Mechanics of Materials - Lab
Course no: IDE120
Department: (interdisciplinary engineering department)

Contents:
▶ Lab assignments
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To: IDE 120 Section E Students
From: Krishna Kolan, GTA; Sean Smith, TA;
Subject: Lab # 12 – Eccentric Loading
Date: April 26, 2010
Report Due: May 7, 2010(Friday – by 4:00 PM)

Lab Background

Eccentric axial loads are one of the most common loads found in real world loading situations. It is important to properly account for the effect of an eccentric axial load so a safe design can be created.

Lab Procedure

We will be applying an offset load to an aluminum beam in the lab this week. Each group needs to perform the test on only one beam. The following steps should be completed in the lab:

1) Measure and record all the dimensions required on the data sheet
2) Load the beam in the machine.
3) Use the testing machine to apply around 100 lb of pre-load to the beam.
4) Connect all 5 strain gages to the switch and balance unit.
5) Zero the amp, set the gage factor, and record the initial strain readings.
6) Zero the load reading on the testing machine.
7) Apply an additional 8,000-10,000 lb load to the beam and record the final strains on your data sheet.

Calculations

1) You should begin your calculations by inputting your data to Excel.
2) Calculate the stresses present at the strain gage locations using Eq. (1). Use $E = 10.6 \times 10^6$ psi as the modulus of elasticity for the aluminum beam.
3) Create a plot of stress vs. position relative to the centroid. The positive direction for the position relative to the centroid is shown on the data sheet.
4) Use linear regression to find the equation of the regression line through your data. You will need both the slope (m_{exp}) and the y-intercept value (b_{exp}). Your equation should be of the form $\sigma_{exp} = m_{exp} y + b_{exp}$.
5) Find the location of the experimental neutral axis by setting $\sigma_{exp} = 0$ in your regression equation. The result should be an equation as shown in Eq. (2).
6) Calculate the experimental maximum tensile and compressive stresses in your beam. These can be found by plugging $y = \pm \frac{h}{2}$ into your regression equation.
7) Find the theoretical stress vs. position equation using Eq. (3). Plot this equation on the same graph you created in step 3 remembering not to use markers since this is a theoretical line.
8) Find the theoretical neutral axis location and maximum tensile and compressive stresses using the same method as for the experimental values described in steps 5 and 6. The only change you need to make is to work with the theoretical values when performing these calculations.

Lab Report

The report for this lab should be a TEAM WORKSHEET written by your group worth 50 points. Be sure to attach your initialed data sheet and a set of sample calculations. The following describes what is expected in your worksheet.

Experimental Results

Show the graph of stress vs. position with equations and labels. Include both the experimental and theoretical lines in the same graph. Summarize all your calculated experimental and theoretical values in a table.

Discussion of Results

Use percent errors to compare your experimental values to those predicted by theory. You will need to compare your experimental and theoretical values for neutral axis location, maximum tensile stress, and maximum compressive stress. Use table(s) for comparison.

COMMENT on how well your experimental results match the theory.

Equations

(1) Uniaxial Hooke's Law

$$\sigma_i = E\varepsilon_i$$

σ_i = stress at gage i location, psi

E = modulus of elasticity, psi

ε_i = axial strain on gage i, in/in

(2) Experimental Neutral Axis

$$y_{NA,exp} = \frac{-b_{exp}}{m_{exp}}$$

$y_{NA,exp}$ = location of exp. NA, in

b_{exp} = y-intercept from regression, psi

m_{exp} = slope from regression, psi/in

(3) Theoretical Stress vs. Position

$$\sigma_{th} = \left(\frac{Pe}{I_c}\right)y - \frac{P}{A} = m_{th}y + b_{th}$$

σ_{th} = theoretical stress, psi

P = applied load, lb

e = load offset distance, in

y = position from centroid, in

A = cross sectional area, in^2

I_c = moment of inertia about centroid, in^4

m_{th} = slope of theoretical line, psi/in

b_{th} = intercept of theoretical line, psi

– theoret matched

Given experiment, valid assumption to

NOTE: Drop your reports in my mail box (KOLAN) located in Room: 190 (Toomey) by 4:00 PM, Friday, May 7, 2010. Don't forget to mention your **Name** and **Section**.

*********************BEST OF LUCK*********************

To: IDE 120 Section E Students
From: Krishna Kolan, GTA; Sean Smith, TA;
Subject: Lab # 11 – Pressure Vessels
Date: April 19, 2010
Report Due: April 26, 2010

Lab Background

This week we will use strain gages to measure the strains on two different pressure vessels. The measured strains will then be used to calculate the stresses present in the pressure vessel walls. It is important to be able to measure the stresses in pressure vessel walls to ensure they are properly designed to prevent bursting or implosion.

Lab Procedure

Each group will be working with two different pressure vessels this week. The first vessel is a thin-walled steel pressure vessel. The second pressure vessel is thick-walled and made from duralumin. The following is a brief outline of the procedure you should follow for each vessel:

Thin-Walled Steel Pressure Vessel

1) Begin by observing and recording the orientation of the strain gage rosette on the vessel. Be sure to label which gage is which on your data sheet.
2) Measure the orientation angle of the strain rosette. This angle should be measured as the angle between the axial direction of the cylinder and the gage closest to the axial direction (gage A). Define the x' axis to be along the same direction as gage A and the y' axis to be along the direction of gage C.
3) Zero the amp, set the gage factor, and balance the strains on the strain indicators.
4) Close the pressure relief valve.
5) Use the pump to increase the pressure inside the cylinder in 200 psi increments. Take readings from all three strain gages at every 200 psi increment until the pressure reaches 2000 psi or may be 1800 psi.
6) When finished, open the pressure relief valve.

Thick-Walled Aluminum Pressure Vessel

1) The two strain gages used for this vessel are oriented along two of the principal directions. Gage #1 is in the hoop direction and gage #2 is in the radial direction.
2) Zero the amp, set the gage factor, and balance the strains on the strain indicator. You will only be able to balance the strain for one of the strain gages. For the other gage, just record the strain value shown on the indicator. We are interested in finding the slope of the regression line and not bothered whether it passes through the origin.
3) Close the pressure relief valve.
4) Use the pump to increase the pressure in 125 psi increments. Take readings from the two strain gages at each 125 psi increment. Continue taking readings until the pressure reaches 1000 psi.
5) When finished, open the pressure relief valve.

Calculations

The calculations for this lab are fairly involved, but by no means impossible to complete. If you have any difficulties, feel free to contact me and I will help you with them. If you follow the steps listed below, you should be able to complete your calculations without too much trouble.

For thin walled pressure vessel:

1) Use Excel to plot normal strain (y-axis) vs. pressure (x-axis).

2) Use linear regression to find the slope of each normal strain vs. pressure data set on your graph. There should be one line for each strain gage used. This will give you values for $\left(\frac{\varepsilon_A}{p}\right)$, $\left(\frac{\varepsilon_B}{p}\right)$, and $\left(\frac{\varepsilon_C}{p}\right)$.

3) Find the normal strains along the x' and y' axes and the shearing strain for the thin-walled vessel by applying the equations for a 0, 45, 90° strain rosette which are given in Eq. (1).

4) From the Eq. (7), calculate the orientation of the principal axes, θ_p for the thin-walled vessel.

5) Use Eq. (8) to find the principal strain ratios $\frac{\varepsilon_{p1}}{p}$ and $\frac{\varepsilon_{p2}}{p}$.

6) Calculate the principal normal stresses per unit pressure in hoop and axial directions using the Eq.(2). $\frac{\sigma_{p1}}{p}$ will be the principal stress in the hoop direction and $\frac{\sigma_{p2}}{p}$ will be the principal stress in the axial direction.

For thick walled pressure vessel:

1) Use Excel to plot normal strain (y-axis) vs. pressure (x-axis).
2) Use linear regression to find the slope of each normal strain vs. pressure data set on your graph. This will give you values for $\left(\frac{\varepsilon_1}{p}\right)$ (hoop direction) and $\left(\frac{\varepsilon_3}{p}\right)$ (radial direction)

3) The principal stresses in the thick-walled vessel can be found using a slightly different version of Hooke's law shown as Eq. (3).

For comparisons:

7) Apply the thin-wall theory given in Eq. (4) to both of the vessels tested in the lab to find reference values for your results.
8) Also apply the thick-wall theory given in Eq. (5) to both the thin-walled and thick-walled vessels to find a second set of reference values for your results.

Lab Report

The report for this lab should be a GROUP WORKSHEET worth 50 points. Be sure to attach your initialed data sheet. A set of sample hand calculations should also be included. The following describes what is expected in your worksheet.

Experimental Results

Include the two graphs created in Excel. Make sure to show all the regression lines and their equations on the graph. Include a table showing the following experimental values for the thin-walled vessel:

$\frac{\varepsilon_{x'}}{p}$	$\frac{\varepsilon_{y'}}{p}$	$\frac{\gamma_{x'y'}}{p}$	θ_p	$\frac{\varepsilon_{p1}}{p}$	$\frac{\varepsilon_{p2}}{p}$	$\frac{\sigma_{p1}}{p}$	$\frac{\sigma_{p2}}{p}$	$\frac{\tau_{x'y'}}{p}$

For the thick-walled vessel create a table showing the following experimental values:

$\frac{\varepsilon_1}{p}$	$\frac{\varepsilon_3}{p}$	$\frac{\sigma_1}{p}$	$\frac{\sigma_3}{p}$

In the third table, compare your experimental principal stresses per unit pressure to the values predicted by the thin-walled and thick-walled theories. You need to compare each experimental vessel to both of the theories. Use percent errors to show how accurate the theories are. Also, compare your calculated orientation of the principal axes to the actual orientation of the principal axes. In theory, the principal axes should be directly aligned with the axial and hoop directions. Tables should be used to help organize all your comparisons. Comment on the results obtained and the observations you have made.

Equations

(1) 0, 45, 90° Strain Rosette

$$\frac{\varepsilon_A}{p} = \frac{\varepsilon_{x'}}{p}$$

$$\frac{\varepsilon_C}{p} = \frac{\varepsilon_{y'}}{p}$$

$$\frac{2\varepsilon_B}{p} - \left(\frac{\varepsilon_A}{p} + \frac{\varepsilon_B}{p}\right) = \frac{\gamma_{x'y'}}{p}$$

ε = normal strain, in/in

γ = shear strain, rad

p= gage pressure, psi

(2) Biaxial Hooke's Law

$$\frac{\sigma_{p1}}{p} = \frac{E}{1-\nu^2}\left(\frac{\varepsilon_{p1}}{p} + \nu\frac{\varepsilon_{p2}}{p}\right)$$

$$\frac{\sigma_{p2}}{p} = \frac{E}{1-\nu^2}\left(\frac{\varepsilon_{p2}}{p} + \nu\frac{\varepsilon_{p1}}{p}\right)$$

$$\frac{\tau_{x'y'}}{p} = G\frac{\gamma_{x'y'}}{p}$$

ε = normal strain, in/in

γ = shear strain, rad

p= gage pressure, psi

σ = normal stress, psi

τ = shear stress, psi

E= modulus of elasticity, psi

G= modulus of rigidity, psi

υ= Poisson's ratio

(3) Biaxial Hooke's Law

$$\frac{\sigma_1}{p} = \frac{E}{1-\nu^2}\left(\frac{\varepsilon_1}{p} + \nu\frac{\varepsilon_3}{p}\right)$$

$$\frac{\sigma_3}{p} = \frac{E}{1-\nu^2}\left(\frac{\varepsilon_3}{p} + \nu\frac{\varepsilon_1}{p}\right)$$

σ_1 = principal hoop stress, psi

σ_3 = principal radial stress, psi

ε_1 = hoop strain, in/in (gage #1)

ε_3 = radial strain, in/in (gage #2)

(4) Thin-Wall Theory

$$\frac{\sigma_1}{p} = \frac{a}{t} \text{ (hoop)}$$

$$\frac{\sigma_2}{p} = \frac{a}{2t} \text{ (axial)}$$

$$\frac{\sigma_3}{p} = -1 \text{ (radial)}$$

a = inner radius, in

t = vessel wall thickness, in

(5) Thick-Wall Theory

$$\frac{\sigma_1}{p} = \frac{a^2\left(1+\frac{b^2}{r^2}\right)}{b^2-a^2} \text{ (hoop)}$$

$$\frac{\sigma_2}{p} = \frac{a^2}{b^2-a^2} \text{ (axial)}$$

$$\frac{\sigma_3}{p} = \frac{a^2\left(1-\frac{b^2}{r^2}\right)}{b^2-a^2} \text{ (radial)}$$

a = inner radius, in

b= outer radius, in

r = radius to gage, in

(6) Elastic Constants Relationship

$$G = \frac{E}{2(1+\upsilon)}$$

(7) Principal Angle Eqn

$$\theta_p = \frac{1}{2}\tan^{-1}\left[\frac{\frac{\gamma_{x'y'}}{p}}{\frac{\varepsilon_{x'}}{p} - \frac{\varepsilon_{y'}}{p}}\right]$$

(8) Principal Strain Eqn

$$\frac{\varepsilon_{P_1}}{P}, \frac{\varepsilon_{P_2}}{P} = \frac{\frac{\varepsilon_{x'}}{P} + \frac{\varepsilon_{y'}}{P}}{2} \pm \left[\frac{\frac{\varepsilon_{x'}}{P} - \frac{\varepsilon_{y'}}{P}}{2}\cos(2\theta_p) + \frac{\frac{\gamma_{x'y'}}{P}}{2}\sin(2\theta_p)\right]$$

To: IDE 120 Section E Students
From: Krishna Kolan, GTA; Sean Smith, TA;
Subject: Lab #10 – Strain Transformation
Date: April 12, 2010
Report Due: April 19, 2010

Lab Background

The topic of strain transformation is important because it allows the use of arbitrarily oriented strain gage rosettes to find the principal strains for a given loading situation. Without the use of strain transformation the measurement of strains on complex geometries is nearly impossible since it is very difficult to know ahead of time how the principal strains will be oriented.

Lab Procedure

Each group will be given a transparency sheet with four squares printed on it. Each of the squares will be oriented differently on the sheet. The following procedure should be followed in the lab:

1) Before deforming the sheet, measure the lengths of all the sides of the squares (4 per square, 16 total) using calipers and record them on your data sheet in the left column.
2) Measure and record the angles between the sides of the squares (4 per square, 16 total). The measurements recorded on your data sheet can be in degrees, but before you perform any calculations you need to convert to radians.
3) Measure and record the orientation angle of each square with respect to the horizontal.
4) Use a UTM to deform the transparency sheet by 1.5-2 inches. Be careful not to touch the ink after deformation since it will easily rub off and ruin your results.
5) After deforming your sheet, measure the lengths of all the sides of the squares and the angles between the sides of the squares and record them on your data sheet in the middle column.
6) You do not need to measure the orientation angle of the square after deformation.

Calculations

You should begin your calculations by finding the average normal strain in the x-direction (ε_x) and y-direction (ε_y) for each square using Eq. (1). Then, find the average shear strain (γ_{xy}) for each square using Eq. (2). Next, you will need to find the principal strains, maximum shear strain, and principal direction for each square. The principal strains (ε_1 and ε_2), maximum shear strain ($\gamma_{\max}$), and principal direction (θ_p) can be found using either Mohr's circle or the equations method. If you choose to use the equations method, the required equations are given as Eqs. (3)-(5). If you choose to use Mohr's circle, the required equations are given in Eq. (6).

Lab Report

The report for this lab should be a TEAM WORKSHEET that will be worth 50 points. Show hand calculations for one of the squares. Also, be sure to attach your original data sheet.
The results of your calculations should be reported in typed tables. The following values should be shown in one table in your report.

Square #	θ	ε_x	ε_y	γ_{xy}	θ_p	ε_1	ε_2	$\gamma_{\max}$
1								
2								
3								
4								

Include the following discussion points in your worksheet giving appropriate reason(s) for each comparison:

1) How do the calculated angles of rotation (θ_p) compare with the angles of rotation measured (θ) at the beginning of the experiment?
2) Why are the principal strains (ε_1 and ε_2) similar for all four square orientations?
3) Compare ε_x, ε_y for square 1 to ε_1, ε_2 for all the 4 squares. What do you observe? Why?
4) Do the calculated maximum-shear-strain values (γ_{max}) agree with the measured shear strains in the four orientations? (mention the trend among shear strains as we move from square 1 to square 4)
5) Compare γ_{xy} for square 4 to γ_{max} for all the 4 squares. What do you observe? Why?

Include any reasons you can think of for why your results differ from what is expected.

Equations

(1) Average Normal Strain

$$\varepsilon_x = \frac{1}{2}\left(\frac{L_{x1,f} - L_{x1,i}}{L_{x1,i}} + \frac{L_{x2,f} - L_{x2,i}}{L_{x2,i}}\right)$$

ε_x = normal strain in x-direction, in/in

$L_{x,f}$ = final length, in

$L_{x,i}$ = initial length, in

(2) Average Shear Strain

$$\gamma_{xy} = \frac{1}{4}\left(\left|\alpha_{1,f} - \frac{\pi}{2}\right| + \left|\alpha_{2,f} - \frac{\pi}{2}\right| + \left|\alpha_{3,f} - \frac{\pi}{2}\right| + \left|\alpha_{4,f} - \frac{\pi}{2}\right|\right)$$

γ_{xy} = shear strain, rad

α_f = final angle between sides, rad

(3) In-Plane Principal Strains

$$\varepsilon_{1,2} = \frac{\varepsilon_x + \varepsilon_y}{2} \pm \sqrt{\left(\frac{\varepsilon_x - \varepsilon_y}{2}\right)^2 + \left(\frac{\gamma_{xy}}{2}\right)^2}$$

$\varepsilon_{1,2}$ = in-plane principal strains, in/in

(4) Maximum In-Plane Shearing Strain

$$\gamma_{\max} = 2\sqrt{\left(\frac{\varepsilon_x - \varepsilon_y}{2}\right)^2 + \left(\frac{\gamma_{xy}}{2}\right)^2}$$

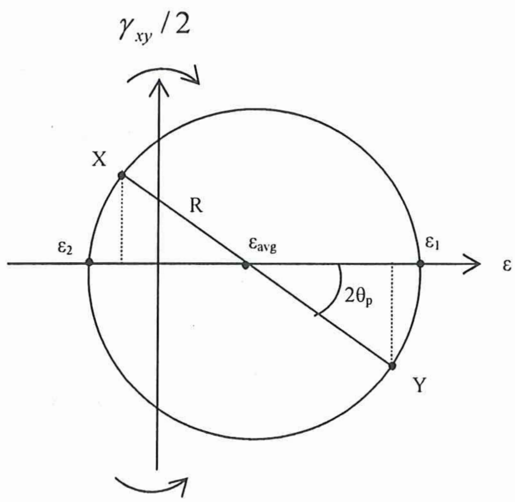
$\gamma_{\max}$ = maximum in-plane shearing strain, rad

(5) In-Plane Principal Direction

$$\theta_p = \frac{1}{2}\tan^{-1}\left(\frac{\gamma_{xy}}{\varepsilon_x - \varepsilon_y}\right)$$

θ_p = in-plane principal direction

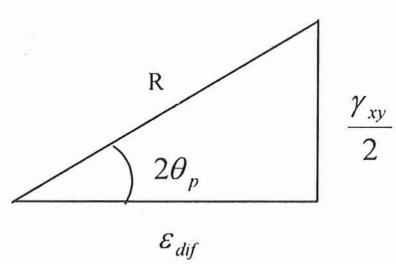
(6) Mohr's Circle Equations



$$\varepsilon_{avg} = \frac{\varepsilon_x + \varepsilon_y}{2} \qquad \varepsilon_{dif} = \left|\frac{\varepsilon_x - \varepsilon_y}{2}\right|$$

$$R = \sqrt{\varepsilon_{dif}^{\,2} + \left(\frac{\gamma_{xy}}{2}\right)^2}$$

$$\theta_p = \frac{1}{2}\tan^{-1}\left(\frac{\frac{\gamma_{xy}}{2}}{\varepsilon_{dif}}\right) \qquad \varepsilon_{1,2} = \varepsilon_{avg} \pm \qquad \gamma_{\max} = 2R$$



(7) Percent Difference

$$\%Diff. = \frac{|Exp_1 - Exp_2|}{\left(\frac{Exp_1 + Exp_2}{2}\right)}(100\%)$$

Exp_1 = experimental value #1

Exp_2 = experimental value #2

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To:	Krishna Kolan, GTA; Sean Smith, TA;
From:	Team 8: David Malawey, Jacob Spooler, Scott Kapshandy
Subject:	Lab #8 – Hardness Testing
Date:	March 22, 2010
Report Due:	April 5, 2010

Introduction:

In this lab, the hardness of various metals and polymers was determined using Rockwell, Brinell and Durometer tests. Hardness tests are very useful since they are fast, cheap, and usually non-destructive.

The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload. The Brinell test determines the hardness by measuring the diameter of the indention left by a 10mm diameter steel ball which has been acted on by 3,000 kg of mass.

Each group member selected different materials to perform the three tests on in order to acquire . The hardness values and corresponding tensile strengths were compared to reference values and to the other materials selected for testing in tables 1-3, with percent error calculated in table 4.

Experimental Results:

A chart was used to convert Brinell and Rockwell hardness numbers to material strengths in ksi. No calculations were actually needed, but one example is shown for "hand calculations."

