Lab: Three-Point Bending Test

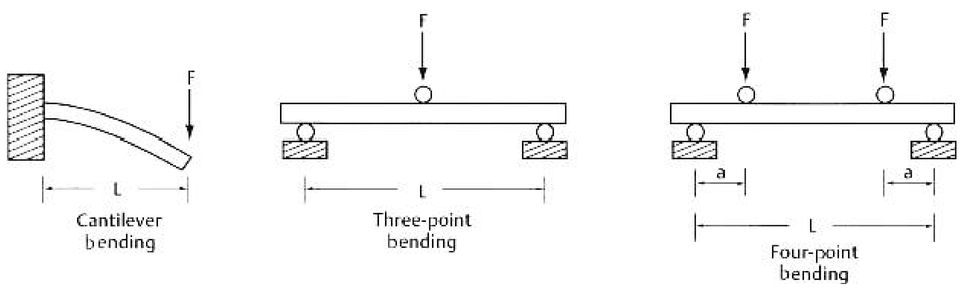
Objectives

Bend testing is mostly common for brittle materials, like glass, ceramic, concrete, stone, wood, and some types of plastic. It is suitable for evaluating strength of brittle materials because under tensile conditions their elongation is very small and an interpretation of test results is difficult or sometimes even impossible.

The objective of this Lab is to conduct 3-point bending of different materials and to investigate their response. Students should be able to:

1. Understand the fundamentals of flexural bend and define flexural stress and strain.
2. Determine the Young’s modulus for different materials and elastic to plastic transition.
3. Analyse statistical nature of the test data.

Background



Comparison of the load of a cantilever beam and three- and four-point bending test.

The test specimen (a beam) which is simply-supported at the ends and the load is applied at the center is considered to be in three-point bending. For most cases, the weight of the beam is neglected or sometimes is included in the load. The longitudinal stresses in the specimens are tensile at their lower surfaces and compressive at their upper surfaces. The bend or flexural strength is defined as the maximum uniaxial tensile strength at failure and it is often referred to as the flexural strength or modulus of rupture (MOR).

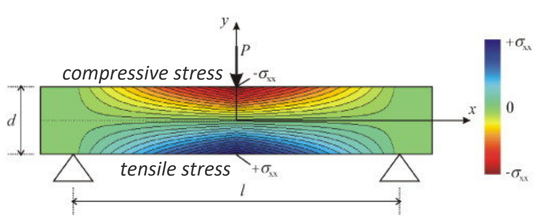


Figure 1. Contours of equal longitudinal stress in a beam in three-point bending as predicted by elementary beam theory. Tensile stress is denoted as positive.

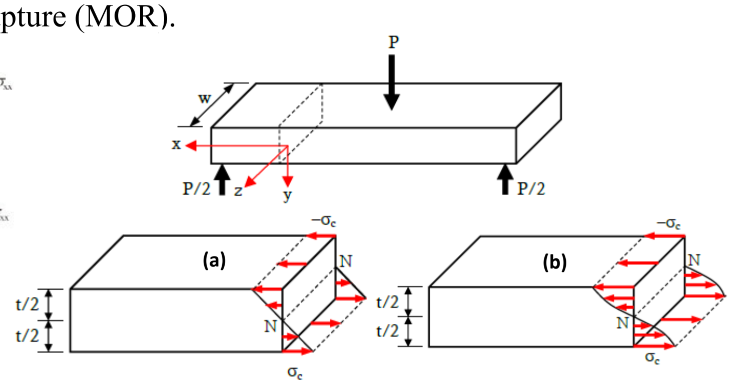


Figure 1. Stress distributions in a rectangular bar when (a) elastically bended and (b) after yielding

