations

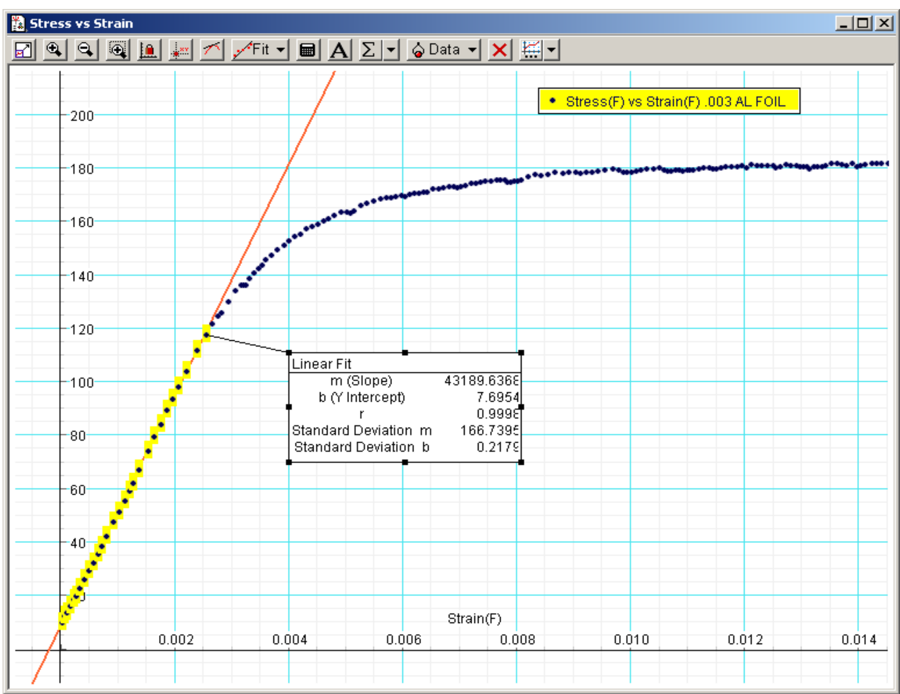
Percent error

% =

Sample Problem

The following image is a stress vs. strain graph of with a linear best fit line plotted on a selected area. The substance used was aluminum with a thickness of .003. The slope of the line was found to be 43189.636. This value is also the value of young's modulus in MPa. So when convert it to GPa, the value is about 43.2 GPa.

Stess/Strain Graph



Appendix D: Handwritten Data

Plastic

L_i = 85.3mm W = .01in thickness = .4cm

A = .157mm^2

Young's modulus: obtained = 2.21 GPa

theoretical = 2.3 GPa

used Data Studio

- Plot stress vs strain
- Linear best fit line over. selected area

theoretical results = www.engineeringtoolbox.com/young-modulus-d_417.html