Metal Specimen Rockwell Test								
	Material	Size (in)	Ref B or C	Anvil	RTS (ksi)	Readings	Average	Tens Strength (ksi)
Scott	4140 Steel	.5x3x3	C: 13	flat	95	17,18,17	17.33	102
David	Brass	.5x3x3	B	flat	55.8	59,59,58.5	58.566	50
Jacob	C1018 Cold Drawn Steel	.5x3x3	B: 71	flat	63.8	92, 91.5, 93	92.16	92

Table 1: Rockwell Test Results

Metal Specimen Brinell Test								
	Material	Ref Brinell	RTS (ksi)	P (kg)	D (mm)	d (mm)	HB	Tens Strength (ksi)
Scott	4140 Steel	197	95	3000	10	5	142.55	102
David	1045	187	95	3000	10	3.9	241	116
Jacob	C1018 Cold Drawn Steel	126	63.8	3000	10	4.6	170	83

Table 2: Brinell Test Results

Polymer Durometer Test				
	Material	Ref. Hardness Value	Readings	Average
Scott	Polypropylene	D-77	74,70,75	73
David	LD Polyethylene	D-42	45,44,44	44.67
Jacob	Buna-N O-Ring	A-70 - A-75	70, 69, 76	71.66

Table 3: Durometer Test Results

		Experimental Value	Reference Value	Percent Error
Rockwell Hardness Test	4140 Steel	17.33	13	33.3%
	Brass	58.566	62	5.8%
	C1018 Cold Drawn Steel	92.16	71	29.8%
Tensile Strength (from Rockwell) ksi	4140 Steel	102	95	6.9%
	Brass	50	55.8	10.4%
	C1018 Cold Drawn Steel	92	63.8	44.2%
Brinell Hardness Test	4140 Steel	142.55	197	27.6%
	~~Brass~~	~~241~~	~~187~~	~~28.9%~~
	C1018 Cold Drawn Steel	170	126	34.9%
Tensile Strength (from Brinell) ksi	4140 Steel	102	95	7.4%
	Brass	116	95	22.1%
	C1018 Cold Drawn Steel	83	63.8	30.1%
Durometer Test	Polypropylene	73	77	5.2%
	LD Polyethylene	44.67	42	6.4%
	Buna-N O-Ring	71.66	70 -75	0.0%

No Brinnel on Brass

Table 4: Analysis of Experimental vs. Referenced values

Discussion of Results:

Our most accurate results came from the durometer tests, which gave within about five percent error every time. The polymers tested with the durometers displayed very close strengths to those referenced. The tensile strength results on 4140 steel also landed within single-digit percent errors from reference strengths. The least accurate results came from a C1018 Cold Drawn steel. Using the Rockwell test and the Brinell test, the experimental results for this steel came out far from the reference value. This inaccuracy may be due many previous tests that were performed on the specimen. The surface of the material was not perfect when the tests were started. Neither Brinell nor Rockwell tests proved significantly more accurate than the other.

References:

Blackboard.mst.edu
Lab #8 handout (for reference values)

IDE 120 – HARDNESS TESTING

Section (circle): A B C D E F G H I J K Date: 3-22-10

Group (circle): 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Data Recorder: ______

Metal Specimen, Rockwell Test

Procedure: (circle one)
Rockwell B: 1/16" indenter, 100 kg major load, red dial
Rockwell C: diamond indenter, 150 kg major load, black dial

Material (see table on next page): Brass

Size: 5 x 3 x 3

Anvil (flat for rectangular or vee for cylindrical): flat

Reference Rockwell B or C value: B

Reference tensile strength: 55.8 ksi

Three experimental readings: 59 / 59 / 58.5

Average of three experimental readings: 58.566

Corrected experimental value (cylindrical specimens only), from wall chart or ASTM E18 Table 11 or 12: ——

Tensile strength, from wall chart or ASTM E140: 50 ksi

Metal Specimen, Brinell Test

Material (see table on next page): 1045

Reference Brinell hardness value: 187

Reference tensile strength: 95 ksi

Load, P: 3000 kg

Indenter diameter, D: 10 mm

Indentation diameter, d: 3.9 mm mm

WR

$$HB = \frac{2P}{\pi D\left[D - \sqrt{(D^2 - d^2)}\right]}$$

Brinell hardness from table on testing machine or formula: 241 89

Tensile strength, from wall chart or ASTM E140: 116 ksi 90

Polymer Specimen, Durometer or Rockwell Test

Procedure: (circle one)

Durometer A2: analog, operating stand
Durometer A: analog, hand-held
Durometer D: analog, hand-held
Durometer M: electronic, operating stand
Durometer Foam: analog, hand-held
Rockwell M: 1/4" indenter, 100 kg major load, red dial
Rockwell R: 1/2" indenter, 60 kg major load, red dial

Material (see table below): L.D. Polyethylene

Reference hardness value: 42

Three experimental readings: Type D 45 / 44 / 44

Average of three experimental readings: 49.66

Materials

Material	Reference Hardness	Reference Tensile Strength (ksi)	Available Sizes	Identification Color or Code
C11000-H2 Copper	Rockwell B: 40	41.2	ϕ 5/8"x6"	blue
6061-T651 Aluminum	Brinell: 95 Rockwell B: 60	45	1/2"x3"x3" ϕ 5/8"x6"	blue-green, AL 6061
C36000-H1 Brass	Rockwell B: 62	55.8	1/2"x3"x3" ϕ 5/8"x6"	orange, BRS 36000
A36 Hot-Rolled Steel	Brinell: 119-159 Rockwell B: 67-83	58 - 80	1/2"x3"x3" ϕ 5/8"x6"	green-white, ST A36
C1018 Cold-Drawn Steel	Brinell: 126 Rockwell B: 71	63.8	1/2"x3"x3"	red-white, ST 1018
2024-T4 Aluminum	Brinell: 120 Rockwell B: 75	68.2	1/4"x1"x6" ϕ 5/8"x6"	blue-red, AL 2024
7075-T651 Aluminum	Brinell: 150 Rockwell B: 87	82.7	ϕ 5/8"x6"	blue-yellow, AL 7075
1035 Cold-Drawn Steel	Brinell: 170 Rockwell B: 86	84.8	ϕ 5/8"x6"	red-orange, ST 1035
1045 Cold-Drawn Steel	Brinell: 187 Rockwell B: 90 Rockwell C: 10	95	1"x1"x3" ϕ 5/8"x6"	red-yellow, ST 1045
C95400 Aluminum Bronze	Brinell: 195 Rockwell B: 94	89.9	1/2"x3"x3"	BRZ 95400
4140 Annealed Steel	Brinell: 197 Rockwell B: 92 Rockwell C: 13	95	1/2"x3"x3"	ST 4140
4130 Steel	Brinell: 197 Rockwell B: 92 Rockwell C: 13	97.2	1/4"x5/8"x6"	ST 4130
Gray Cast Iron	Brinell: 183-234 Rockwell B: 97 Rockwell C: 20	40 (minimum)	ϕ 3/4"x6"	green
Buna-N Square O-Ring Cord Stock	Shore A: 70-75	---	3/4"x3/4"x6"	yellow
Low-Density Polyethylene	Rockwell R: 60 Shore D: 42	1.6	1"x1"x6"	red
High-Density Polyethylene	Rockwell R: 65 Shore D: 68	4.4	1"x1"x6"	black
Polypropylene	Rockwell R: 92 Shore D: 77	4.8	1"x1"x6"	green
PVC Type I	Rockwell R: 110 Shore D:80	7.3	1"x1"x6"	orange-silver
PVC Type I	Rockwell R: 114 Shore D: 89	7.5	1"x1"x6"	orange-gold
Cast Acrylic	Rockwell M: 93	10	1" cube	blue

IDE 120 – HARDNESS TESTING

Section (circle): A B C D E F G H I J K — Date: 3-22-10

Group (circle): 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Data Recorder: Scott Krupshandy

Metal Specimen, Rockwell Test

Procedure: (circle one)
Rockwell B: 1/16" indenter, 100 kg major load, red dial
Rockwell C: diamond indenter, 150 kg major load, black dial

Material (see table on next page):	4140 Steel
Size:	½"X3"x3"
Anvil (<u>flat</u> for rectangular or <u>vee</u> for cylindrical):	flat
Reference Rockwell B or C value:	C: 13
Reference tensile strength:	95 ksi
Three experimental readings:	17, 18, 17
Average of three experimental readings:	17.33
Corrected experimental value (cylindrical specimens only), from wall chart or ASTM E18 Table 11 or 12:	—
Tensile strength, from wall chart or ASTM E140:	102 ksi

Metal Specimen, Brinell Test

Material (see table on next page):	4140 steel
Reference Brinell hardness value:	197
Reference tensile strength:	95 ksi
Load, P:	3000 kg
Indenter diameter, D:	10 mm
Indentation diameter, d:	5 mm

$$HB = \frac{2P}{\pi D\left[D - \sqrt{(D^2 - d^2)}\right]}$$

Brinell hardness from table on testing machine or formula:	142.55
Tensile strength, from wall chart or ASTM E140:	102 ksi

Polymer Specimen, Durometer or Rockwell Test

Procedure: (circle one)

Durometer A2: analog, operating stand
Durometer A: analog, hand-held
Durometer D: analog, hand-held
Durometer M: electronic, operating stand
Durometer Foam: analog, hand-held
Rockwell M: 1/4" indenter, 100 kg major load, red dial
Rockwell R: 1/2" indenter, 60 kg major load, red dial

Material (see table below): Polypropylene

Reference hardness value: D 77

Three experimental readings: 74 / 70 / 75

Average of three experimental readings: 73

Materials

Material	Reference Hardness	Reference Tensile Strength (ksi)	Available Sizes	Identification Color or Code
C11000-H2 Copper	Rockwell B: 40	41.2	ϕ 5/8"x6"	blue
6061-T651 Aluminum	Brinell: 95 Rockwell B: 60	45	1/2"x3"x3" ϕ 5/8"x6"	blue-green, AL 6061
C36000-H1 Brass	Rockwell B: 62	55.8	1/2"x3"x3" ϕ 5/8"x6"	orange, BRS 36000
A36 Hot-Rolled Steel	Brinell: 119-159 Rockwell B: 67-83	58 - 80	1/2"x3"x3" ϕ 5/8"x6"	green-white, ST A36
C1018 Cold-Drawn Steel	Brinell: 126 Rockwell B: 71	63.8	1/2"x3"x3"	red-white, ST 1018
2024-T4 Aluminum	Brinell: 120 Rockwell B: 75	68.2	1/4"x1"x6" ϕ 5/8"x6"	blue-red, AL 2024
7075-T651 Aluminum	Brinell: 150 Rockwell B: 87	82.7	ϕ 5/8"x6"	blue-yellow, AL 7075
1035 Cold-Drawn Steel	Brinell: 170 Rockwell B: 86	84.8	ϕ 5/8"x6"	red-orange, ST 1035
1045 Cold-Drawn Steel	Brinell: 187 Rockwell B: 90 Rockwell C: 10	95	1"x1"x3" ϕ 5/8"x6"	red-yellow, ST 1045
C95400 Aluminum Bronze	Brinell: 195 Rockwell B: 94	89.9	1/2"x3"x3"	BRZ 95400
√ 4140 Annealed Steel	Brinell: 197 Rockwell B: 92 Rockwell C: 13	95	1/2"x3"x3"	ST 4140
4130 Steel	Brinell: 197 Rockwell B: 92 Rockwell C: 13	97.2	1/4"x5/8"x6"	ST 4130
Gray Cast Iron	Brinell: 183-234 Rockwell B: 97 Rockwell C: 20	40 (minimum)	ϕ 3/4"x6"	green
Buna-N Square O-Ring Cord Stock	Shore A: 70-75	---	3/4"x3/4"x6"	yellow
Low-Density Polyethylene	Rockwell R: 60 Shore D: 42	1.6	1"x1"x6"	red
High-Density Polyethylene	Rockwell R: 65 Shore D: 68	4.4	1"x1"x6"	black
√ Polypropylene	Rockwell R: 92 Shore D: 77	4.8	1"x1"x6"	green
PVC Type I	Rockwell R: 110 Shore D:80	7.3	1"x1"x6"	orange-silver
PVC Type I	Rockwell R: 114 Shore D: 89	7.5	1"x1"x6"	orange-gold
Cast Acrylic	Rockwell M: 93	10	1" cube	blue

IDE 120 – HARDNESS TESTING

Section (circle): A B C D E F G H I J K Date: 3/22/2010

Group (circle): 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Data Recorder: Jake Spooler

Metal Specimen, Rockwell Test

Procedure: (circle one)
Rockwell B: 1/16" indenter, 100 kg major load, red dial
Rockwell C: diamond indenter, 150 kg major load, black dial

Material (see table on next page): 1018

Size: Square

Anvil (flat for rectangular or vee for cylindrical): flat

Reference Rockwell B or C value: B-71

Reference tensile strength: 63.8 ksi

Three experimental readings: 92, 91.5, 93

Average of three experimental readings: 92.

Corrected experimental value (cylindrical specimens only), from wall chart or ASTM E18 Table 11 or 12:

Tensile strength, from wall chart or ASTM E140: 92 ksi

Metal Specimen, Brinell Test

Material (see table on next page): 1018

Reference Brinell hardness value: 126

Reference tensile strength: 63.8 ksi

Load, P: 3000 kg

Indenter diameter, D: 10 mm

Indentation diameter, d: 4.6 mm

$$HB = \frac{2P}{\pi D\left[D - \sqrt{(D^2 - d^2)}\right]}$$

Brinell hardness from table on testing machine or formula: 170 (table on machine)

Tensile strength, from wall chart or ASTM E140: 83 ksi

Polymer Specimen, Durometer or Rockwell Test

Procedure: (circle one)

- Durometer A2: analog, operating stand
- Durometer A: analog, hand-held
- Durometer D: analog, hand-held
- Durometer M: electronic, operating stand
- Durometer Foam: analog, hand-held
- Rockwell M: 1/4" indenter, 100 kg major load, red dial
- Rockwell R: 1/2" indenter, 60 kg major load, red dial

Material (see table below): Buna-N - Square O-rings - red C - black

Reference hardness value: Shore ~~A: 80~~ 70-75

Three experimental readings: 70 / 69 / 76

Average of three experimental readings: ________

Materials

Material	Reference Hardness	Reference Tensile Strength (ksi)	Available Sizes	Identification Color or Code
C11000-H2 Copper	Rockwell B: 40	41.2	ϕ 5/8"x6"	blue
6061-T651 Aluminum	Brinell: 95 Rockwell B: 60	45	1/2"x3"x3" ϕ 5/8"x6"	blue-green, AL 6061
C36000-H1 Brass	Rockwell B: 62	55.8	1/2"x3"x3" ϕ 5/8"x6"	orange, BRS 36000
A36 Hot-Rolled Steel	Brinell: 119-159 Rockwell B: 67-83	58 - 80	1/2"x3"x3" ϕ 5/8"x6"	green-white, ST A36
C1018 Cold-Drawn Steel	Brinell: 126 Rockwell B: 71	63.8	1/2"x3"x3"	red-white, ST 1018
2024-T4 Aluminum	Brinell: 120 Rockwell B: 75	68.2	1/4"x1"x6" ϕ 5/8"x6"	blue-red, AL 2024
7075-T651 Aluminum	Brinell: 150 Rockwell B: 87	82.7	ϕ 5/8"x6"	blue-yellow, AL 7075
1035 Cold-Drawn Steel	Brinell: 170 Rockwell B: 86	84.8	ϕ 5/8"x6"	red-orange, ST 1035
1045 Cold-Drawn Steel	Brinell: 187 Rockwell B: 90 Rockwell C: 10	95	1"x1"x3" ϕ 5/8"x6"	red-yellow, ST 1045
C95400 Aluminum Bronze	Brinell: 195 Rockwell B: 94	89.9	1/2"x3"x3"	BRZ 95400
4140 Annealed Steel	Brinell: 197 Rockwell B: 92 Rockwell C: 13	95	1/2"x3"x3"	ST 4140
4130 Steel	Brinell: 197 Rockwell B: 92 Rockwell C: 13	97.2	1/4"x5/8"x6"	ST 4130
Gray Cast Iron	Brinell: 183-234 Rockwell B: 97 Rockwell C: 20	40 (minimum)	ϕ 3/4"x6"	green
Buna-N Square O-Ring Cord Stock	Shore A: 70-75	---	3/4"x3/4"x6"	yellow
Low-Density Polyethylene	Rockwell R: 60 Shore D: 42	1.6	1"x1"x6"	red
High-Density Polyethylene	Rockwell R: 65 Shore D: 68	4.4	1"x1"x6"	black
Polypropylene	Rockwell R: 92 Shore D: 77	4.8	1"x1"x6"	green
PVC Type I	Rockwell R: 110 Shore D:80	7.3	1"x1"x6"	orange-silver
PVC Type I	Rockwell R: 114 Shore D: 89	7.5	1"x1"x6"	orange-gold
Cast Acrylic	Rockwell M: 93	10	1" cube	blue

Hand Calculations - Lab #8 Hardness Testing

$$HB = \frac{2P}{\pi D[D - \sqrt{(D^2 - d^2)}]}$$

4140 Steel: $d = 5$ mm

$$\frac{2(3000)}{\pi(10)[10 - \sqrt{(10^2 - 5^2)}]} = \underline{\underline{142.55}}$$

1045 : $d = 3.9$ mm

$$\frac{2(3000)}{\pi(10)[10 - \sqrt{10^2 - 3.9^2}]} = \underline{\underline{241}}$$

C 1018 Cold Drawn Steel $d = 4.6$

$$\frac{2(3000)}{\pi(10)[10 - \sqrt{10^2 - 4.6^2}]} = \underline{\underline{170}}$$

Use the Eqn only if diameter is not listed in the chart provided on the Brinnel machine

To: IDE 120 Section E Students
From: Krishna Kolan, GTA; Sean Smith, TA;
Subject: Lab # 9 – Fastener Testing & Wood Connections
Date: April 5, 2010
Report Due: April 12, 2010

Lab Background

This in the lab this week we will be testing fasteners. Fasteners are used in almost all items made from more than one part. Understanding how to select appropriate fasteners for a given situation is important to ensure a safe design. Also, we will be performing two demo tests on Wood.

Lab Procedure

1. Each group member will select a fastener to perform hardness tests on according to ASTM standard F606. The fastener to test can be any of the nuts, bolts, and washers available in the lab.
2. Each group will need to perform hardness tests and a tension test according to standard F606 on a 3/8"-16 UNC bolt provided in the lab. There is no set procedure to follow this week. It is up to each group to determine how to test the fasteners in accordance with the standard. Be sure to read the appropriate sections of the standard before beginning. Also, make sure to fully document your testing methods so you can describe your testing methods when writing your report.

Lab Report

The lab report for this lab should be a formal TEAM REPORT written by your group, worth 100 points. Remember to follow the guidelines you were given covering formal reports along with the guidelines for graphs and tables. The following describes what should be included in several sections of your report.

Procedure:
Be very thorough when describing your testing methods. You need to describe where the fasteners were tested, how many tests were performed, any assumptions your group made during the tests, and any other important information.

Experimental Results:
Report all the hardness values found for your fasteners along with an average value for each fastener. For the 3/8"-16 UNC bolt, use your average hardness value to estimate the tensile strength from the same table used in the Hardness Testing Lab. Also, calculate and report the actual tensile strength of the bolt found from the tension test. The actual tensile strength can be calculated using Eqs. (1) and (2). In Eq. (2), the major diameter of the bolt is 3/8 in. and the number of threads per inch is 16.

Discussion of Results:
In this section you should determine the SAE grade for each of your fasteners if it was unknown before testing. Use the reference table on the back of this page to determine the SAE grade. Select the highest grade that the fastener satisfies based on hardness. If the grade of your fastener was known before testing, compare

your experimental values to the reference values using percent difference. For the 3/8-16 UNC bolt tested both by hardness testing and tension testing, compare your hardness test estimated tensile strength to the actual tensile strength from the tension test. Also, compare both your estimated and actual tensile strengths to the minimum value given in the reference table. Finally, compare all your fasteners based on hardness and discuss if the results match what was expected prior to testing.

Conclusions:

You should mention any difficulty you had while following the ASTM standard in your conclusion. Also, discuss any changes you would make to your testing procedure if you were to repeat the tests.

Equations

(1) Bolt Tensile Strength:

$$S_{ut} = \frac{F}{A_s}$$

S_{ut}= tensile strength
F = load, lb
A_s = thread stress area, in^2

(2) Thread Stress Area:

$$A_s = 0.7854\left(D - \frac{0.9743}{N}\right)^2$$

A_s= thread stress area, in^2
D= major diameter, in
N= threads per inch, tpi

Reference Values

SAE Grade	Diameter (in)	Minimum Tensile Strength (ksi)	Hardness	
			Minimum	Maximum
1	0.25 – 1.5	60	70 HRB	100 HRB
2	0.25 - 0.75	74	80 HRB	100 HRB
5	0.25 - 1	120	25 HRC	34 HRC
8	0.25 – 1.5	150	33 HRC	39 HRC

(Source: www.zerofast.com/markings.htm)

Note: ASTM A307 bolts have the same required properties as SAE Grade 1

Wood Connections

We will be performing two tests on wood this week. The entire class will work together to perform the plate-connector joint test and the janka hardness test. The procedure for each test is listed below.