From the beam theory the shape of the beam is related to the moment acting on the beam:

$$\frac{d^2y}{dx^2} = \frac{\mathrm{M(x)}}{\mathrm{EI}} \tag{1}$$

where M is the applied moment, E – elastic modulus, and I – the second moment of area (area moment of inertia) of the beam cross section about the neutral axis, assuming elastic behavior of a beam. The slope of the beam is given by:

$$\theta = \frac{\mathrm{dy}}{\mathrm{dx}} \tag{2}$$

Integrating eq.(1) we get:

$$EI\frac{dy}{dx} = \int_0^{\mathrm{x}} \mathrm{M(x)dx} + \mathrm{C_1} \tag{3}$$

where C_1 is a constant of integration and can be determined from a slope condition. Integrating both sides of eq.(3) in terms of x we have:

$$EIy = \int_0^{\mathrm{x}} \mathrm{dx} \int_0^{\mathrm{x}} \mathrm{M(x)dx} + \mathrm{C_1x} + \mathrm{C_2} \tag{4}$$

where C_2 is a constant of integration and can be determined from the boundary conditions. For a beam supported as shown in Fig.1, if the load is P and it is applied *at* $l/2$ where l is the length of the beam between the support points, the deflection curve is given by:

$$\text{for } (0 \le x \le l/2) \qquad y(x) = -\frac{Px}{48EI}(4x^2 - 3l^2)$$

$$\text{for } (l/2 \le x \le l) \qquad y(x) = \frac{P(x-l)}{48EI}(l^2 - 8lx + 4x^2) \tag{5}$$

and the maximum deflection of the beam, y (or δ) at $x = l/2$ is:

$$y_{max}\ (\text{or } \delta_{max}) = \frac{Pl^3}{48\mathrm{EI}} \tag{6}$$

From the experimental results, one can obtain the elastic bending modulus, E_B, of the material by measuring the slope, k, of the load-deflection curve ($\boldsymbol{k} = dP/d\delta$) in the linear region of the load-deflection dependence:

$$E_B = \frac{l^3}{48I}\left(\frac{dP}{d\delta}\right) \tag{7}$$

For a rectangular test specimen $I = wt^3/12$, thus

$$E_B = \frac{l^3}{4\,\mathrm{w}\,t^3}k \tag{8}$$

From a simple beam theory, the maximum outer surface stress value is:

$$\sigma = \frac{M\,t/2}{I} \tag{9}$$

And the bending moment, in the 3-point bending experiment, is $M = \frac{1}{2}P\,(l/2)$. Thereby the stress (flexural bending strength) on the surface of a rectangular test specimen is:

$$\sigma = \frac{P\,l\,t}{8I} = \frac{3Pl}{2wt^2} \tag{10}$$

Lab Procedure

Safety: all personnel are required to wear safety glasses at all time in this lab.

A. Apparatus

Students will use Tinius-H5KT Universal Three Point Bending Testing Machine.

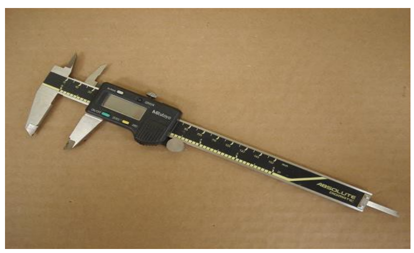



Figure 2. (a) Tinius-H5KT Universal Testing Machine; (b) Bridge and Crosshead Probe; (c) "5 K" Software USB Key; (4) Vernier Calipers; and Computer Station