Plate-Connector Joint Test (ASTM D1761)

1) Obtain (2) 1"x2"x6" pieces of pine, (2) Simpson MP14 mending plates, (2) 1"x3"x6" pieces of pine, and (2) Simpson MP24 mending plates.
2) Use a hammer to attach an MP14 mending plate to each side of the 1"x2"x6" pieces butted end-to-end. Also use a hammer to attach an MP24 mending plate to each side of the 1"x3"x6" pieces butted end-to-end.
3) Load the 1"x2"x6" specimen with the MP14 plates into the testing machine and secure the specimen using the machine's pneumatic grips.
4) Apply load to the specimen using a cross-head speed of 0.035 in/min and a maximum displacement of 0.600 in.
5) Once the load begins to decrease, stop the test and record the maximum load from the computer.
6) Repeat steps 3 through 5 for the 1"x3"x6" specimen with the MP24 mending plates.

Janka Hardness Test (ASTM D143)

1) Select a wood test specimen of your choice.
2) Load the block in the testing machine and move the cross-head which holds janka indenter down until it is nearly touching the specimen.
3) Zero the load and reset the gage length on the machine.
4) Apply load to the specimen using a cross-head speed of 0.25 in/min.
5) The machine is preset to stop when the janka indenter drives a distance of 0.222" into the specimen.

Obtain the maximum load from the computer for the specimen you have selected and compare it with the reference values given in the datasheet.

Also, include these results in your report:

1. Show the maximum load supported by the two different Simpson plate-connector joints. Also, calculate the load per tooth for each plate-connector and discuss whether the results are as you would expect.

2. For the janka hardness test you need to report the maximum load for the specimen you have selected from the test. You will also need to calculate the percentage of error when compared with the reference values given in the handout.

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Lab #6 – Composite Beams

IDE 120 Section E

David Malawey

Jake Spooler

Scott Kapshandy

Due 3/15/10

GTA – Krishna Kolan

TA – Sean Smith

Good Job but where's the Data sheet ??

Introduction

Composites are materials that are combinations of two or more organic or inorganic components. One material serves as a matrix. One material holds everything together, while the other material serves as reinforcement, in the form of fibers embedded in the matrix. Composites are commonly used in today's world. Some examples of common composites are: wood, bone, muscle, fiberglass, and pre-stressed steel-concrete beams. These are just a tiny example of the numerous, widely used composite materials. This lab purposes to measure strain associated with composite materials and learn how properties differ from one solid material.

Objectives:

Test the behavior of a composite beam with regard to stress and loading. Find stress and strain values for a composite beam, and compare them to theoretical values based on hand calculations. Portray the findings with a report, including graphs and tables.

Procedure:

1) Aluminum section was placed face up and a point was selected to apply load.
2) Measure all the required dimensions and record them on your data sheet.
3) Connect the strain gages to the strain indicators. Then zero the amp, set the gage factor, and balance the load.
4) Apply load to the beam in 10 lb increments from 0 to 100 lb. Record the strain values from the two indicators at each 10 lb load increment.
5) Make calculations based on recorded data

Experimental Results

Using the data from Table 4, which shows the strain in each component of the composite beam, it was calculated that the neutral axis was a distance of .416 inches from the bottom of the beam. It was also calculated that the stress per unit load of the stainless steel was 36.6 in2 and 19.12 in2 on the aluminum. Theoretically, the distance from the bottom of the beam to the neutral axis was 0.385 inches, the stress per unit load of the stainless steel was 32.86 in2, and the stress per unit load of the aluminum was 37.15 in2. Graph 1 is a visual representation of the stress in each component of the composite beam vs. the load that was applied. Both plots are linear, but the slope for the stainless steel is about 1.9 times steeper than the slope of the aluminum.

It is always good to include equations along the text instead of mentioning them in Appendix.

Discussion of Results

Comparing our theoretical results to our experimental results using percent errors, it can be concluded that the distance to the neutral axis was off by 7.7%. The stress per unit load for the stainless steel was off by 10.8%, and the stress per unit load for the aluminum was off by a huge 64.1%. The composite beam theory predicted our experimental values reasonably well aside from aluminum. No reason could be found why it was so far off, however the values were checked several times. It should be noted that the procedure has been changed from having steel on top to having aluminum on top.

Composite materials are significant because they allow a single material to obtain the properties of multiple materials. This has proven to be an excellent way to create materials desired for specific functions. One natural composite material we use widely is wood, which has an oriented hard phase providing strength and stiffness, as well as a soft phase providing toughness to the material, keeping it from buckling and snapping as it would if it were only hard. The materials of wood are lignin and cellulose. The lignin bonds to the cellulose chains and holds them together, and is the source of the pliability of the wood which gives it toughness. The cellulose chains are the hard material which contributes strength and stiffness to the wood.

Concrete is a manmade composite material designed for construction, and it has three ingredients: cement, water, and an aggregate. Cement consists of a mixture of calcium, silicon, and aluminum, and gives concrete its defining property of hardening into a solid state. Water makes the cement into a paste, which makes it easy to work with and fills in voids between the cement and aggregate. As a paste, the cement can be poured into the desired area, then when the water evaporates, a strong durable concrete is left over. The paste also acts as glue for the aggregate into the cement. Aggregate is usually sand, gravel, or limestone, and makes up the bulk of the concrete mixture. The aggregate contributes the strength of its material to the concrete composite.

Conclusions:

The basic findings of the experiment show that the composite beam formula is useable aside from some error involved in the particular results for aluminum. All objectives were filled, and it was found that a composite beam could yield good properties of both materials included in it. It would be good in the future to have more results produced by repeating the experiment for each group.

References

Blackboard Academic Suite
<https ://blackboard.mst.edu/webapps/login/?new_loc=%2rwebapp s%fframeset.jsp>
http://composite.about.com/1ibrary/g1ossary/ntldefn5 htm
http://studiorob.blogspot.comJ2008/O4/wood-natural-compositematerial.html
http://en. wikipedia. org/wiki/Composite.material
http://en.wikipedia.org/wiki/Concrete

you lost points by not attaching Data Sheet

Appendix A: Tables

Table 1: Experimental Values

E ss (psi) =	28*10^6
E al (psi)=	10.6*10^6
stress/load ss (1/in^2)	36.60
stress/load al (1/in^2)	-19.12
strain/load ss (microstrain/lb)	1.307
strain/load al (microstrain/lb)	-1.804
y exp (in. from bottom)	0.416

Table 2: Theoretical Values

n, ratio of E's	2.642
modified base ss = n*b ss (in)	2.616
y theoretical (in. from bottom)	0.385
I N.A. (in^4)	0.1249
stress/load ss (1/in^2)	32.86
stress/load al (1/in^2)	37.15

Table 3: Results comparison

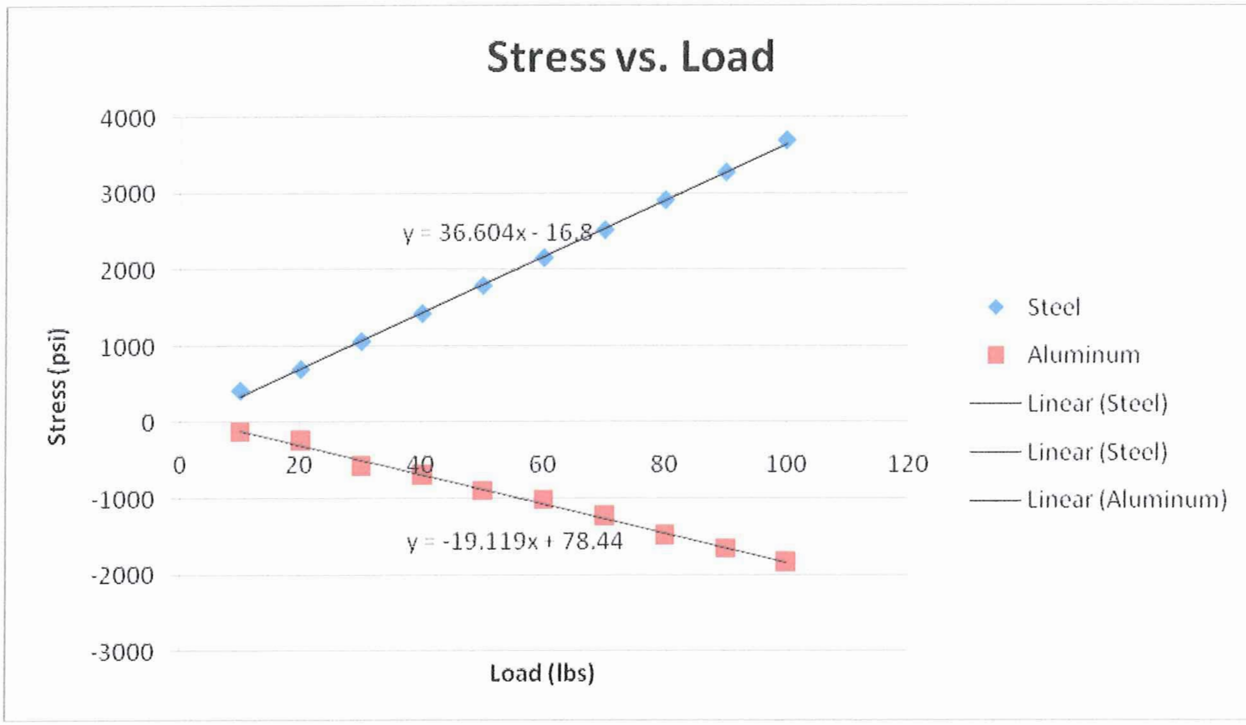
	Theoretical Results	Experimental Results	Percent Difference
Stress-Load Ratio (SS)	32.86	36.60	10.8%
Stress-Load Ratio (AL)	37.15	19.12	64.1%
Neutral Axis Location	0.385	0.416	7.7%

Table 4: Raw data

Load (lbs)	Steel Strain (micro-strain)	Aluminum Strain (micro-strain)	Steel Stress (psi)	Aluminum Stress (psi)
10	15	-12	420	-127.2
20	25	-22	700	-233.2
30	38	-54	1064	-572.4
40	51	-65	1428	-689
50	64	-85	1792	-901
60	77	-96	2156	-1017.6
70	90	-116	2520	-1229.6
80	104	-139	2912	-1473.4
90	117	-156	3276	-1653.6
100	132	-173	3696	-1833.8

Appendix B: Figures

Graph 1 – Stress vs. Load



Appendix C: Equations

(1) Uniaxial Hooke's Law

$$\sigma_i = E_i \varepsilon_i$$

$$\frac{\varepsilon_i}{P} = \left(\frac{1}{E_i}\right)\left(\frac{\sigma_i}{P}\right)$$

σ_i = stress in material i, psi

E_i = modulus of elasticity of material i, psi

ε_i = axial strain in material i, in/in

P = load, lb

(2) Experimental Neutral Axis

$$\bar{y}_{exp} = \frac{h_{ss} + h_{al}}{1 + \left|\frac{\varepsilon_{ss}/P}{\varepsilon_{al}/P}\right|}$$

$\bar{y}_{exp}$ = location of neutral axis, in (from bottom)

h_{ss} = height of S.S. section, in

h_{al} = height of aluminum section, in

ε_i / P = strain per unit load in material i, in/(in-lb)

(3) Ratio of E's for Composite Beam

$$n = \frac{E_{ss}}{E_{al}}$$

n = ratio of E's

E_i = modulus of elasticity of material i, psi

(4) Theoretical Stresses per Unit Load

$$\frac{\sigma_{al}}{P} = \frac{\left(\frac{L_g L_2}{L}\right)\bar{y}_{th}}{I_{NA}}, \quad \frac{\sigma_{ss}}{P} = \frac{n\left(\frac{L_g L_2}{L}\right)\left(h_{ss} + h_{al} - \bar{y}_{th}\right)}{I_{NA}}$$

$\frac{\sigma_i}{P}$ = stress per unit load, in^{-2}

L_g = distance to strain gages, in

L_2 = distance from load to closest support, in

L = length of beam, in

I_{NA} = moment of inertia of transformed cross section about neutral axis, in^4

$\bar{y}_{th}$ = location of neutral axis of transformed cross section, in (measured from bottom)

Composite Beams   Sample Calculations

1) $\sigma_{SS} = E_{SS}\,\varepsilon_{SS} = (28\times10^{6}\ psi)(15\times10^{-6}\ in/in) = 420\ psi$

$\sigma_{AL} = E_{AL}\,\varepsilon_{AL} = (10.6\times10^{6}\ psi)(-12\times10^{-6}\ in/in) = -127.2\ psi$

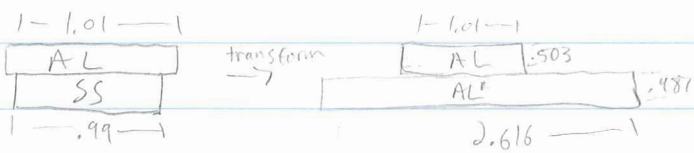
2) $\frac{\varepsilon_{SS}}{P}\ exp. = \left(\frac{1}{E_{SS}}\right)\left(\frac{\sigma_{SS}}{P}\right)_{\text{lin regress}} = \left(\frac{1}{28\times10^{6}}\right)\left(36.6\ \frac{1}{in^2}\right) = 1.307\times10^{-6}\ in/in\ lb$

$\frac{\varepsilon_{AL}}{P}\ exp. = \left(\frac{1}{E_{AL}}\right)\left(\frac{\sigma_{AL}}{P}\right)_{\text{from lin. regress}} = \left(\frac{1}{10.6\times10^{6}}\right)\left(-19.12\ \frac{1}{in^2}\right) = -1.804\times10^{-6}\ \frac{in}{in\ lb}$

3) $y_{exp} = \dfrac{h_{SS} + h_{AL}}{1 + \left(\frac{\varepsilon_{AL}/P}{\varepsilon_{SS}/P}\right)}$ ← NOTE: formula changed, $\left(\frac{\varepsilon_{SS}/P}{\varepsilon_{AL}/P}\right) \Rightarrow \frac{\varepsilon_{AL}/P}{\varepsilon_{SS}/P}$ because aluminum was on top, ~~not~~ not steel

$y_{exp} = \dfrac{.487 + .503}{1 + \left|\frac{-1.804}{1.307}\right|} = .416$ in from bottom

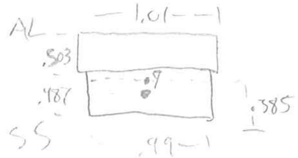
4) $n = \dfrac{E_{SS}}{E_{AL}} = \dfrac{28\times10^{6}}{10.6\times10^{6}} = 2.642$

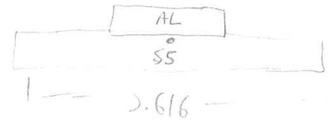


$\bar{Y}_{theoretical} = \dfrac{\bar{y}_{AL}A_{AL} + \bar{y}_{SS}A_{SS}}{A_{AL} + A_{SS}} = \dfrac{\left(h_{SS} + \frac{h_{AL}}{2}\right)(h_{AL}b_{AL}) + \left(\frac{h_{SS}}{2}\right)(h_{SS}\,n\,b_{SS})}{(h_{AL}b_{AL}) + (h_{SS}\,n\,b_{SS})}$

$\bar{Y}_{theoretical} = \dfrac{\left(.487 + \frac{.503}{2}\right)(.503\times1.01) + \left(\frac{.487}{2}\right)(.487)(2.642)(.99)}{(.503)(1.01) + (.487)(2.642)(.99)}$

$\bar{y}_{theoretical} = \dfrac{.6853}{1.78} = .385$ in from bottom





5)

$$I_{NA} = I_{SS} + (\bar{y}_{SS})^2 A_{SS} + I_{AL} + (\bar{y}_{AL})^2 A_{AL}$$

$$I_{NA} = \frac{(.487)^3(2.616)}{12} + \left(.385 - \frac{.487}{2}\right)^2 (2.616)(.487) + \frac{(1.01)(.503)^3}{12} + \left(\frac{.503}{2} + (.487 - .385)\right)^2 (.503)(1.01)$$

$$I_{NA} = .02518 + .02551 + .01071 + .06349$$

$$I_{NA} = .1249 \text{ in}^4$$

6)

$$\frac{\sigma_{AL}}{P} = \frac{\left(\frac{L_1 L_2}{L}\right)(h_{AL} + h_{SS} - \bar{y} + h)}{I_{NA}} = \frac{\frac{(12.875)(10.5)}{(33.5)} \times (.503 + .487 - .385)}{.1249 \text{ in}^4}$$

$$\frac{\sigma_{AL}}{P} = 37.15 \frac{1}{in^2}$$

$$\frac{\sigma_{SS}}{P} = \frac{n\left(\frac{L_1 L_2}{L}\right)(\bar{y} + h)}{I_{NA}} = \frac{(2.642)\left(\frac{12.875 \times 10.5}{33.5}\right)(.385)}{.1249 \text{ in}^4}$$

$$\frac{\sigma_{SS}}{P} = 32.86 \frac{1}{in^2}$$

7)

$$\%\ \text{Difference} = \frac{|Exp_1 - Exp_2|}{\frac{(Exp_1 + Exp_2)}{2}} (100\%) = \frac{|32.86 - 36.6|}{\frac{(32.86 - 36.6)}{2}} (100)$$

$$\%\ \text{Diff} = 10.8\%$$

To: IDE 120 Section E Students
From: Krishna Kolan, GTA; Sean Smith, TA;
Subject: Lab #8– Hardness Testing
Date: March 22, 2010
Report Due: April 5, 2010

Lab Background

In this lab we will be performing hardness tests on different materials. There are many different hardness tests that can be performed. Hardness tests are very useful since they are fast, cheap, and usually non-destructive.

Lab Procedure

Each group member will select specimens to perform hardness tests on. Each person needs to select a specimen for Brinell testing, a specimen for Rockwell testing, and a specimen for polymer testing. When selecting your materials, make sure a reference value is given on the data sheet for the test you intend to perform on the material. Once you have selected your materials, you need to complete the following steps. The Brinell, Rockwell, and polymer tests can be performed in any order.

Brinell Test

1) Use the Brinell hardness testing machine to create an indention in your specimen. Select a location at least 2.5 times the indention diameter away from the specimen edge and the edge of any previous test.
2) Measure the diameter of the indention from the Brinell test using a microscope. The numbers read from the microscope are in millimeters.
3) Use the indention diameter to find the Brinell hardness number (HB) using the chart on the front of the machine. If your diameter is not on the chart, use Eq. (1) to calculate HB.
4) Estimate the tensile strength of your specimen by using the chart on the wall in the lab. When using the chart you do not need to interpolate. Select the value closest to your HB and use that value to estimate tensile strength.

Rockwell Test

1) Perform three Rockwell tests on your specimen. The distance between any two indentions should be 3 times the indention diameter and the centers of all indentions must be 2.5 times the indention diameter away from the edge of the specimen.
2) Read the Rockwell hardness number from the machine and record it on your data sheet. If you get a Rockwell B number above 100, you should switch to the Rockwell C machine and perform three hardness tests using that machine.
3) Average your three Rockwell hardness numbers.
4) If testing on a cylindrical face of a specimen you need to apply a correction factor. These correction factors can be found on the wall chart or in Tables 11 and 12 of ASTM E18 available on the IDE 120 lesson page for this lab.
5) Use your average Rockwell hardness number to estimate the tensile strength of your specimen using the chart on the wall. Again, you do not need to interpolate when using the chart.

Polymer Test

1) Select a polymer and determine which test you want to perform. You should choose a test that has a reference value given on the data sheet.
2) You need to perform hardness tests at three different locations on your polymer specimen.
3) Average your three hardness values.
4) You do not need to estimate the tensile strength of the polymer you test.

Lab Report

The format for your lab report should be a TEAM MEMO worth 50 points written by your group. Don't forget to attach your individual initialed data sheets to the memo. Include a table showing your results for the lab. Compare your hardness and tensile strength values with reference values for your materials. The reference values you should use are provided on the data sheet. Calculate the percent errors for each value and include this information in your table. You will not have a percent error comparison for the tensile strength of your polymer since it was not determined experimentally.

You need to discuss in your memo how well your experimental values match the reference values. Give reasons for any major differences between the values.

Equations

(1) Brinell Hardness (HB):

$$HB = \frac{2P}{\pi D\left[D - \sqrt{(D^2 - d^2)}\right]}$$

P= Load, kg
D= Indenter Diameter, mm
d= Indention Diameter, mm

To: IDE 120 Section E Students
From: Krishna Kolan, GTA; Sean Smith, TA
Subject: Lab # 7 – Beam Deflection
Date: March 15, 2010
Report Due: March 22, 2010

Lab Background

Beam deflection is an important topic since beams are found everywhere and understanding how they deform due to load is crucial when designing structures.

Lab Procedure

Each group will perform a beam deflection test on a cantilevered wood beam and a simply supported aluminum beam. The following steps should be followed in the lab:

1) Place the dial indicators in the proper locations. For the wood beam, one indicator should be placed roughly half way along the span and the other indicator should be placed near the free end. On the aluminum beam, one indicator should be placed a distance of L/4 from one support and the other indicator should be placed close to the center of the beam.
2) Measure all the dimensions required on your data sheet.
3) Place the weight hanger on the beam at the appropriate location.
4) Zero the dial indicators.
5) Apply load in 0.5 lb increments from 0 to 5 lb for the wood beam. For the aluminum beam, apply load in 5 lb increments from 0 to 50 lb. Record the deflections measured by the indicators at each load increment.

Calculations

1) You should begin your calculations by entering your data in Excel.
2) √ Use Excel to create two graphs (one for Aluminum and one for wood). The first graph should show deflection (y-axis) vs. load (x-axis) for the two indicators on the aluminum beam. The second graph should show deflection vs. load for the wood beam.
3) √ Use linear regression on the deflection vs. load data for each indicator to find the slope $\left(\frac{y_i}{P}\right)_{exp}$ of the regression line through the data.
4) √ Apply the beam theory formula given in Eq. (1) to find the theoretical deflection per unit load $\left(\frac{y_i}{P}\right)_{th}$ for the two indicators on the aluminum beam. When using Eq. (1), assume E_{al} = $\boxed{E_{Al} = 10.6\text{x}10^6 \text{ psi.}}$ The x in Eq. (1) is the distance from the left support to the indicator position since we have defined our x = 0 location at the left end of the beam.
5) √ Find the experimental value for the modulus of elasticity of wood (E_{wood}) by using Eq. (2). The reference value of modulus of elasticity for your particular wood beam can be found on the data sheet.

Lab Report

The report for this lab should be a TEAM REPORT written by your group worth 100 points. Make sure to attach your initialed data sheet and a set of hand calculations. The following describes what is expected in two sections of your report.

Experimental Results

Include a table of your experimental data. Also, include the graphs created when performing regression. Show your calculated theoretical deflection per load for the aluminum and experimental modulus of elasticity of the wood. Summarize your experimental and theoretical values in a table.

Discussion of Results

In this section you should compare your experimental values to theoretical or reference values using percent errors. You also need to give an explanation for any major differences between your experimental and theoretical or reference values. Include an explanation of how well the assumptions of beam theory were met for each of the materials tested. Also, discuss whether the beam theory worked better for aluminum or for wood based on the percent differences you found.

Equations

(1) Deflection per Unit Load (Al Beam)

$$\left(\frac{y_i}{P}\right)_{th} = \frac{x\left(3L^2 - 4x^2\right)}{48E_{al}I_{NA}}$$

$\left(\frac{y_i}{P}\right)_{th}$ = theoretical deflection per unit load, in/lb

x = distance from left support, in

L = length of beam, in

E_{al} = modulus of elasticity of Al, psi

I_{NA} = moment of inertia, in^4

(2) Modulus of Elasticity of Wood

$$E_{wood} = \frac{x^2(3L - x)}{6I_{NA}\left(\frac{y_i}{P}\right)_{exp}}$$

E_{wood} = modulus of elasticity of wood, psi

x = distance from left support, in

L = length of beam, in

$\left(\frac{y_i}{P}\right)_{exp}$ = experimental deflection per load, in/lb

I_{NA} = moment of inertia, in^4

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Lab #5 – Strain Gages, Flexure Testing for Elastic Constants

IDE 120 Section E

David Malawey

Jake Spooler

Scott Kapshandy

Due 03/01/10

GTA – Krishna Kolan

TA – Sean Smith

Introduction:

There are many different elastic constants in engineering, and most relate the elastic displacement in a material to an applied load. This lab considered the modulus of elasticity, modulus of rigidity, and Poisson's ratio. These particular elastic constants are used when applying Hooke's law to relate stress and strain in a material. Magnesium will be the material used for this lab.

Objectives:

The objective of this lab was to acquire knowledge of how strain gages function in finding elastic constants of materials. An understanding of Hooke's law, modulus of elasticity, modulus of rigidity, and Poisson's ratio and how to calculate each value should also be acquired.

Procedure:

1. Measure and record the length between supports, cross-sectional dimensions of the beam, and the distance to the strain gages from the nearest support. (measurements recorded on Appendix D: Experimental Data Sheet
2. Place the weight hanger on the beam making sure it is centered between the supports.
3. Determine the orientation of the two strain gages on the beam. One gage measures axial strain and the other measures transverse strain so it is important to know which is which.
4. Connect the strain gages to the strain indicators. Then zero the amp, set the gage factor, and balance the strain.
5. Magnesium Beam procedure (lighter weight)- place weights on the hanger in 1 lb increments until the total weight reaches 10 lb. Record the strains at each 1 lb increment.

Experimental Results:

The calculated Modulus of Elasticity (E) was 6.529(10^6) psi, the modulus of rigidity was 2.4983(10^6) psi and Poisson's ratio was calculated to be .3067. See Appendix A, Table 1 for a comparison of these values to referenced values. See appendices D and E for the raw data acquired and the equations used to calculate the elastic constants.

This section should be in detail.
1) mention the Eqns you've used here ~~and~~ Explaining how you used & calculated.
2) maintain uniform font size throughout the report

Discussion of Results:

Tables 2 and 3 in Appendix A display the experimental data that was acquired from the strain gages. These values were used to create the graphs in Appendix B, Figures 1 and 2. Figure 1 is a visual representation of how load affects axial strain. Figure 2 is a comparison of transverse strain and axial strain. Elastic constants were derived from raw data using equations in appendix E, shown in "hand calculations" attachment. To find Poisson's ratio, transverse and axial strains were put into ratio form. Experimental data was compared with referenced values for elastic constants of magnesium in Table 1 with percent differences calculated. Experimental values came very close to referenced values from "engineeringtoolbox." Slight deviations may be due to unbalanced weight placement on the magnesium specimen or imperfect length and width measurements of the specimen.

Conclusions:

It was found that an apparatus like the one in this experiment's procedure, with strain gauges and hanging weights is a very accurate way to find elastic constants in a material. Both transverse and axial deformations are linear in the elastic range, and the magnesium bar proved to be within close tolerances of referenced values for Elastic Modulus, Modulus of Rigidity, and Poisson's Ratio (as shown in table 1).

References:

Blackboard Academic Suite
http://blackboard.mst.edu/webapps/portal/frameset.jsp?tab_id=_2_1&url=%2fwebapps%2fblackboard%2fexecute%2flauncher%3ftype%3dCourse%26id%3d_47924_1%26url%3d

Magnesium Referenced Elastic Constants- engineeringtoolbox.com

Attachments-

Appendix A: Tables

Appendix B: Figures

Appendix C: Hand Calculations

Appendix D: Experimental Data Sheet

Appendix E: Equations Used

Appendix A: Tables

Magnesium	E (psi)	G (psi)	V (Poisson's ratio)
Experimental	6.529 x10^6	2.4983 x10^6	.3067
Referenced	6.4 x 10^6	2.4 x 10^6	0.35
% Difference	2.0	4.01	-13.19

Table 1: Comparison of Experimental Constants and Referenced Constants

ΣNA^2 ?

Load Vs Axial Strain	
Load (lb)	Axial Strain (micro-strain)
5	-23
10	-47
15	-71
20	-93
25	-115
30	-135
35	-155
40	-173
45	-193
50	-205

Table 2: Load vs. Axial Strain

Transverse Strain Vs Axial Strain	
TS (micro-strain	AS (micro-strain)
5	-23
11	-47
18	-71
24	-93
30	-115
37	-135
43	-155
49	-173
55	-193
62	-205

Table 3: Transverse vs. Axial Strain

Appendix B: Figures

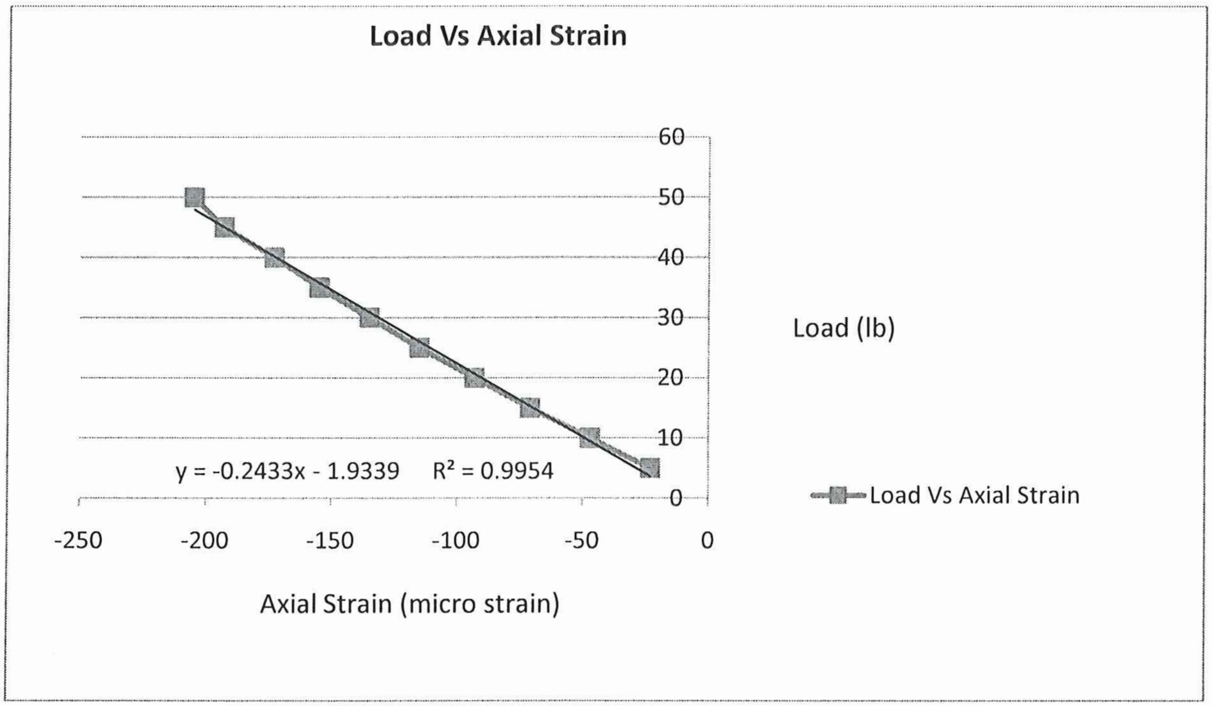


Figure 1: Load vs. Axial Strain Plot

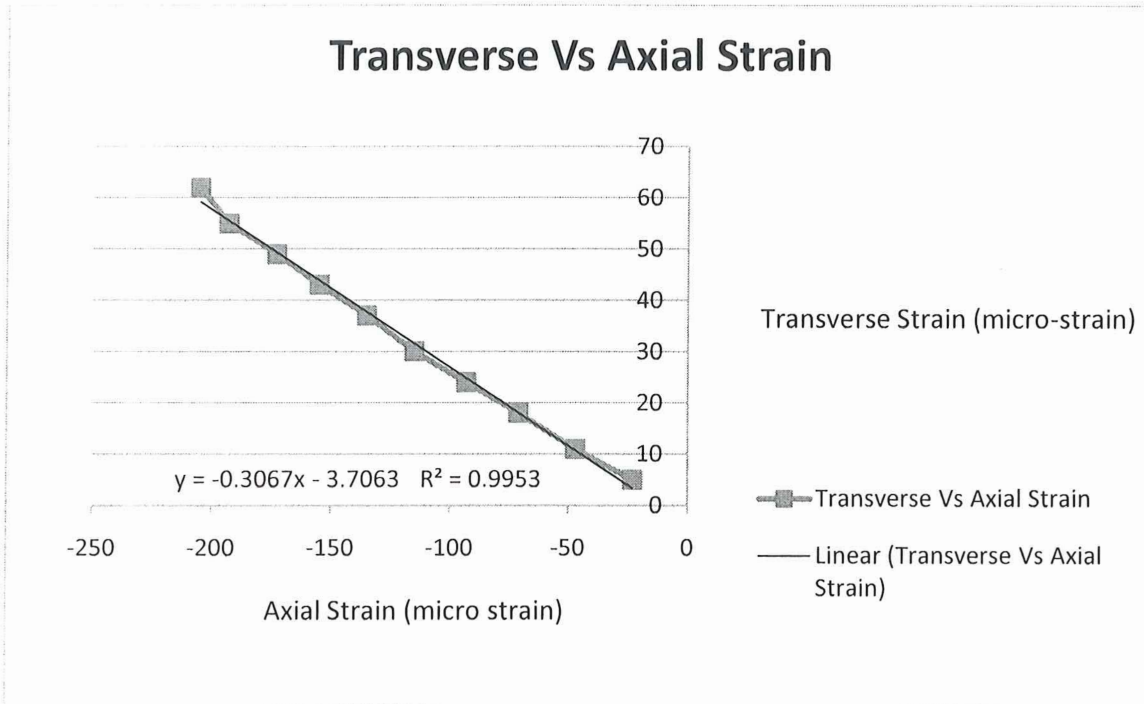


Figure 2: Transverse Strain vs. Axial Strain

Appendix C:

Hand Calculations:

Group 8

1. Poisson's Ratio

$$\nu = \left| \frac{\Delta \varepsilon_{transverse}}{\Delta \varepsilon_{axial}} \right| = \boxed{0.3067}$$

2 Modulus of Elasticity

$$E = \left(\frac{yd}{2I_{NA}}\right) \left| \left(\frac{\Delta P}{\Delta \varepsilon_{axial}}\right) \right|$$

(x10^6)

$$E = \frac{(.38in)(7.75in)}{2(.054872in^4)} (0.2433\ lb) = 6.529\ lb/in^2 = \boxed{6.529\ psi}$$

3. $I_{NA} = \frac{1}{12}bh^3 = \frac{1}{12}(1.5)(.76)^3 = \boxed{0.054872\ in^4}$

4. $$G = \frac{E}{2(1+\nu)} = \frac{6.529\ lb/in^2}{2(1+.3067)} = \boxed{2.4983\ psi}$$

(x10^6)

Appendix D: experimental data sheet

IDE 120 – FLEXURE TESTING FOR ELASTIC CONSTANTS

Section (circle): A B C D E F G H I J K Date: 2-22-10

Group (circle): 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Data Recorder: Scott Kopshandy

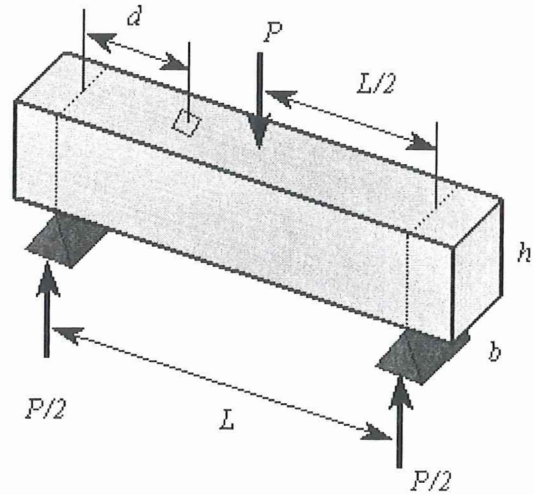
L: 30 in

b: 1.5 in

h: 0.76 in

d: 7.75 in

material: Magnesium



Load (lb)	Axial Strain (micro-strain)	Transverse Strain (micro-strain)
5	-23	+5
10	-47	+11
15	-71	+18
20	-93	+24
25	-115	+30
30	-135	+37
35	-155	+43
40	-173	+49
45	-193	+55
50	-205	+62

Appendix E: Equations Used

Equations

(1) Poisson's Ratio

$$\upsilon = \left| \frac{\Delta \varepsilon_{transverse}}{\Delta \varepsilon_{axial}} \right|$$

υ = Poisson's ratio

$\frac{\Delta \varepsilon_{transverse}}{\Delta \varepsilon_{axial}}$ = slope of transverse strain vs. axial strain line

(2) Modulus of Elasticity

$$E = \left(\frac{yd}{2I_{NA}} \right) \left(\left| \frac{\Delta P}{\Delta \varepsilon_{axial}} \right| \right)$$

E = modulus of elasticity, psi

y = distance from neutral axis, in

d = distance from support to strain gage, in

I_{NA}= moment of inertia about the neutral axis, in^4

$\frac{\Delta P}{\Delta \varepsilon_{axial}}$ = slope of load vs. axial strain plot, lb

(3) Area Moment of Inertia

$$I_{NA} = \frac{1}{12} bh^3$$

I_{NA} = area moment of inertia, in^4

b = width of beam, in

h = height of beam, in

(4) Modulus of Rigidity

$$G = \frac{E}{2(1+\upsilon)}$$

G = modulus of rigidity, psi

E= modulus of elasticity, psi

υ = Poisson's ratio

% Error:

$$\%Error = \frac{|\text{Exp. Value - Ref. Value}|}{\text{Ref. Value}}(100\%)$$

Eqns should be mentioned in Exp Results in line with text.

To: IDE 120 Section E Students
From: Krishna Kolan, GTA; Sean Smith, TA;
Subject: Lab # 6 – Composite Beams
Date: March 1, 2010
Report Due: March 15, 2010

Lab Background

In this lab we will be working with beams made of two different materials. These beams are considered composites since they are made of more than one material. Composites are widely used today and it is important to understand how their properties differ from parts made of a single material.

Lab Procedure

The procedure we will follow in the lab is very similar to the one used for the elastic constants lab. We will use composite beams made by connecting an aluminum section to a stainless steel section. Two strain gages are attached to each beam. One strain gage is attached to the top surface of the beam and the other is attached to the bottom surface. Both gages are aligned to measure axial strain. The following steps should be completed in the lab:

1) Make sure the stainless steel section is facing up and then select a point to apply the load. If using the lathe bed tester, place the weight hanger on the beam in the location where you want to apply the load. You can select any arbitrary location for the load that satisfies Saint-Venant's principle.
2) Measure all the required dimensions and record them on your data sheet.
3) Connect the strain gages to the strain indicators. Then zero the amp, set the gage factor, and balance the load.
4) Apply load to the beam in 10 lb increments from 0 to 100 lb. Record the strain values from the two indicators at each 10 lb load increment.

Calculations

<u>Experimental</u>

1) Begin your calculations by entering your data in Excel.
2) Convert your strains into stresses using the first form of the uniaxial version of Hooke's law given as Eq. (1).
3) Use Excel to create a stress (y-axis) vs. load (x-axis) plot. Plot the points for the aluminum and stainless steel on the same graph.
4) Use linear regression to find the slope of the two lines which will give the stress per unit load $\left(\frac{\sigma_i}{P}\right)$ for each material.
5) Calculate the strain per unit load $\left(\frac{\varepsilon_i}{P}\right)$ by using Eq. (1) in the second form given. The $\left(\frac{\sigma_i}{P}\right)$ term in this form of Eq. (1) is just the regression slope found in step 4.
6) Finally, find the location of the experimental neutral axis by plugging your strain per unit load values found in step 5 into Eq. (2).

Theoretical

The composite beam theory is based on transforming the cross section into an equivalent cross section composed of only one material.

1) Begin transforming the cross section by finding the ratio of the modulus of elasticities (n) of the two materials as shown in Eq. (3).
2) Next, multiply the width of the stainless steel section by n. The resulting value is the width of an aluminum section that is equivalent to the stainless steel in flexure. Do not change the height of the stainless steel section when performing the cross section transformation.
3) Find the theoretical location of the neutral axis ($\bar{y}_{th}$) by finding the centroid of the transformed cross section.
4) Once the neutral axis location is found, calculate the moment of inertia of the transformed cross section about the neutral axis.
5) Finally, calculate the theoretical stress per unit load for the two materials by applying Eq. (4).

Lab Report

The report for this lab should be a POSTER prepared by your group which would be graded for 100 points. Make sure to attach your initialed data sheet and show a set of sample calculations at the back of the poster. The following shows what is expected in certain sections of your poster.

Experimental Results

~~Create a table showing the original data collected in lab. Also, include the graph of stress vs. load used in your calculations. You should also report the calculated experimental values for location of experimental neutral axis and stress per unit load for each material. You also need to report the theoretical location of the neutral axis and the theoretical stress per unit load ratios. A table or tables may be used to organize your experimental and theoretical values.~~

Discussion of Results

In this section you should compare your experimental and theoretical values for the location of the neutral axis and the stress per unit load for the two materials. Use percent errors to make your comparisons. Discuss how well the composite beam theory predicted your experimental values and give reasons for any major differences. Finally, research two composites and tell what materials are used to create the composites. Also describe how the materials are joined and the benefits gained by using the materials as a composite.

Presentation

Each group will present their poster on their respective table. All the remaining groups would grade your poster for 50 points. Taking the average of all the groups and I would grade it for remaining 50 points. Try to include the pictures of real life examples where composite materials are used to make your poster colorful.