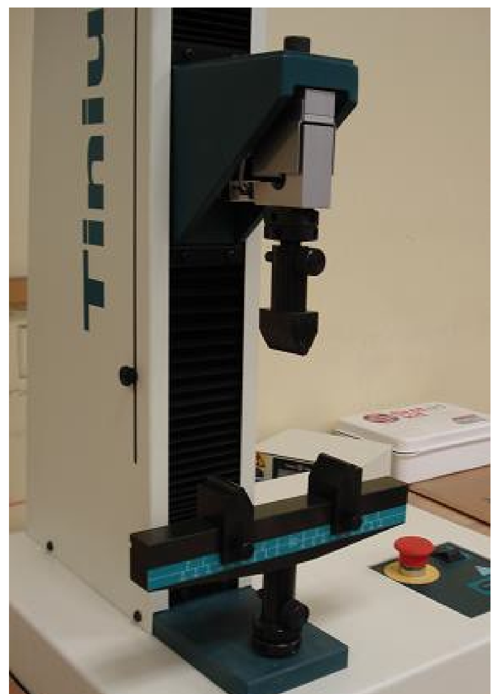


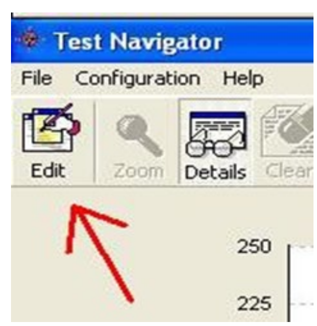
Figure 3. Bridge and Crosshead Probe Installation

B. Specimens

Students will test samples provided in the set box. Each student will test at least two-three samples: a non-ferrous sample, such as aluminum alloys, brass, bronze, copper, and polymers. **At least three measurements** have to be performed on each specimen to obtain meaningful statistics.

C. Test Setup

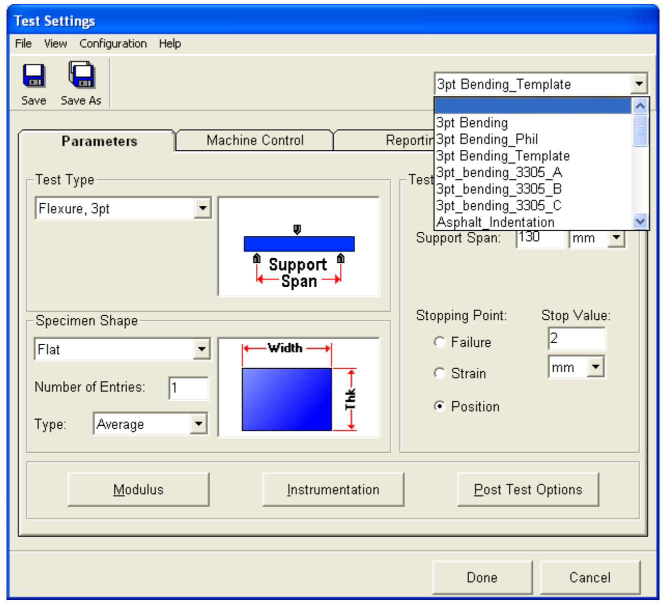
1. Switch on the T-O H5KT machine.
2. Power on the Computer Station.
3. Insert USB Key "H5KT" into computer.
4. Login to the "Solids Lab # 3" Profile.
5. Install the Bridge and Crosshead Probe as shown in Figure 3. Make sure all securing nuts are tightened.
6. Make sure both supporting sections of the bridge span are equally spaced.

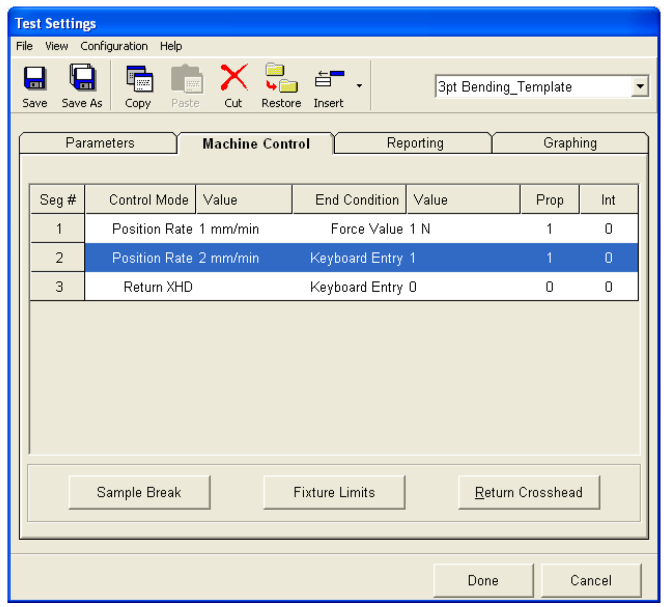


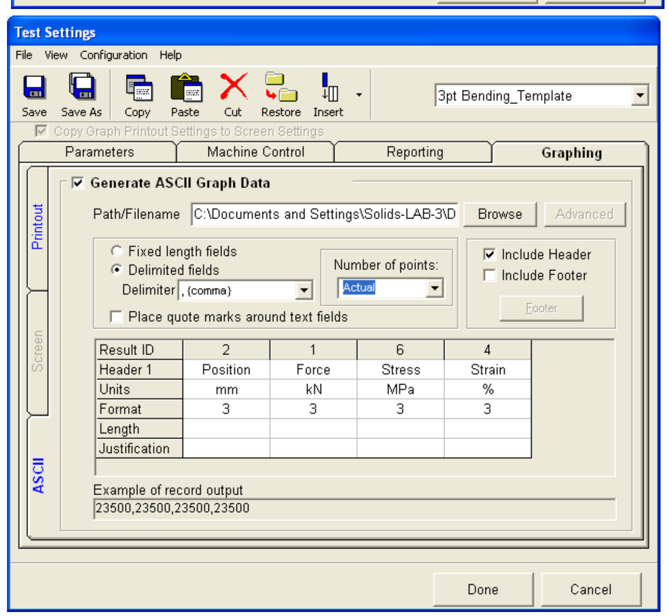
7. Click on the **Navigator** icon located on Desktop to launch the testing software.

8. Click Edit in top-left of screen
9. On the top right of the Test Settings screen, use drop down arrow and select the appropriate test.

- Choose **3pt_Bending_**
- Under Parameters Tab, Select the specimen shape
- Input the support span length
- Select stopping point and input value. (Test can always be aborted manually at any time and still save the data.)
- Under the Machine Control tab,
- The first segment is the preload. The force head will move at that rate until it detects 1-N of force
- The second segment can be changed by double-clicking it. Only change the position rate value. During the test, a keyboard entry of "1" will stop the test.
- Under the Graphing tab/ASCII
- Click "Browse" and make sure the file will be saved to the Desktop under an identifiable title. Click "Save." This will enter the test data points into Excel for further data processing, plotting, and analysis.
- <u>All data will be saved in ONE Excel sheet and collate after the other after each "export."</u>
- <u>Change this saved location name for each different specimen.</u>







D. Testing

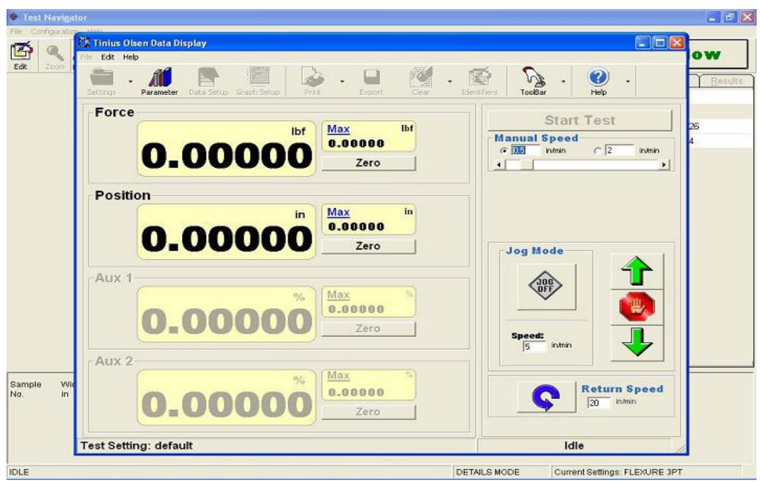
The parameters for this test are the support span, the speed of the loading, and the maximum deflection for the test. These parameters are based on the test specimen thickness and are defined differently by ASTM (American Society for Testing and Materials) and ISO (International Organization for Standardization). For ASTM D790, the test is stopped when the specimen **reaches 5% deflection** or the specimen breaks before 5%. For ISO 178, the test is stopped when the specimen breaks. Of the specimen does not break, the test is continued as far as possible and the **stress at 3.5%** (conventional deflection) is reported.