Equations

(1) Uniaxial Hooke's Law

$$\sigma_i = E_i \varepsilon_i$$

$$\frac{\varepsilon_i}{P} = \left(\frac{1}{E_i}\right)\left(\frac{\sigma_i}{P}\right)$$

σ_i = stress in material i, psi

E_i = modulus of elasticity of material i, psi

ε_i = axial strain in material i, in/in

P = load, lb

(2) Experimental Neutral Axis

$$\bar{y}_{exp} = \frac{h_{ss} + h_{al}}{1 + \left|\frac{\varepsilon_{ss}/P}{\varepsilon_{al}/P}\right|}$$

$\bar{y}_{exp}$ = location of neutral axis, in (from bottom)

h_{ss} = height of S.S. section, in

h_{al} = height of aluminum section, in

ε_i/P = strain per unit load in material i, in/(in-lb)

(3) Ratio of E's for Composite Beam

$$n = \frac{E_{ss}}{E_{al}}$$

n = ratio of E's

E_i = modulus of elasticity of material i, psi

(4) Theoretical Stresses per Unit Load

$$\frac{\sigma_{al}}{P} = \frac{\left(\frac{L_g L_2}{L}\right)\bar{y}_{th}}{I_{NA}}, \quad \frac{\sigma_{ss}}{P} = \frac{n\left(\frac{L_g L_2}{L}\right)\left(h_{ss} + h_{al} - \bar{y}_{th}\right)}{I_{NA}}$$

$\frac{\sigma_i}{P}$ = stress per unit load, in^{-2}

L_g = distance to strain gages, in

L_2 = distance from load to closest support, in

L = length of beam, in

I_{NA} = moment of inertia of transformed cross section about neutral axis, in^4

$\bar{y}_{th}$ = location of neutral axis of transformed cross section, in (measured from bottom)

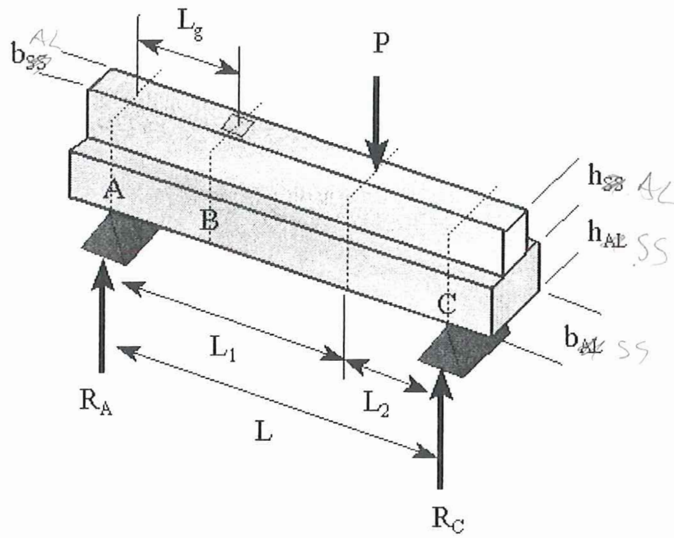
IDE 120 – BEAM OF TWO MATERIALS Lab #6

Section (circle): A B C D E F G H I J K   Date: 3-1-10

Group (circle): 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Data Recorder: Spooler

b_{ss}:	.99		
h_{ss}:	.487		
b_{al}:	1.01	L_g:	12 1/8
h_{al}:	.503	L:	33.5
E_{ss}:	28 x 106 psi	L_1:	23
E_{al}:	10.6 x 106 psi	L_2:	10.5



Load (lb)	Steel Strain (micro-strain)	Aluminum Strain (micro-strain)
10	+15	-12
20	+25	-22
30	+38	-54
40	+51	-65
50	+64	-85
60	+77	-96
70	+90	-116
80	+104	-139
90	+117	-156
100	+132	-173

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IDE 120 Section E

Team 8

David Malawey

Jacob Spooler

Scott Kapshandy

Torsion Testing and Direct Shear Testing – Lab 3

GTA: Krishna Kolan

TA: Sean Smith

February 15, 2010

Introduction

Metals contain intrinsic properties that determine their performance abilities. Two methods for finding these properties are shear and torsion tests. A direct shear test involves putting a specimen under a shear force that is perpendicular to its length. A torsion test applies a torque on the specimen along its length. The modulus of rigidity, maximum elastic torque, shearing yield strength and ultimate shear strength are several properties that can be determined by these tests. The material used for these tests is A36 steel. Knowing the structural properties of metal is essential for all design engineering projects using the metal. A real world example would be the design of a skyscraper. The building will be put under shear and torsion stresses by the wind.

Objectives

Objectives are to determine the modulus of rigidity and shearing yield point for A36 steel and portray data findings with tables. Many characteristics could be observed while gaining a deeper understanding of the mechanical properties of the steel. By the torsion and shear tests, one can learn whether a material is either ductile or brittle.

Procedure

Torsion Testing

Procedure Should be in point-wise

1) Punch marks were placed on the A36 steel test bar 12 inches apart. The punch marks were close to being in line with each other. The troptometer was mounted on our specimen and a steel scale was placed on the troptometer for the use of arc length measurements. The test bar was loaded in the torsion testing machine as instructed by our TA. The diameter of the A36 steel bar was measured and 2) recorded on our data sheet. The troptometer's radius was measured from the center of the A36 bar to the end of the troptometer where the readings were taken. A torsion load was applied by the testing machine to the bar. 3) The arc length was recorded at every 100 in-lb increment of torque for torque values from 0 to 1000 in-lb. The readings were taken at every 0.1 inch increment of arc length after the torque exceeded 1000 in-lb. The readings were taken until the torque value clearly reached a constant value. The troptometer was removed after the torque reached a constant value. The bar continued to twist until it fractured and the maximum torque was recorded. Justify

Direct Shear

The diameter of the A36 steel bar was measured. The specimen was loaded in the shear testing fixture. The load was applied to the specimen using a cross-head speed of 0.1 in/min. The load was recorded at the 0.2% offset yield point and the maximum load when the computer stopped the test.

Discussion of Results

The points on Figure 2, (Torque Vs. Arc Length, Linear) stray only slightly from the linear regression line. This may be due to flaws in reading the arc length measurement during testing. The first point in particular is inconsistent with the line, probably as a result of slack or slipping on the testing machine or measuring apparatus. Additionally, the apparatus only measured in a certain increment, which may not have been accurate for the first reading.

Using tables 2 and 3, the experimental shear strength results can be can be compared. Using equation (8) for percent differences, the shearing yield strength from the direct shear test shows a 15.7% difference greater than the calculated torsion yield strength, (28199psi, 24095psi, respectively) Ultimate strength from torsion test (77186 psi) was also less than direct shear ultimate strength (55160psi), by 33.3%.

Experimental calculated Modulus of rigidity (10,373 ksi) was less than the referenced value at 11,200ksi, and percent difference was 7.67%. References are shown in appendix C

Exp. Results section ??
[Talk about how you calculated using Eqns]
Conclusions ??
[Compare with ref values & add comments]

Appendix A: Tables

Table 1: Raw Torsion Data

Torque (in-lb)	Arc Length (in)	Angle of Twist (rad)
0	0.00	0.000
100	0.19	0.018
200	0.23	0.021
300	0.32	0.030
400	0.40	0.037
500	0.48	0.045
600	0.55	0.051
700	0.63	0.059
800	0.71	0.066
900	0.79	0.073
1000	0.87	0.081
1080	0.97	0.090
1240	1.07	0.099
1380	1.17	0.109
1480	1.27	0.118
1540	1.37	0.127
1540	1.47	0.137
1540	1.57	0.146
1540	1.67	0.155
1560	1.77	0.164
1540	1.87	0.174
1540	1.97	0.183

Table 2: Direct Shear Data

Direct Shear Data	
Shearing Yield Strength (psi)	28198.9
Ult. Shearing Strength (psi)	55660.1

Table 3: Calculated Values for torsion test

	Rtrop= 10.7625 in
	Tfp= 1540 lb
	Te=1155 lb
	Tmax=3700 lb
polar moment J (in^4)=	0.01498
modulus of rigidity G (psi) =	10373831.78
Shear Yield Ssy (psi)=	24094.6
Ult. Shear Strength (psi) =	77186.2
calculated values table for torsion test	

% Diff table ??

~~Torsi~~ Direct Shear results.

	Exp value	Ref values	% Diff
Torsion			
Direct Shear			

Appendix B: Graphs

Figure 1

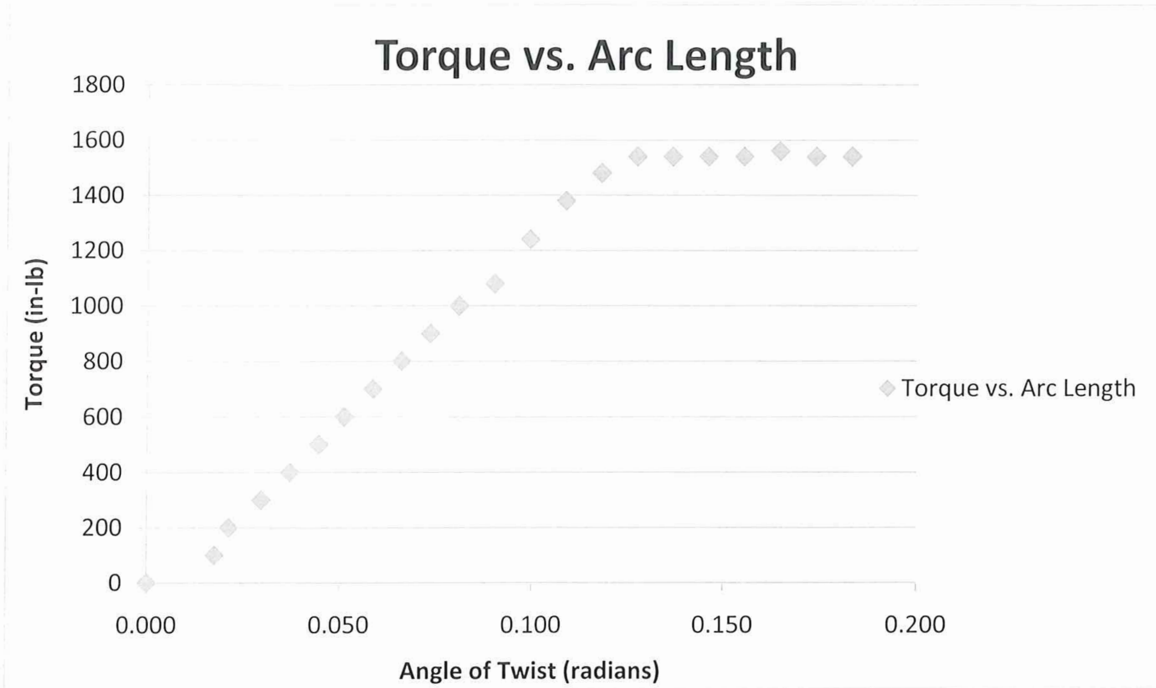
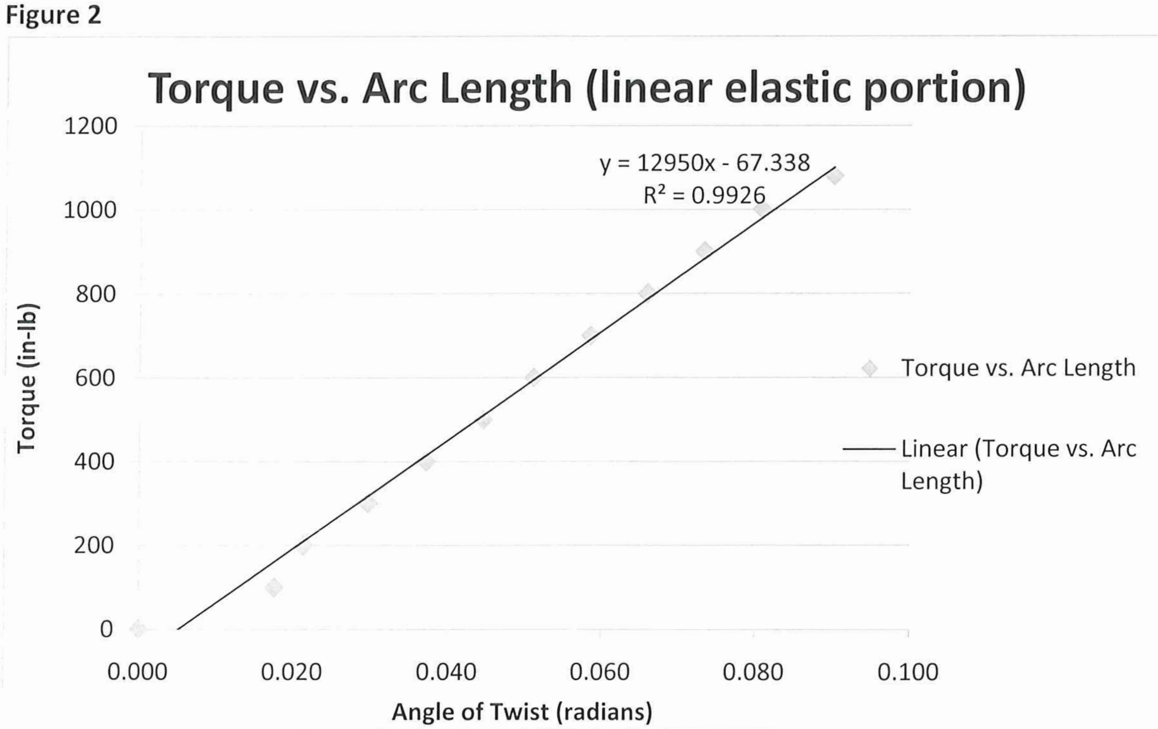


Figure 2



Appendix C: References

Website for A36 steel modulus of rigidity:

http://www.modernsteel.com/steelinterchange_details.php?id=133

Equations

(1) Angle of Twist:

$$\phi = \frac{s}{r_{trop}}$$

ϕ = angle of twist, rad

s = arc length, in

r_{trop}= troptometer radius, in

(2) Modulus of Rigidity:

$$G = \left(\frac{\Delta T}{\Delta \phi}\right)\left(\frac{L}{J}\right)$$

G= modulus of rigidity, psi

$\frac{\Delta T}{\Delta \phi}$ = regression slope, in-lb/rad

L= length, in

J= polar moment of inertia, in^4

$$J = \frac{\pi}{32} d^4 = \frac{\pi}{2} c^4 \text{ (circular)}$$

(3) Max. Elastic Torque:

$$T_E = \frac{3}{4} T_{FP}$$

T_E = maximum elastic torque, in-lb

T_{FP}= fully plastic torque, in-lb

(4) Shearing Yield Strength: (Torsion Test)

$$S_{sy} = \frac{T_E c}{J}$$

S_{sy} = shearing yield point, psi

T_E= maximum elastic torque, in-lb

c = radius, in

J = polar moment of inertia, in^4

(5) Ult. Shear Strength: (Torsion Test)

$$S_{us} = \frac{T_{max} c}{J}$$

S_{us} = ult. shear strength, psi

T_{max} = max. torque, in-lb

c = radius, in

J = polar moment of inertia, in^4

(6) Shearing Yield Strength: (Direct Shear Test)

$$S_{sy} = \frac{V_y}{A} = \frac{V_y}{\left(2\left(\frac{\pi}{4} d^2\right)\right)}$$

S_{sy} = shearing yield strength, psi

V_y = load at yield point, lb

A = cross-sectional area, in^2

d = diameter, in

(7) Ult. Shearing Strength: (Direct Shear Test)

$$S_{us} = \frac{V_{max}}{A} = \frac{V_{max}}{\left(2\left(\frac{\pi}{4} d^2\right)\right)}$$

S_{us} = ultimate shearing strength, psi

V_{max} = max. load, lb

A = cross-sectional area, in^2

d = diameter, in

(8) Percent Difference

$$\%\ \text{Diff.} = \frac{\left|\text{Exp}_1 - \text{Exp}_2\right|}{\left(\frac{\text{Exp}_1 + \text{Exp}_2}{2}\right)}(100)\%$$

Exp_1= first experimental value

Exp_2= second experimental value

$d_{tor} = .625$ in

$T_{FP} = 1540$ in lb

Hand Calculations

Equation (1)

$\phi = \frac{S}{r_{trop}}$ where $r_{trop} = \frac{d}{2} + 10.45$

$\phi = \frac{.19 \text{ in}}{10.763 \text{ in}}$ $\quad r_{trop} = 10.763$

$\phi = .018$ radians

Equation (2)

$G = \left(\frac{\Delta T}{\Delta \phi}\right)\left(\frac{L}{J}\right)$ where $J = \frac{\pi}{32}(d^4)$

$G = \left(12950 \frac{\text{in lb}}{\text{rad}}\right)\left(\frac{12 \text{ in}}{.0141 \text{ in}^4}\right)$ $\quad J = .01498$

$G = 10373831.8$ psi

Equation (3)

$T_E = \frac{3}{4} T_{FP}$

$T_E = \frac{3}{4}(1540)$

$T_E = 1155$ in lb

Equation (4)

$S_{xy} = \frac{T_E\, C}{J}$, where $c = \text{radius} = \frac{.625}{2}$

$S_{xy} = \frac{1155 \cdot (.3125)}{.0149}$ $\quad c = .3125$

$S_{xy} = 24094.6$

Equation (5)

$S_{us} = \frac{T_{max}\ C}{J}$

$S_{us} = 3700 \cdot .3125 / .01498$

$S_{us} = 77186.2$

Equation (6)

$S_{sy} = \frac{V_Y}{A} = \frac{V_Y}{(2 \cdot \frac{\pi}{4} d^2)}$

$S_{sy} = 16972 / (2 \cdot \frac{\pi}{4}(.619)^2)$

$S_{sy} = 28198.9$ psi

Equation (7)

$S_{us} = \frac{V_{max}}{A} = \frac{V_{max}}{(2(\frac{\pi}{4} d^2))}$

$S_{us} = 33500 / (2 \cdot \frac{\pi}{4}(.619)^2)$

$S_{us} = 55660.1$

Equation (8)

$\% \text{Diff} = \frac{|Exp_1 - Exp_2|}{\left(\frac{Exp_1 + Exp_2}{2}\right)}(100\%)$

$|28199 - 24095| \Big/ \frac{(28199 + 24095)}{2} * 100\%$

$\%$ diff $= 15.7\%$

IDE 120 – DIRECT SHEAR and TORSION

Section (circle): A B C D E F G H I J K Date: 2-8-10

Group (circle): 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Data Recorder: Jake Spooler

Direct Shear

specimen material: A36 steel

test speed: 0.1 in/min

specimen diameter: .619 => calculate 2A = .602

0.2% yield load: 16972 lbf

ultimate load: 33500 lbf

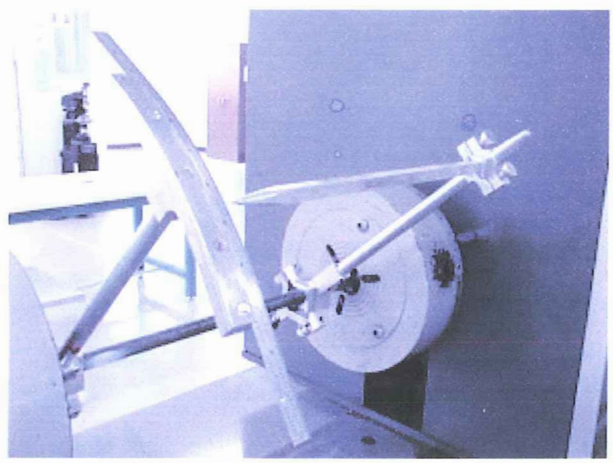
Torsion

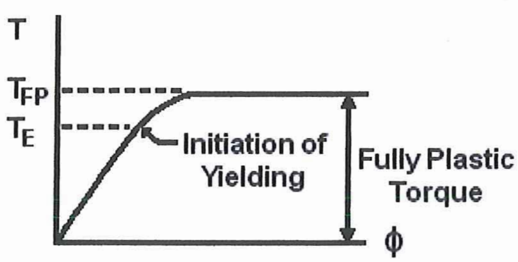
specimen material: A36 steel

specimen diameter: .625

troptometer gage length: 12"

troptometer radius: speced/2 + 10.45 = 10.763





T_{FP}: 1540

T_E: 1155 $T_E = \frac{3}{4} T_{FP}$

T_{max}: 3700

"precision" 200 in lb

initial = 5 in

Torque (in-lb)	Arc Length (in)	Torque (in-lb)	Arc Length (in)
0	5 in	1540	6.87
100	5.19	1540	6.97
200	5.23		
300	5.32		
400	5.40		
500	5.48		
600	5.55		
700	5.63		
800	5.71		
900	5.79		
1000	5.87		
1080	5.97		
1240	6.07		
1380	6.17		
1480	6.27		
1540	6.37		
1540	6.47		
1540	6.57		
1540	6.67		
1560	6.77		

Lab Report Guidelines

You will write two types of reports this semester. The two types are formal reports and memos. The sections to include in your reports are shown below. Formal reports should have all the sections shown in the same order listed. For the memos you do not need to use appendices for your tables, figures, and hand calculations, but they should be included somewhere in the memo. Don't forget to attach your initialed original data sheet at the end of all your reports regardless of the required format.

Formal Reports
- Title Page
- Introduction
- Objectives
- Procedure
- Experimental Results
- Discussion of Results
- Conclusions
- References
- Appendix A: Tables
- Appendix B: Figures
- Appendix C: Hand Calculations

Memos
- Introduction
- Experimental Results
- Discussion of Results
- References
- Tables
- Figures
- Hand Calculations

You need to label all the sections in your reports except for the title page. A description of each section of the report is given below.

Title Page

The title page should include the title of the experiment, course name, section letter, the names of all group members, group number, the date the report is due, and the names of your GTA and TA. You do not need to label the title page. It is up to you to decide the formatting and layout of the title page.

Introduction

The introduction of your report should start at the top of page 2 for formal reports (the Title Page will be page 1). The introduction describes the basic subject area of the report. You should tell the reader the tests that were performed and the materials that were tested. An example of a real world application of your experimental findings should be included.

Objectives

The objectives section should tell the reader what you were trying to learn by performing the experiment.

Procedure

The procedure section of your report should be a step-by-step description of how you used the lab equipment to obtain your data. Another IDE 120 student should be able to perform the experiment using your procedure. You can use a numbered list to show the steps of the procedure. Do not copy the procedure word for word from the handouts or the course website.