In this lab students will **carry out the bend test until:**

(1) failure takes place for some of the samples;
(2) plastic deformation visible on the load-displacement curve
(3) instrument reached its limit (?)

At least for one sample, execute the same test for different orientations of a specimen in respect to its cross section.

10. Using the pop-up toolbar at the top of the screen click on Data Display, the left-most button.

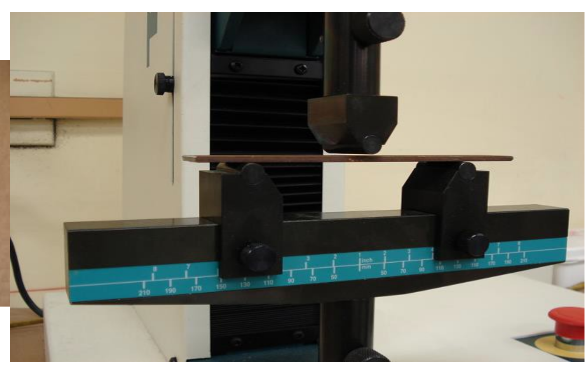


11. Data Display

12. Moving Crosshead Probe

- JOG OFF - means one/two clicks will create continuous head movement
- JOG ON - means the head moves only with a "hold down" click
- Manual Speeds - recommended 1 mm/sec and 5 mm/sec
- Speed: 5 mm/sec Return: 10 mm /sec

13. Practice moving the probe head up and down. Change speeds to fit your comfort level. **Use JOG ON for more control.**



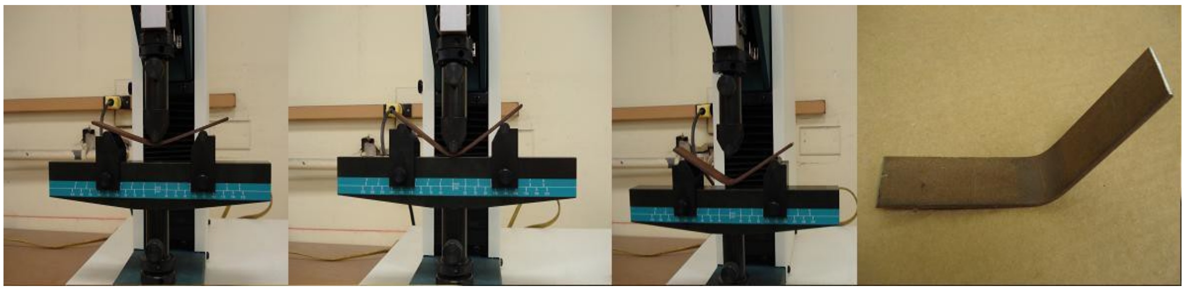
14. Measure the width and thickness of the specimen. Mark on the locations where the load will be applied under three-point bending.

15. Place your sample centered on the bridge and normal to the force applicator. Make sure that the loading point is placed on to the marked location.