Experimental Results

The experimental results section is where you will report the data you collected and your calculated values. For most reports, you should use tables to show your experimental and calculated values. The tables should be placed in Appendix A for formal reports. A short description of how you found any calculated values should be included along with the equations you used. Equations can be either typed or hand written. With either method, equations should be numbered and referred to as Eq. x where x is the equation number. An example of an equation is shown as Eq. 1 on the back of this page.

$$\sigma = \frac{F}{A_o} \qquad (1)$$

Discussion of Results

In this section of the report you should discuss the most important aspects of your experimental results including any trends that you notice in your data sets. The main purpose of this section is to give you a chance to comment on the validity of the experimental data and explain anything important that you might notice. In this section you should make comparisons between your data and reference values. You should also compare the data sets to one another (if you have more than one). A discussion of whether any data points appear incorrect and the reasons you have for why the data may be incorrect should be included. You should include some insightful remarks in this section to show that you understand the results and what they tell you.

Conclusions

In the conclusions section you will briefly restate the major findings of your experiment and discuss why they are important. This section is also where you tell what you learned from the experiment and whether all the objectives were fulfilled. Feel free to add any comments or suggestions about the lab at the end of your conclusions section.

References

In the references section of your report you need to give credit to any books, journals, websites, or other sources used while writing your report. You should include any sources used to look up reference values for the materials tested. You can use any standard format for listing your references. Pick a format that you are familiar with and are comfortable using.

Appendix A: Tables

This appendix is where you place all the tables in your formal report. Make sure the tables are large enough to read and that you follow the guidelines you were given for tables.

Appendix B: Figures

All graphs and other figures should be placed in Appendix B for formal reports. Again, be sure to follow the guidelines you were given covering graphs. Do not try to save space by cramming several figures on one page.

Appendix C: Hand Calculations

You need to include a sample of your hand calculations in Appendix C. You only need to show one hand calculation for each equation used. The hand calculations will be used to determine if partial credit should be awarded if an incorrect answer is found.

General Guidelines

1. Use 3rd person in your reports. Do not use "I" or "we" when describing how you completed the report.
2. Use past tense throughout your report. By the time you write your report you should be done with everything else so it makes sense to write about your work in the past tense.
3. Use single spacing between lines in your report.
4. Use an easily readable 12 point font for the body of your report. Headings and other titles can be larger if desired.
5. Staple your report before you turn it in.

To:	IDE 120 Section E Students
From:	Krishna Kolan, GTA; Sean Smith, TA;
Subject:	Lab # 4 – Failure and Fully Plastic Action
Date:	February 15, 2010
Report Due:	February 22, 2010

Lab Background

Understanding what it means for a material to fail is important for you as an engineer to understand. Some failures are planned and others are not. Planned failures can often be beneficial if properly designed. Unplanned failures often lead to catastrophic results with loss of life and/or property.

Lab Procedure

We will be performing flexure tests in the lab this week. The tests will be performed on A36 steel bars similar to the ones used for the tension and torsion labs. An Instron UTM will be used to perform a 3-point flexure test on the bars. The following steps should be followed in the lab:

1) Measure the diameter of your A36 bar and the distance between the two supports on the fixture. The distance between the supports is the value for L you will use in your calculations.
2) Place your bar on the supports and then apply load to the bar.
3) When the load becomes constant while the deflection continues to increase, the fully plastic load (P_{FP}) has been reached. You will select this point on the computer and the value for P_{FP} will be shown in the e-mail sent to you with the test data.
4) When the machine is finished applying load, remove your specimen.

Calculations

You will use the fully plastic load value found during your flexure test to calculate the normal yield strength of the A36 steel bar. All equations are shown on the back of this page. Your calculations should follow these steps:

1) Begin by applying Eq. (1) to find the fully plastic moment, M_{FP}.
2) Next, use Eq. (2) to calculate the maximum elastic moment, M_{yp}. The maximum elastic moment is the moment required to cause the outside of the bar to yield. Eq. (2) only applies for circular cross sections.
3) Use Eq. (3) to find the normal yield strength of the A36 bar. This equation was developed from the generic $\sigma = \frac{My}{I}$ for a circular beam with the appropriate values entered for y and I.

Lab Report

The report for this lab should be a <u>TEAM MEMO</u> worth 50 points written by your group. Be sure to include a printed copy of the test data sent to you in an e-mail. In your memo you should create a table that compares the results of your tension, torsion, and flexure tests on A36 steel. Your table should be similar to the one shown on the next page with your experimental yield strength values filled in.

Test	Yield Strength of Interest	Experimental Value (psi)
Tension	S_y	—
Torsion	S_{sy}	—
Flexure	S_y	64,161.6

include hand-calc. for eq's 4 & 5.

You will also need to calculate two experimentally determined strength ratios and summarize them in a table. The first experimental ratio to calculate is $\dfrac{S_{sy}(torsion)}{S_y(tension)}$ and the second experimental ratio is $\dfrac{S_{sy}(torsion)}{S_y(flexure)}$. Then, compare your experimental strength ratios to the ratios predicted by the Maximum Shear Stress Failure Theory and the von Mises Failure Theory using percent errors. The theoretical ratios are given as Eqs. (4) and (5). Include the percent error values in the table showing your experimental strength ratios. In the written part of your report comment on which failure theory appears to be more accurate based on your experimental findings.

Equations

(1) Fully Plastic Moment

$$M_{FP} = \frac{P_{FP}L}{4}$$

M_{FP} = fully plastic moment, lb-in

P_{FP} = fully plastic load, lb

L = distance between supports, in

(2) Maximum Elastic Moment

$$M_{yp} = \frac{3\pi}{16} M_{FP}$$

M_{yp} = maximum elastic moment, lb-in

M_{FP} = fully plastic moment, lb-in

(3) Normal Yield Strength

$$S_y = \frac{4M_{yp}}{\pi c^3}$$

S_y = normal yield strength, psi

M_{yp} = maximum elastic moment, lb-in

c = radius of bar, in

(4) Strength Ratio for Max. Shear Stress Theory

$$\frac{S_{sy}}{S_y} = 0.5$$

S_{sy} = shearing yield point, psi

S_y = normal yield point, psi

(5) Strength Ratio for von-Mises Theory

$$\frac{S_{sy}}{S_y} = 0.577$$

S_{sy} = shearing yield point, psi

S_y = normal yield point, psi

	Exp. Value	Max. Shear Stress theory (.5)	Von-mises Theory (.577)
Torsion / Tension	.522	% diff	% diff
Torsion / Bending	.573	% diff	% diff

To: IDE 120 Section E Students
From: Krishna Kolan, GTA; Sean Smith, TA;
Subject: Lab # 5 – Strain Gages, Flexure Testing for Elastic Constants
Date: February 22, 2009
Report Due: March 1, 2009

Lab Background

This lab will teach you more about how elastic constants are determined. We will be working with three elastic constants in particular. These constants are: modulus of elasticity, modulus of rigidity, and Poisson's ratio. These elastic constants are used when applying Hooke's law to relate stress and strain in a material.

Lab Procedure

We will be performing flexure tests to find the elastic constants of a material. The procedure for the tests is given below.

1) Make all necessary measurements. You will need to measure the length between supports, cross-sectional dimensions of the beam, and the distance to the strain gages from the nearest support.
2) Place the weight hanger on the beam making sure it is centered between the supports.
3) Determine the orientation of the two strain gages on the beam. One gage measures axial strain and the other measures transverse strain so it is important to know which is which.
4) Connect the strain gages to the strain indicators. Then, zero the amp, set the gage factor, and balance the strain.
5) If you are using the larger aluminum beam on the lathe bed, place weights on the hanger in 5 lb increments until the total weight is 50 lb. Record the strains at each 5 lb increment of weight.
6) If you are using the smaller aluminum beam or the magnesium beam, place weights on the hanger in 1 lb increments until the total weight reaches 10 lb. Record the strains at each 1 lb increment.

Calculations

The calculations for this lab are very straightforward if you follow the steps given below.

1) Begin your calculations for the flexure test data by entering your data in Excel. You will then need to create two plots. The first plot should be load (y-axis) vs. axial strain (x-axis) and the second plot should be transverse strain vs. axial strain.
2) Next, use linear regression to find the slope of the regression line for both plots.
3) Poisson's ratio (υ) can be found by applying Eq. (1) shown below. This shows that Poisson's ratio is simply the absolute value of the slope of your transverse strain vs. axial strain regression line.
4) The modulus of elasticity (E) can be found using Eq. (2). In Eq. (2) the value of $\left(\left|\frac{\Delta P}{\Delta\varepsilon_{axial}}\right|\right)$ is the absolute value of the slope of the regression line from your load vs. axial strain plot. The area moment of inertia term, $I_{NA,}$ in Eq. (2) can be found using Eq. (3). In this case the neutral axis is the centroidal axis of the rectangular cross section.
5) The modulus of rigidity can be calculated by applying Eq. (4) using the values for E and υ found above.

Lab Report

The lab report for this lab should be a TEAM REPORT written by your group worth 100 points. Be sure to attach your initialed data sheet and include a set of hand calculations. Your report should include the graphs created during your calculations. Make sure to show your regression lines on the graphs and the equations for the lines. Include a table in your report that summarizes your calculated values for modulus of elasticity, modulus of rigidity, and Poisson's ratio. Also, look up reference values for all the elastic constants and compare your experimental values to the reference values using percent differences. In the appropriate section of your report discuss how well your experimental values matched the reference values and give reasons for any major deviations.

Table

Equations

(1) Poisson's Ratio

$$\upsilon = \left| \frac{\Delta\varepsilon_{transverse}}{\Delta\varepsilon_{axial}} \right|$$

υ = Poisson's ratio

$\frac{\Delta\varepsilon_{transverse}}{\Delta\varepsilon_{axial}}$ = slope of transverse strain vs. axial strain line

(2) Modulus of Elasticity

$$E = \left(\frac{yd}{2I_{NA}} \right) \left(\left| \frac{\Delta P}{\Delta\varepsilon_{axial}} \right| \right)$$

E = modulus of elasticity, psi

y = distance from neutral axis, in

d = distance from support to strain gage, in

I_{NA} = moment of inertia about the neutral axis, in^4

$\frac{\Delta P}{\Delta\varepsilon_{axial}}$ = slope of load vs. axial strain plot, lb

(3) Area Moment of Intertia

$$I_{NA} = \frac{1}{12} bh^3$$

I_{NA} = area moment of intertia, in^4
b = width of beam, in
h = height of beam, in

(4) Modulus of Rigidity

$$G = \frac{E}{2(1+\upsilon)}$$

G = modulus of rigidity, psi
E= modulus of elasticity, psi
υ = Poisson's ratio

T_1 Load Vs Axial Vs. Transverse

Graph: 1) Load vs. Ax ← lines, eq's
2) Load vs Trans ← lines, eq's

T_2 E, G, ν
- experiment
- reference
- % diff

I print

45

To: Krishna Kolan, GTA; Sean Smith, TA;
From: Team 8: David Malawey, Jacob Spooler, Scott Kapshandy
Subject: Lab #2 – Tension Testing
Date: February 1, 2010
Report Due: February 8, 2010

Introduction:

Tensile Testing provides information on the relationship between stress and strain for a given material. Characteristics for materials such as ultimate strength, yield strength, modulus of elasticity, engineering stress, and more are acquired through measuring tension and deformation of a material with given dimensions. The materials subjected to tests for this lab are A36 steel and 2024 T4 aluminum. Having this knowledge allows one to perform proper designs for strength in suspension bridges, automobile frames, or bolts for many types of couplings.

Experimental Results:

The results are contained within the appendices attached. Values were calculated by the computer and gathered through emailed documents. These graphs and tables are found in Appendices A and B, representing A36 steel and 2024 T4 Aluminum, respectively. Values for the summary of results used equations listed in Appendix D.

Mention Eqn's used?

Discussion of Results:

Table C1 shows how the experimental values from lab 2 compare to standard values for specimens. The modulus of elasticity found for the test specimen A36 steel was very close to the referenced value (only 3.21 percent error). Experimental offset yield strength for A36 steel was 40.5% higher than the referenced value, as shown in Table C1. Ultimate Tensile strength for the specimen resulted in an acceptable value according to the referenced range. Percent elongation, however, was 33.7% higher than reference value.
The greatest discrepancy in the results is that of offset yield strength, and this could be due to poor quality steel, making a flawed measurement on dimensions, or not following ASTM E8 standard procedures.

In general, the aluminum specimen was found to be nearly as strong but much less ductile than the steel specimen. The steel had a greater percent elongation which could be useful in certain situations. A less brittle material such as the A36 steel would be advantageous in products such as nails so that the product does not crack when struck. Aluminum may be more advantageous in situations with lower shocks and vibrations, such as gear housings or a bicycle frame.

The ASTM E8 states a few things that would improve this lab procedure. The first improvement is being completely sure that the axis of the test specimen coincided with the center line of the heads of the testing machine. Doing this minimizes bending stresses which could affect the results. Another way to improve this lab would be to inspect each testing item thoroughly to make completely sure that it has no flaws. If flaws were detected, then it could possibly throw off data severely because of a weak spot. The last way to improve this lab is to fashion a marking system on the specimen before tension is applied so it would be easier to see the elongation, and also make it easier to measure. Marks could be made using chalk or a wax pen.

ASTM Standards!?

Have you read them??

I've asked for at least 3 things

which we performed differently.

11

Appendix A: A36 Steel Rod Tension Test

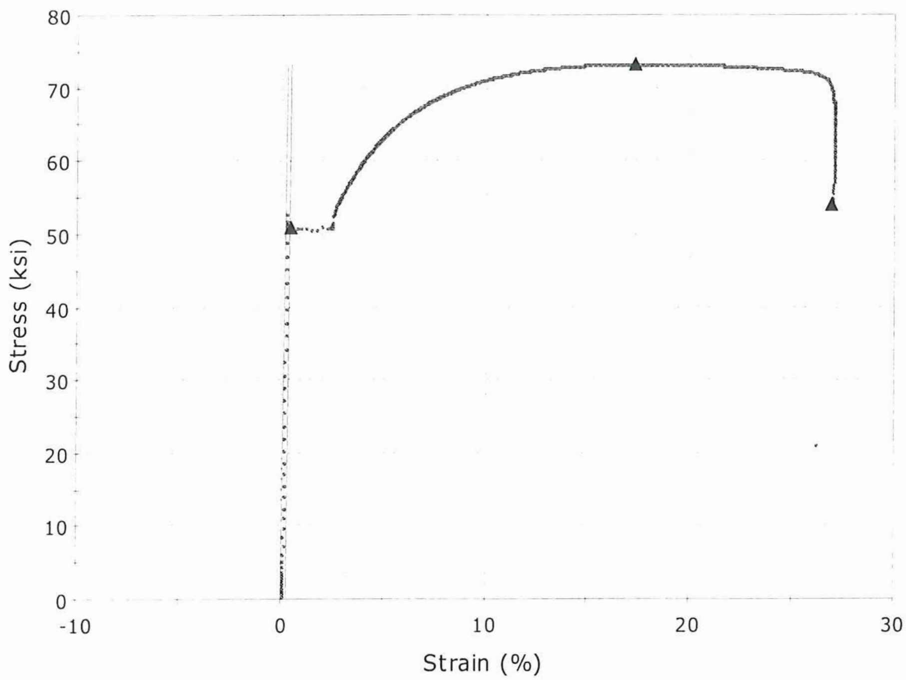


Figure A1: Stress vs. strain for A36 Steel Rod

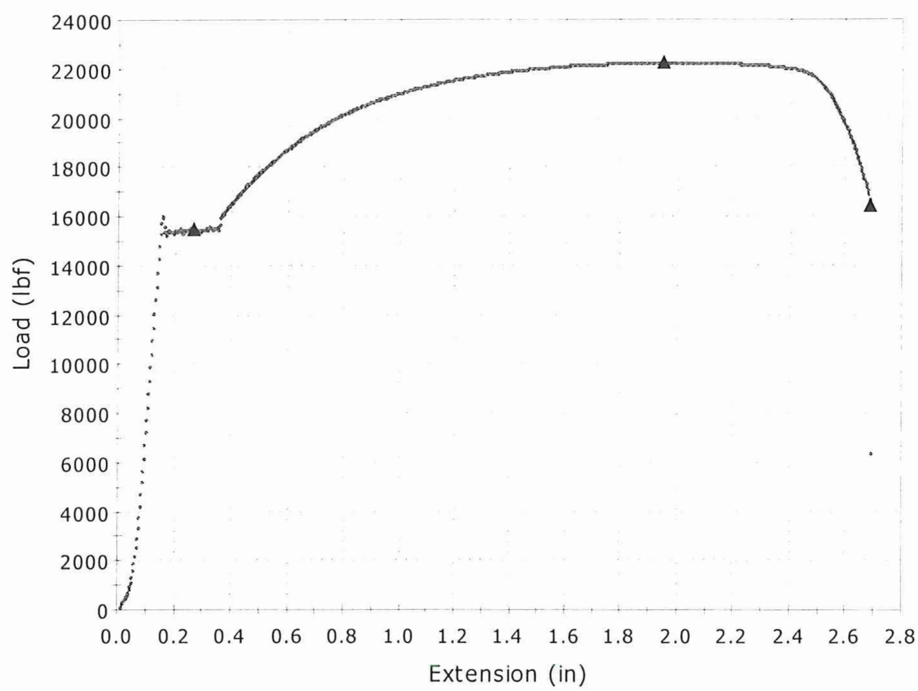


Figure A2: Load vs. Extension for A36 Steel Rod

	Initial length (in)	Initial width of plate (in)	Initial thickness of plate (in)	Initial diameter of cylinder (in)
1	11.9380			0.622

	Initial outer diameter of tube (in)	Initial wall thickness of tube (in)	Initial linear density (tex)	Initial area (in^2)
1				0.304

	Final length (in)	Final width of plate (in)	Final thickness of plate (in)	Final diameter of cylinder (in)
1	14.8750			0.392

	Final outer diameter of tube (in)	Final wall thickness of tube (in)	Final linear density (tex)	Final area (in^2)
1				0.121

Table A3: Dimensions for A36 Steel rod

Appendix B: 2024 T4 Aluminum Rod Tension Test

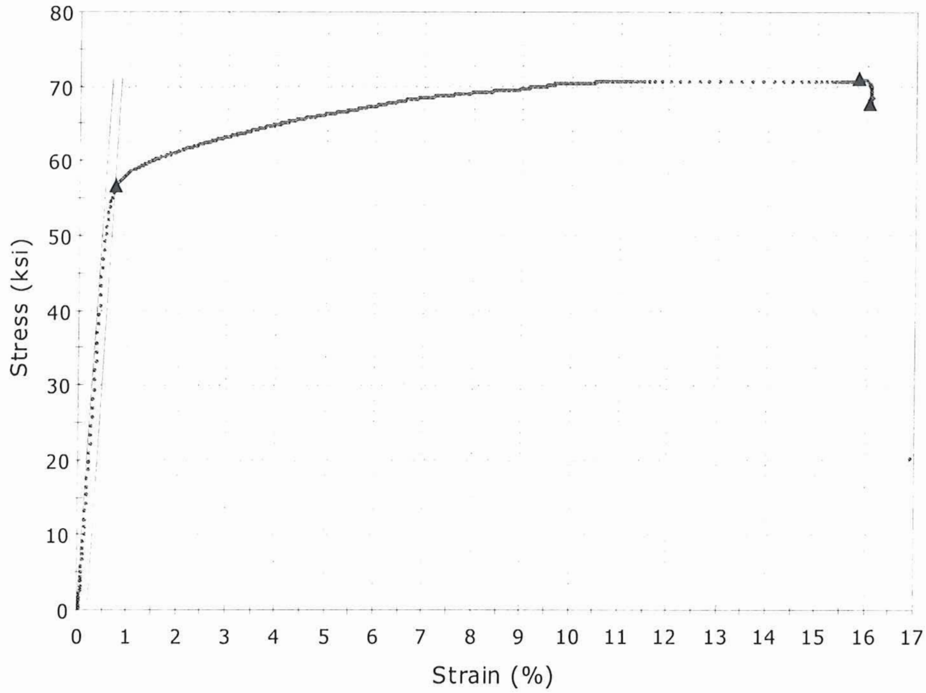


Figure B1: Strain vs. Stress for 2024 T4 aluminum rod

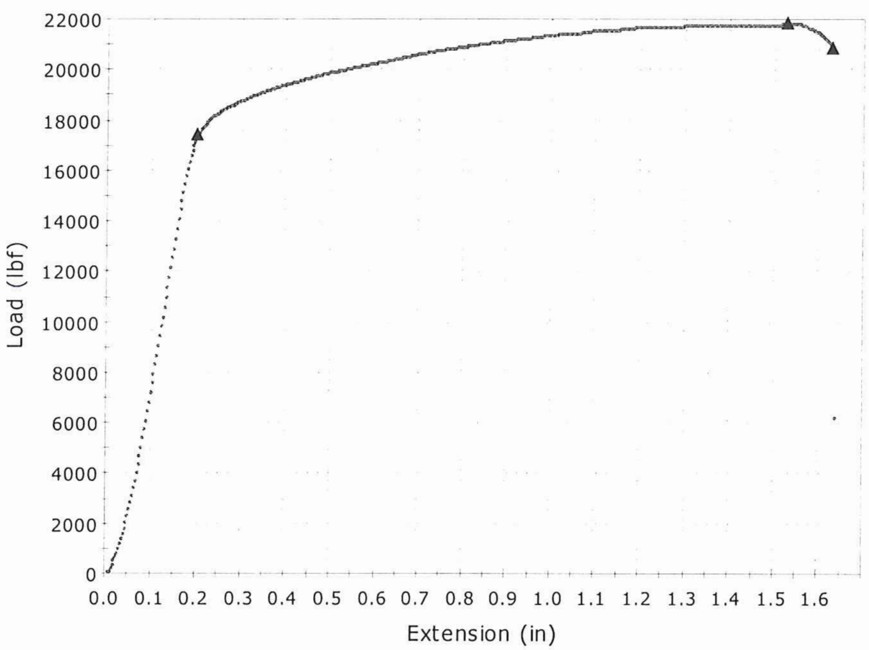


Figure B2: Extension vs. Load for 2024 T4 aluminum Rod

Test 1 Conditions	
Temperature (F)	70
Humidity (%)	50

Table B1: 2024 T4 Aluminum Rod Test Conditions

	Specimen Label	Geometry	Crosshead Speed (in/min)	Modulus of Elasticity (ksi)
1		Circular	2.000	11113

	Load at 0.2%-Offset Yield (lbf)	Extension at 0.2%-Offset Yield (in)	Stress at 0.2%-Offset Yield (ksi)	Strain at 0.2%-Offset Yield (%)
1	17452	0.200	56.7	0.71

	Load at Max. Load (lbf)	Extension at Max. Load (in)	Stress at Max. Load (ksi)	Strain at Max. Load (%)
1	21863	1.527	71.0	15.83

	Load at Break (lbf)	Extension at Break (in)	Stress at Break (Engineering) (ksi)	Strain at Break (%)
1	20854	1.630	67.8	16.06

	Yield Energy (ft-lbf)	Break Energy (ft-lbf)	Modulus of Resilience (ksi)	Modulus of Toughness (ksi)
1	6.4	274.1	0.250	10.688

	True Break Stress (ksi)	Reduction of Area (%)	Elongation at Max. Load, Plastic (%)	Elongation at Break, Plastic (%)
1	92.4	26.687	15.19	15.45

	Strength Coefficient, K (ksi)	Strain Hardening Exponent, n ()	Break Location	Specimen note
1	104.6	0.130	Outside GL	

Table B2: Results for 2024 T4 Aluminum Rod

	Initial length (in)	Initial width of plate (in)	Initial thickness of plate (in)	Initial diameter of cylinder (in)
1	11.7500			0.626

	Initial outer diameter of tube (in)	Initial wall thickness of tube (in)	Initial linear density (tex)	Initial area (in^2)
1				0.308

	Final length (in)	Final width of plate (in)	Final thickness of plate (in)	Final diameter of cylinder (in)
1	13.1250			0.536

	Final outer diameter of tube (in)	Final wall thickness of tube (in)	Final linear density (tex)	Final area (in^2)
1				0.226

Table B3: Dimensions for 2024 T4 Aluminum rod

Appendix C: Results Summary

Material	Modulus of Elasticity (ksi)	0.2% Offset Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	% Elongation	% Reduction in Area	Engineering Stress at Fracture (ksi)	True Stress at Fracture (ksi)
A 36 Steel	29930	51.0	73.4	26.75	60.18	54.0	135.6
2024 T-4 Aluminum	11113	56.7	71.0	15.45	26.69	67.8	92.4
(reference) A 36 Steel	29000	36.3	58.0-79.8	20.0	n/a	n/a	n/a
% Error b/t sample and reference	3.21%	40.5%	0.0%-26.5%	33.75%	n/a	n/a	n/a

Table C1: Results summary

Appendix D: Equations

Engineering Stress:

$$S = \frac{F}{A_0}$$

S= engineering stress, psi
F= load, lb
A_0= initial cross-sectional area, in^2

True Stress:

$$\sigma = \frac{F}{A}$$

σ = true stress, psi
F= load, lb
A= cross-sectional area when load measured, in^2

Engineering Strain:

$$e = \frac{L_f - L_0}{L_0}$$

e= engineering strain, in/in
L_f= final gauge length, in
L_0 = initial gauge length, in

Mention them in Exp. Results

Modulus of Elasticity:

$$E = \frac{\Delta S}{\Delta e}$$

E= modulus of elasticity, psi
ΔS= change in engineering stress, psi
Δe= change in engineering strain, in/in

% Elongation:

$$\% Elong = \frac{L_f - L_0}{L_0}(100\%)$$

L_f= final length, in
L_0 = initial length, in

% Reduction in Area:

$$\% RA = \frac{A_f - A_0}{A_0}(100\%)$$

A_f = final cross-sectional area, in^2
A_0 = initial cross-sectional area, in^2

% Error:

$$\% Error = \frac{|\text{Exp. Value - Ref. Value}|}{\text{Ref. Value}}(100\%)$$

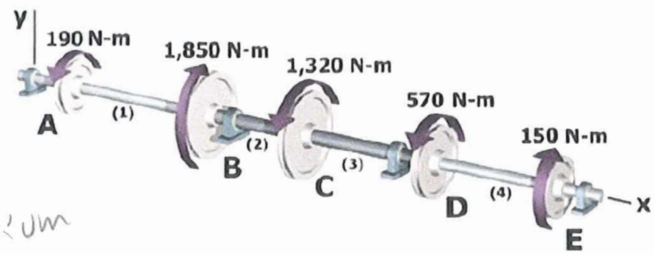
Appendix E: references

Reference data for A-36 steel from:
http://www.matweb.com/search/datasheet.aspx?matguid=d1844977c5c8440cb9a3a967f8909c3a&ckck=1

Blackboard Academic Suite
ASTM E8 Tension Testing Standards pdf file, found at: http://blackboard.mst.edu in IDE120 documents.

IDE 110 S08 Test 3 Name: Malawey

1. A compound shaft supports several pulleys. The bearings allow the shaft to turn freely. Using the sign convention shown in the text and MecMovies, determine the internal torque in each segment of the shaft.



Not equilibrium

$T_1 =$ 190 N-m

$T_2 =$ -1660 N-m

Or we can evaluate from the other side

$T_3 =$ 340 N-m

$T_4 =$ -230 N-m

2. If $T_E = 600$ N-m in *Image 2*, determine the magnitude of the internal torque in shaft (1). The bearings permit free rotation of the shafts.

$T_1 =$ ________ N-m

1st try:

$\cancel{600\left(\frac{60}{30}\right) = 1200}$

$600\left(\frac{30}{60}\right) = 300$

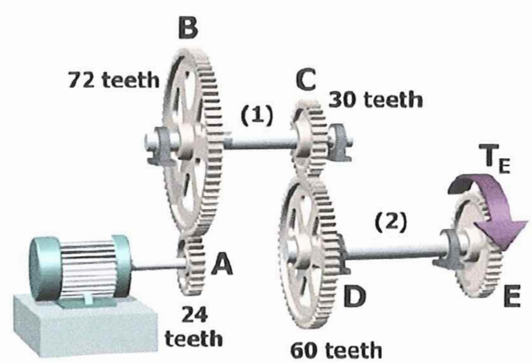


Image 2

3. If the motor in *Image 2* rotates at 4 Hz, determine the rotational speed of shaft (1) in radians per second.

$\omega_1 =$ 8.38 rad/s

$4\,Hz \Rightarrow 4\ cyc/sec\left(\frac{24}{72}\right) = 1.33\,(2\pi)$

4. If the motor in *Image 2* supplies 12 hp at 4 rpm to gear *A*, determine the power in shaft (1) in inch-pounds per second.

~~$550 \text{ ft lb/s} \underbrace{(4)\left(\frac{24}{72}\right)}_{\omega} \left(\frac{12 \text{ in}}{\text{ft}}\right)$~~

$P_1 =$ 79,200 in-lb/s

rpm x torque = power

$T\omega$

$12(550)\left(\frac{12 \text{ in}}{\text{ft}}\right)$

5. If gear *D* in *Image 2* rotates 15 degrees, how much does gear C rotate in radians?

$\phi_C =$ .524 radians

$15\left(\frac{\pi}{180}\right)\left(\frac{60}{30}\right)$

rad.

6. In *Image 2*, if $T_E = 600$ N-m and the allowable shear stress in shaft (2) must be limited to 50 MPa, determine the minimum permissible diameter for solid shaft (2).

$d_2 =$ __________ mm

~~$50 \text{ MPa} = \frac{600 \text{ N(m)}}{\frac{\pi}{4} d^2}$~~

$\tau_2 = \frac{Tc}{J}$

3.91 mm

$50{,}000 \text{ kPa} = \frac{600 \text{ Nm}\left(\frac{d}{2}\right)}{\frac{\pi d^4}{32}} = \frac{300(32)}{\pi d^3}$

OK

$\boxed{d^3 = .3939}$

7. In *Image 2*, if $T_E = 600$ N-m, $G = 80$ GPa for both shafts, the length of shaft (2) is 1 m, and the rotation of gear *D* relative to gear *E* must be limited to 3 degrees, determine the minimum permissible diameter for solid shaft (2).

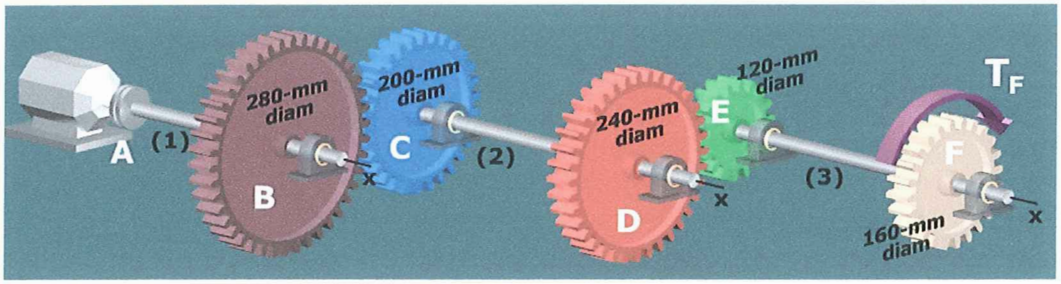
$d_2 =$ 34.75 mm

$\phi = 3\left(\frac{\pi}{180}\right) = \frac{TL}{GJ} = \frac{600(1)}{80(10^6)\ \frac{\pi d^4}{32}}$

$d^4 = \frac{600}{80(10^9)\left(\frac{\pi}{32}\right)\left(\frac{3\pi}{180}\right)}$

$d = .03475 \text{ m}$

8. If the motor at *A* produces a torque of 2,030 N-m, what is the maximum shear stress in shaft (3), which is hollow with an outside diameter of 50 mm and a wall thickess of 5 mm.



$\tau_3 =$ ___50.03___ MPa

$$\tau = \frac{Tc'}{J}$$

50.03

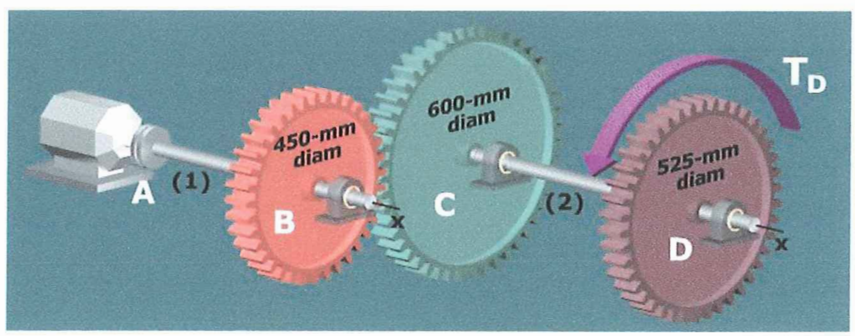
$$T = 2030\left(\frac{200}{280}\right)\left(\frac{120}{240}\right) = 725\ \text{Nm}$$

$$c = 25\text{mm} = .025\text{m}$$

$$J = \frac{\pi}{32}(.050^4 - .040^4) = 3.62265E^{-7}$$

9. A 4,200 N-m torque is applied at *D*. Shafts (1) and (2) are both 52-mm-diameter solid steel shafts 800-mm-long (G = 80 GPa). Determine the rotation angle of gear *D* relative to motor *A*.

$\phi =$ ___.0914___ radians



$$\cancel{\phi = \phi_1 + \phi_2}$$

$T_1 = 3{,}150$

$T_2 = 4{,}200$

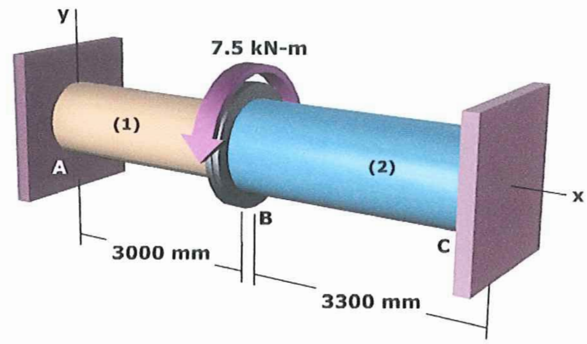
$$\phi_1 = \frac{3150(.8)}{80(10^9)\ \frac{\pi(.052^4)}{32}} = .0439\ \text{rad}$$

$$\phi_2 = \frac{4200(.8)}{} = .0585\ \text{rad}$$

$$\cancel{\phi = .1024\ \text{rad}}$$

$$\phi_{D/A} = \frac{450}{600}\phi_1 + \phi_2 =$$

10. A composite torsion member consists of two solid shafts joined at flange B. Shafts (1) and (2) are attached to rigid supports at A and C, respectively. A concentrated torque T is applied to flange B in the direction shown. Determine the internal torque in shaft (1).



$J_1 = I_{p1} = 1.27\text{x}10^6\ \text{mm}^4$
$G_1 = 25\ \text{GPa}$
$J_2 = I_{p2} = 2.36\text{x}10^6\ \text{mm}^4$
$G_2 = 70\ \text{GPa}$

$T_1 =$ __________ kN-m

$\cancel{J_1 = \frac{\pi(d_o^4 - d_i^4)}{32}}$

$=$

$$\phi = \phi_1 = \phi_2$$

$$7.5(L_2) - T_1(L_2)$$

$$\frac{T_1 L_1}{G_1 J_1} = \frac{(7.5\ \text{kNm} - T_1) L_2}{G_2 J_2}$$

$$T_1\left(\frac{3m}{25(10^9)(1.27)10^6}\right) = \frac{7500(3.3) - T_1(3.3)}{70(10^9)\ 2.36(10^6)}$$

$$T_1(9.449E^{-17}) = 1.4982E^{-13} - T_1(1.998E^{-17})$$

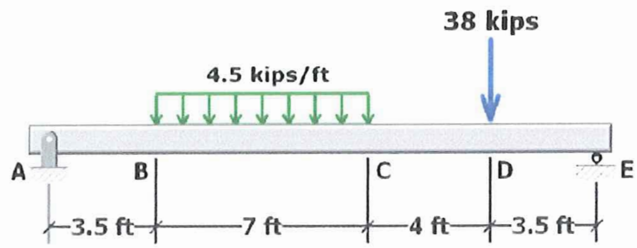
$$T_1(11.447E^{-17}$$

$$T_1 = 1309\ \text{n}\cdot\text{m}$$

$$\boxed{= 1.309\ \text{kN}\cdot\text{m}}$$

perfect!

11. Determine the ground reactions at *A* and *E*.



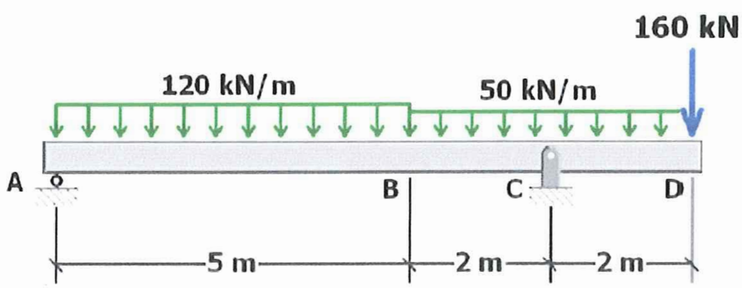
$A_x =$ 0 kips

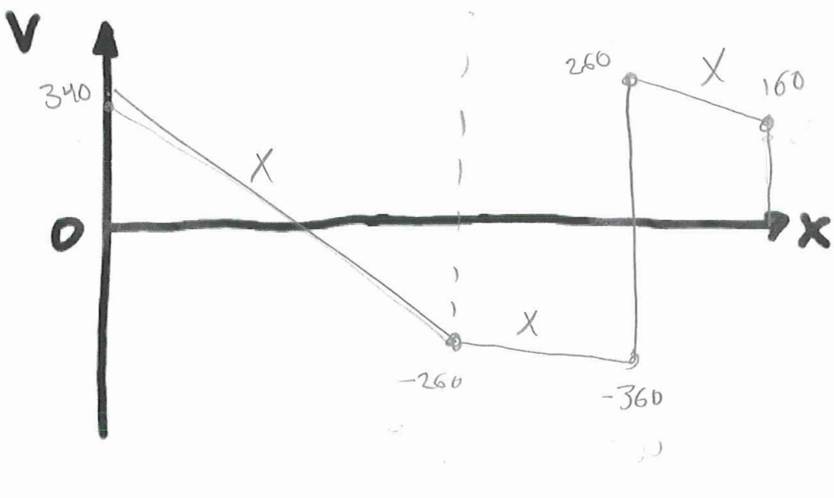
$A_y =$ 26.64 kips

$E_y =$ 42.86 kips

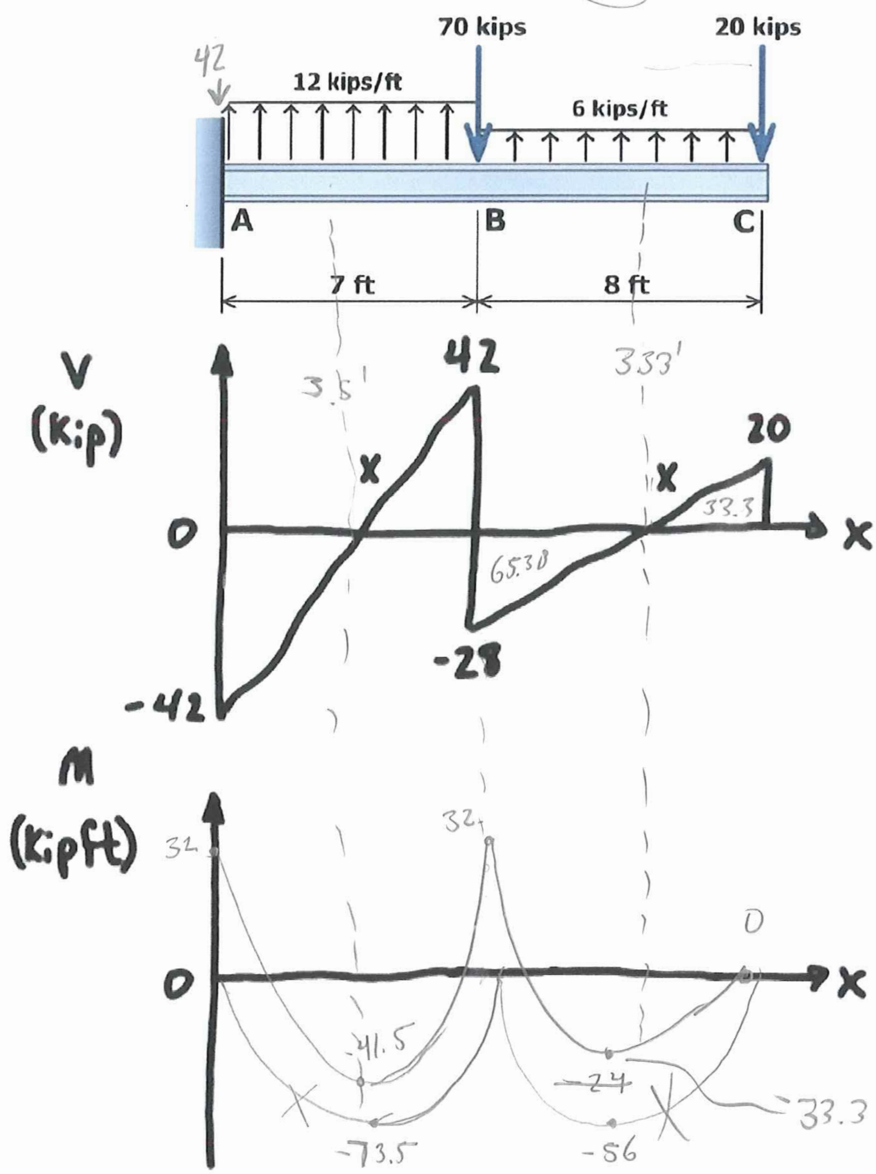
$38(3.5) + 4.5(7)(11) = A_y(18)$

12. Draw the shear-force diagram for the beam shown. Label all significant points on the diagram, and clearly distinguish straight-line and curved portions of the diagram. The ground reactions are $A_y = 340$ kN upward, $C_x = 0$, and $C_y = 620$ kN upward.





13. Draw the bending-moment diagram for the beam shown. Label all significant points on the diagram, and clearly distinguish straight-line and curved portions of the diagram. The ground reactions are $A_x = 0$, $A_y = 42$ kips downward, and $M_A = 32$ kip-ft clockwise.

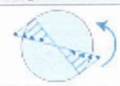


① find X intercepts.

② find area under graph (V)

③ draw ground reactions label on V and M diagrams

④ draw graph.