16. Bring probe very close to sample without touching it.

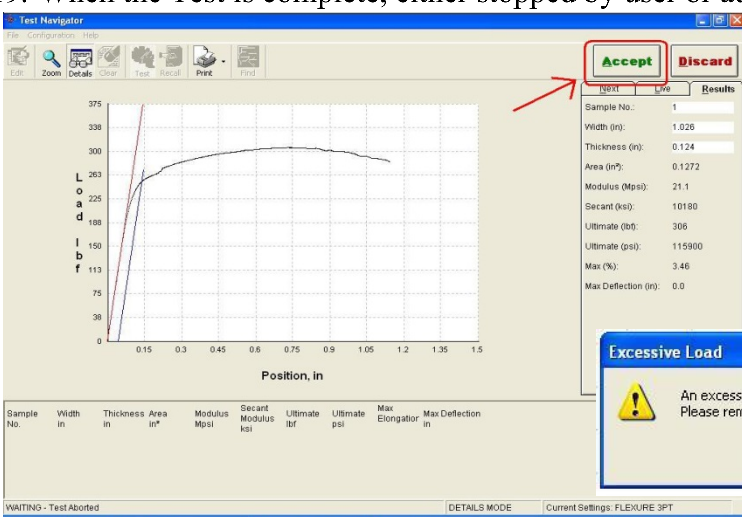
17. In the Data Display Menu, **zero** both Force and Position.

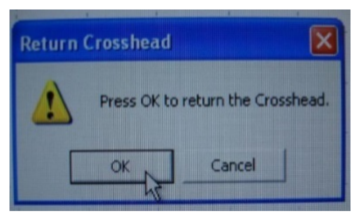
18. Click "Test Now" to begin the test. Note: Test machine will beep while testing. Depending on the material and the parameters the test may take up to 12 minutes. See figures below for testing pictures.



E. Post Testing

19. When the Test is complete, either stopped by user or automatic, click "Accept".





20. Click "OK" to Return the Crosshead.

21. Click "Ignore" on the next message box.

22. When the Crosshead returns remove the tested sample.

23. Record the test data for your sample.

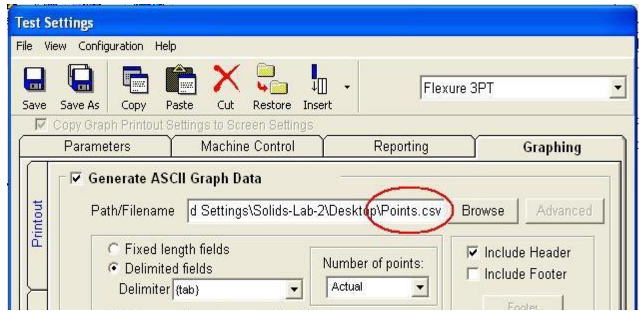
Sample No.	Width in	Thickness in	Area in²	Modulus Mpsi	Secant Modulus ksi	Ultimate lbf	Ultimate psi	Max Elongatior	Max Deflection in
1	1.026	0.124	0.1272	21.1	10180	306	115900	3.46	0.0

24. Be sure to export the data into the file name saved earlier.

Then change filename before exporting each specimen or each test; else the data will compile together in one file.

[- …_filename_.csv]

Repeat steps 15 to 24 to conduct bend tests of other specimens



Requirements for Lab Report (group report)

1. 1. Analyze 3-point bending tests of at least 3 different metal alloys and acrylic. It can be either 3 aluminum alloys or combination of aluminum and copper alloys.
2. Plot a flexure stress-strain diagrams for all beams tested.
3. Using the experimental data, calculate the bend strength at yield criteria and modulus of elasticity, *E*. Show your calculations.
4. For broken samples, determine the modulus of rupture (MOR).
5. Using *E* from the step 4 above, calculate the theoretical maximum deflection of the beam (in elastic area). What is the percent difference from the experimental value? Provide statistical analysis of data.
6. Display the test data in the Tables.
7. In the Discussion:

- Compare experimental data and calculated from the beam theory and include Solidworks simulations for chosen materials and experimental dimensions.
- Compare different materials and their properties measured using unidirectional tensile test and hardness test.
- Explain why flexural strength of brittle materials is always higher than tensile strength of the same material.
- Why does the presence of cracks in ductile materials present not much problem when compare with brittle materials?

Data Sheet for Bend Tests

Sample	Symbol	Unit	Value				
			1	2	3	Average	Standard deviation
Material							
Width	w						
Thickness	t						
Span length	l						
Elastic Bending Modulus	E_B						
Elastic Flexural Strength	σ_E						
Modulus of Rupture	σ_{fB}						