Topic	Symbol	Meaning	Equation	Units
torsion	τ, tau	shear stress 	$\tau_{torsion} = Tc/J$	psi, Pa
	ϕ, phi	angle of twist	$\phi = TL/GJ$	rad, degrees
	θ, theta	angle of twist per unit length, rate of twist	$\theta = \phi/L$	rad/in, rad/m
	P	power	$P = T\omega$; $r_2T_1 = r_1T_2$	watts = Nm/s hp=6600 in-lb/s
	ω, omega	angular speed, speed of rotation	$P = T\omega$; $r_1\omega_1 = r_2\omega_2$	rad/s
	f	frequency	$\omega = 2\pi f$	Hz = rev/s
	K	stress concentration factor	$\tau_{max} = KTc/J$	psi, Pa
flexure	σ, sigma	normal stress 	$\sigma_{beam} = -My/I$	psi, Pa
	σ, sigma	composite beams, $n = E_B/E_A$	$\sigma_A = -My / I^T$; $\sigma_B = -nMy / I^T$	psi, Pa
	τ, tau	shear stress 	$\tau_{beam} = VQ/Ib$ where $Q = \Sigma(y_{bar\ i} A_i)$	psi, Pa
	q	shear flow	$q = V_{beam}Q/I = nV_{fastener}/s$	
	v or y	beam deflection	$v = \iint M(x)\, dx^2 / EI$	in, m

Topic	Equations		Units
stress trans-formation	*planar rotations* $\sigma_u = (\sigma_x+\sigma_y)/2 + (\sigma_x-\sigma_y)/2 \cos(2\theta) + \tau_{xy}\sin(2\theta)$ $\sigma_v = (\sigma_x+\sigma_y)/2 - (\sigma_x-\sigma_y)/2 \cos(2\theta) - \tau_{xy}\sin(2\theta)$ $\tau_{uv} = -(\sigma_x-\sigma_y)/2 \sin(2\theta) + \tau_{xy}\cos(2\theta)$	*principals and max in-plane shear* $\tan(2\theta_p) = 2\tau_{xy} / (\sigma_x-\sigma_y)$, $\theta_s = \theta_p \pm 45^o$ $\sigma_{1,2} = (\sigma_x+\sigma_y)/2 \pm \text{sqrt}\{ [(\sigma_x-\sigma_y)/2]^2 + \tau_{xy}^2 \}$ $\tau_{max} = \text{sqrt}\{ [(\sigma_x-\sigma_y)/2]^2 + \tau_{xy}^2 \} = (\sigma_1-\sigma_2)/2$ $\sigma_{avg} = (\sigma_x+\sigma_y)/2 = (\sigma_1+\sigma_2)/2$	psi, Pa
strain trans-formation	*planar rotations* $\varepsilon_u = (\varepsilon_x+\varepsilon_y)/2 + (\varepsilon_x-\varepsilon_y)/2 \cos(2\theta) + \gamma_{xy}/2 \sin(2\theta)$ $\varepsilon_v = (\varepsilon_x+\varepsilon_y)/2 - (\varepsilon_x-\varepsilon_y)/2 \cos(2\theta) - \gamma_{xy}/2 \sin(2\theta)$ $\gamma_{uv}/2 = -(\varepsilon_x-\varepsilon_y)/2 \sin(2\theta) + \gamma_{xy}/2 \cos(2\theta)$ $\varepsilon_z = -\nu (\varepsilon_x + \varepsilon_y) / (1-\nu)$	*principals and max in-plane shear* $\tan(2\theta_p) = \gamma_{xy} / (\varepsilon_x-\varepsilon_y)$, $\theta_s = \theta_p \pm 45^o$ $\varepsilon_{1,2} = (\varepsilon_x+\varepsilon_y)/2 \pm \text{sqrt}\{ [(\varepsilon_x-\varepsilon_y)/2]^2 + (\gamma_{xy}/2)^2 \}$ $\gamma_{max}/2 = \text{sqrt}\{ [(\varepsilon_x-\varepsilon_y)/2]^2 + (\gamma_{xy}/2)^2 \}$ $\varepsilon_{avg} = (\varepsilon_x+\varepsilon_y)/2$	psi, Pa in/in, m/m
Hooke's law	*1D strain to stress* $\sigma = E\varepsilon$ *2D strain to stress* $\sigma_x = E(\varepsilon_x+\nu\varepsilon_y) / (1-\nu^2)$ $\sigma_y = E(\varepsilon_y+\nu\varepsilon_x) / (1-\nu^2)$ $\tau_{xy} = G\gamma_{xy} = E\gamma_{xy} / 2(1+\nu)$	*2D stress to strain* $\varepsilon_x = (\sigma_x-\nu\sigma_y) / E$ $\varepsilon_y = (\sigma_y-\nu\sigma_x) / E$ $\varepsilon_z = -\nu(\varepsilon_x+\varepsilon_y) / (1-\nu)$ $\gamma_{xy} = \tau_{xy}/G = 2(1+\nu)\tau_{xy} / E$	psi, Pa in/in, m/m
pressure	$\sigma_{spherical} = pr/2t$ $\sigma_{cylindrical,\ hoop} = pr/t$ $\sigma_{cylindrical,\ axial} = pr/2t$	$\sigma_{radial,\ outside} = 0$ $\sigma_{radial,\ inside} = -p$	psi, Pa
[illegible]	[illegible]	[illegible]	[illegible]

To: IDE 120 Section E Students
From: Krishna Kolan, GTA; Sean Smith, TA
Subject: Lab #1 – Spreadsheets and Spring Testing
Date: January 25, 2010
Report Due: February 1, 2010

Lab Procedure

The purpose of this week's assignment is to give everyone a chance to work with a spreadsheet program such as Excel. We will plot data points and perform linear regression on the data. You will be given sample data sets from tensile tests on steel and aluminum and you will collect load versus deflection data for a spring.

→For the assigned sample data sets follow the steps in the Sample Tensile Test Data Sets section.

→For your spring data you need to follow the steps in the Experimental Spring Data section.

Sample Tensile Test Data Sets:

Assigned data sets:

1	6

od = .625"
L = 8.00"

The sample data sets can be found at:

Course Website→Lessons→Introduction, Spring Testing→Data Sets

After obtaining your sample data sets, follow the steps listed below:

1) In Excel set up tables for your data sets. Include appropriate column labels for your data. Input your data sets with separate columns for the load and deformation. Make sure you label the data sets so I know which ones you used.
2) Record the gage length and specimen diameter at a convenient location in your spreadsheet. The specimens have a circular cross-section. Use this information to calculate and record the cross-sectional area of the specimen.
3) Add appropriately labeled columns and generate calculated values of stress and strain. Stress can be calculated using Eq. (1) and strain can be calculated using Eq. (2). All equations are shown in the equations section at the end of this memo.
4) Perform linear regression on your calculated stress vs. strain values. Use all the data points for each set in your regression analysis. Remember to use the stresses as y-values and the strains as x-values. Your regression equation will have the form $y = mx+b$ where y is the stress and x is the strain.
5) Create a graph of your stress vs. strain data. Include your sample data points and the linear regression line along with its equation. You need to create a separate graph for each data set. Start the scales at zero and extend them slightly beyond the limits of your data. Your graph needs to have a caption and the axes should be labeled.

If you need a refresher on spreadsheets there are help files available at:

Course Website→Lessons→Introduction, Spring Testing→Spreadsheets

You can also stop by my office any time and I will help you with the assignment.

Experimental Spring Data:

After performing the test on the selected spring you should have data points showing deflection at different loads. You will need to complete the following for your load vs. deflection data.

1) Record the spring # for your tested spring on the given datasheet.
2) Input your data with separate columns for the load and deflection.
3) Perform linear regression on your experimental load vs. deflection data. Use all the data points in your regression analysis. Remember to use the loads as y-values and the deflections as x-values.
4) The slope found from your regression analysis is by definition the spring constant for your spring as shown in Eq. (3).
5) Create a graph of your load vs. deflection data. Include your data points and the linear regression line along with its equation.

Lab Report

This week's lab report is a TEAM MEMO worth 50 points. Answer the following questions in the appropriate section of your memo.

1. Do the sample tensile test data sets appear to show a linear relationship between stress and strain?
2. What was the spring constant for your tested spring? How would knowing the spring constant be useful in a real world application?
3. Did any of the data points seem out of place for either the sample data or the spring data?
4. Were there any parts of the assignment that were difficult for you?

Also, include or attach the following:

- A table summarizing the slope and y-intercept for each sample tension test data set.
- The graphs of your stress vs. strain data.
- The graph of load vs. deflection for your spring data

Remember to follow the guidelines for graphs and tables that I gave you. Make sure you mention in your memo where your tables and figures are so I know where to find them. Be sure to complete and attach a set of hand calculations showing your calculations of stress and strain. You only need to perform hand calculations for one data point in one of your sample data sets. Don't forget to attach the datasheet.

Equations

(1) Stress

$$\sigma = \frac{F}{A}$$

σ = stress, psi
F= load, lb
A= cross-sectional area, in^2

(2) Strain

$$\varepsilon = \frac{\Delta L}{L_0}$$

ε = strain, in/in
ΔL = deformation, in
L_0= gage length, in

(3) Spring Constant

$$k = \frac{\Delta F}{\Delta L}$$

k= spring constant, lb/in
ΔF = change in force, lb
ΔL = deflection, in

Guidelines for Tables

Tables of data should be included in your reports as appropriate. For formal reports, tables should be placed in Appendix A at the end of the report. When writing a memo, tables can be included in the body of the memo or attached as separate pages. Tables should be numbered with Roman numerals as Table I, Table II, etc. Place the table number and a descriptive caption **above** the table. Refer to tables in your report as Table x where x is the table number.

The tables in your reports should have the following features:

1. The rows and/or columns should be labeled to show what data they represent. Include in your labels the units of the numbers shown.
2. Values measured in the lab should be recorded as read from the measuring instrument. Do not use more or less decimal points or significant digits when reporting the measured values in your table.
3. Do not display your calculated values with more decimal points than are appropriate. This is especially a problem when using Excel since Excel will carry however many decimal points you want. You can count significant digits if you want, but it is not required. For the most part, 3 or 4 significant digits should be used. Scientific notation is useful to show your results concisely.
4. Make sure your tables have lines dividing the rows and columns.
5. Make sure the table's cells are large enough to fully display the data.

A sample table is shown below as Table I.

Table I: Tensile Test Results

Load (lb)	Stress (psi)	Deflection (in)	Strain (in/in)
2100	4.28E+00	18.0	2.25
3925	8.00E+03	32.8	4.10
6225	1.27E+04	52.2	6.53
7800	1.59E+04	64.0	8.00
9850	2.01E+04	80.7	10.1

Lab Report Guidelines

You will write two types of reports this semester. The two types are formal reports and memos. The sections to include in your reports are shown below. Formal reports should have all the sections shown in the same order listed. For the memos you do not need to use appendices for your tables, figures, and hand calculations, but they should be included somewhere in the memo. Don't forget to attach your initialed original data sheet at the end of all your reports regardless of the required format.

Formal Reports	**Memos**
Title Page	Introduction
Introduction	Experimental Results
Objectives	Discussion of Results
Procedure	References
Experimental Results	Tables
Discussion of Results	Figures
Conclusions	Hand Calculations
References	
Appendix A: Tables	
Appendix B: Figures	
Appendix C: Hand Calculations	

You need to label all the sections in your reports except for the title page. A description of each section of the report is given below.

Title Page

The title page should include the title of the experiment, course name, section letter, the names of all group members, group number, the date the report is due, and the names of your GTA and TA. You do not need to label the title page. It is up to you to decide the formatting and layout of the title page.

Introduction

The introduction of your report should start at the top of page 2 for formal reports (the Title Page will be page 1). The introduction describes the basic subject area of the report. You should tell the reader the tests that were performed and the materials that were tested. An example of a real world application of your experimental findings should be included.

Objectives

The objectives section should tell the reader what you were trying to learn by performing the experiment.

Procedure

The procedure section of your report should be a step-by-step description of how you used the lab equipment to obtain your data. Another IDE 120 student should be able to perform the experiment using your procedure. You can use a numbered list to show the steps of the procedure. Do not copy the procedure word for word from the handouts or the course website.

Experimental Results

The experimental results section is where you will report the data you collected and your calculated values. For most reports, you should use tables to show your experimental and calculated values. The tables should be placed in Appendix A for formal reports. A short description of how you found any calculated values should be included along with the equations you used. Equations can be either typed or hand written. With either method, equations should be numbered and referred to as Eq. x where x is the equation number. An example of an equation is shown as Eq. 1 on the back of this page.

$$\sigma = \frac{F}{A_o} \qquad (1)$$

Discussion of Results

In this section of the report you should discuss the most important aspects of your experimental results including any trends that you notice in your data sets. The main purpose of this section is to give you a chance to comment on the validity of the experimental data and explain anything important that you might notice. In this section you should make comparisons between your data and reference values. You should also compare the data sets to one another (if you have more than one). A discussion of whether any data points appear incorrect and the reasons you have for why the data may be incorrect should be included. You should include some insightful remarks in this section to show that you understand the results and what they tell you.

Conclusions

In the conclusions section you will briefly restate the major findings of your experiment and discuss why they are important. This section is also where you tell what you learned from the experiment and whether all the objectives were fulfilled. Feel free to add any comments or suggestions about the lab at the end of your conclusions section.

References

In the references section of your report you need to give credit to any books, journals, websites, or other sources used while writing your report. You should include any sources used to look up reference values for the materials tested. You can use any standard format for listing your references. Pick a format that you are familiar with and are comfortable using.

Appendix A: Tables

This appendix is where you place all the tables in your formal report. Make sure the tables are large enough to read and that you follow the guidelines you were given for tables.

Appendix B: Figures

All graphs and other figures should be placed in Appendix B for formal reports. Again, be sure to follow the guidelines you were given covering graphs. Do not try to save space by cramming several figures on one page.

Appendix C: Hand Calculations

You need to include a sample of your hand calculations in Appendix C. You only need to show one hand calculation for each equation used. The hand calculations will be used to determine if partial credit should be awarded if an incorrect answer is found.

General Guidelines

1. Use 3rd person in your reports. Do not use "I" or "we" when describing how you completed the report.
2. Use past tense throughout your report. By the time you write your report you should be done with everything else so it makes sense to write about your work in the past tense.
3. Use single spacing between lines in your report.
4. Use an easily readable 12 point font for the body of your report. Headings and other titles can be larger if desired.
5. Staple your report before you turn it in.

IDE 120 - Materials Testing Lab

Section E, Spring Semester 2010
Room G6J Interdisciplinary Engineering Building
Monday 3:00 - 4:50 P.M.
Course Website: http://web.mst.edu/~ide120

GTA:
Krishna Kolan
Office: 209 Toomey Hall ("RFP Lab")
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Sean Smith
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Mailbox: G1 IDE

Attendance Policy:
Attendance is required at all lab meetings and everyone is required to perform the lab procedure for all labs. If you miss a lab, please contact the GTA the same day as your absence to arrange a make-up time. If you fail to contact the GTA the same day as your absence, you will only be able to receive 75% of the possible points for the lab. Failure to make up a lab before the next lab meeting will result in an F grade for the course. You also need to be in class at the start time. If you arrive late, your class participation grade will be reduced.

Grading Policy:
Your grade will be determined based on reports, presentations, class participation, and peer evaluations. The following table shows how your grade will be calculated.

	% of Grade
Reports and Presentations	80
Class Participation and Peer Evaluations	20
Total	100

Course grades will be assigned as follows: 90-100%=A, 80-89.9%=B, 70-79.9%=C, 60-69.9%=D, below 60%=F. An optional final will be given at the end of the semester. This final can only help your grade and if you do poorly on it, your grade will not change. More details about the optional final will be given later.

Lab Reports:
There are two types of lab reports you will complete this semester. Some labs will require memos while others will require formal reports. You will be informed of the type of report required for each lab in the weekly handout. If you find any differences between the assignments listed on the course website and the assignment on the handout, always follow the handout. Refer to the Lab Report Guidelines handout for more information on what should be included in your reports. All the handouts will be uploaded in Blackboard. You could take a printout of the handout (one per group) and bring it to the class.

Report Due Dates:
All reports are due at the beginning of the next lab period. Late reports will be accepted until one lab period after the original due date. Late reports will have 50% of the possible points deducted. One class period after the original due date, no late reports will be accepted.

Academic Dishonesty:
Academic dishonesty in the form of plagiarized reports will not be tolerated in this course. You will be required to turn in your original data sheet for each lab with either the GTA or TA's initials to show your work was original. Failure to turn in an initialed data sheet will result in an irreversible loss of 25% of the possible points for the lab. If plagiarism is found or suspected, it will be dealt with according to the Student Academic Regulations. Punishment for plagiarism can be as severe as immediate failure of the course and a note on your academic record. It is not worth it to plagiarize a report. Not only do you risk punishment, but you also do not learn the material that needs to be learned from the lab.

Schedule:
The schedule of labs is shown below.

Week:	Lab Topic
1/11 and 1/18	---------------No lab this week-----------------
1/25	Introduction, Spring Testing
2/1	Tension Testing
2/8	Direct Shear and Torsion Testing
2/15	Failure, Fully Plastic Action
2/22	Strain Gages, Flexure Testing for Elastic Constants
3/1	Composite Materials, Beam of Two Materials
3/8	---------------No lab this week-----------------
3/15	Beam Deflection
3/22	Hardness Testing
3/29	---------------No lab this week-----------------
4/5	Fastener Testing, Wood Connections
4/12	Strain Transformation
4/19	Pressure Vessels
4/26	Eccentric Loading
5/3 and 5/10	-----No lab this week and no final exam----

Notes:
It may be necessary to change items in this syllabus as the semester progresses. If any changes are needed you will be given plenty of notice. If you ever have any questions about this syllabus or anything discussed in class please contact me since it is my job to help you learn the material. If problems arise throughout the semester that you feel are not fully resolved after talking with the GTA and TA you may contact the IDE 120 course director Mr. Jeff Thomas (G6G IDE). I hope you enjoy IDE 120 and I look forward to working with all of you this semester.

Guidelines for Graphs

Graphs should be labeled and referred to as figures. For formal reports, all figures should be placed in Appendix B at the end of your report. For memos, figures can be either included in the body of the memo or attached as separate pages. Figures should be numbered sequentially as Figure 1, Figure 2, etc. Refer to figures in your report using Fig. x where x is the figure number. Place the figure number and a descriptive caption **below** the graph.

The graphs in your lab reports should include the following features:

1. All graphs should have a neat appearance.
2. The size of the graph should be large enough to clearly show all the important features.
3. The caption should summarize the data being displayed.
4. All axes should be labeled. Include units in your labels.
5. Choose a scale that creates reasonably sized divisions.
6. The scales of the axes should be labeled.
7. Plot the dependent variable on the y-axis and the independent variable on the x-axis.
8. Do not connect points obtained from experimental data with smoothed lines. All you need to do is show the data points as discrete points on the graph.
9. Do not show data points on a theoretical curve. Just show the smooth curve and its equation. If the equation clutters the graph, the equation can be placed elsewhere on the same page as the graph.
10. All curves and data sets should be labeled by using a legend.
11. Use different line styles for each curve and use different symbols for the different sets of data points. Use colors that are easily distinguished when copied in black and white.
12. Use a white background on all your graphs.
13. If needed, you can label features of your graph by hand if the software you are using does not allow complete documentation.

An example of a graph is shown below as Fig. 1.

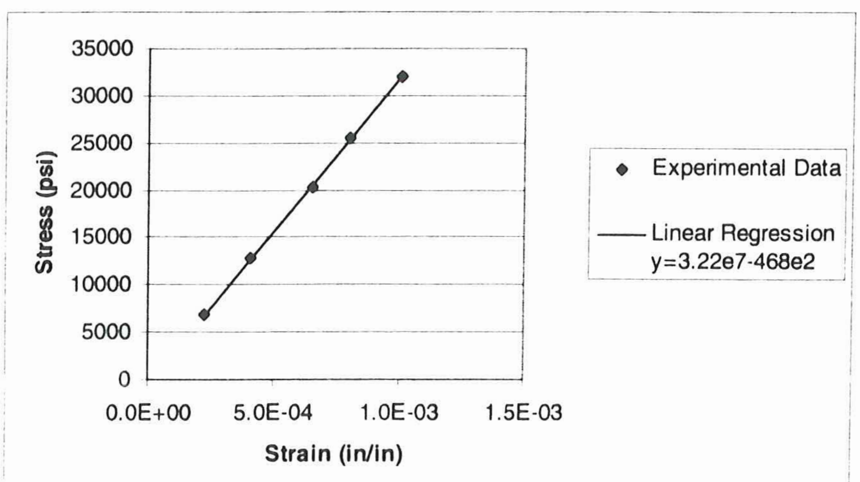


Figure 1: Stress-Strain Diagram for Data Set 1

Exams/Quiz

Mec. Mat Quiz 7 prep

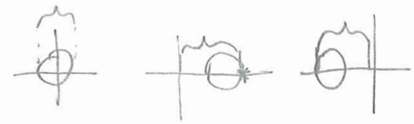
$$\varepsilon_u = \frac{\varepsilon_x + \varepsilon_y}{2} + \frac{\varepsilon_x - \varepsilon_y}{2}\cos 2\theta + \frac{\gamma_{xy}}{2}\sin 2\theta$$

$$= \varepsilon_x \cos^2\theta + \varepsilon_y \sin^2\theta + \gamma_{xy}\sin\theta\cos\theta$$

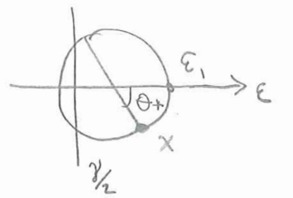
$$\gamma_{\text{max in plane}} = 2\sqrt{\left(\frac{\varepsilon_x - \varepsilon_y}{2}\right)^2 + \left(\frac{\gamma_{xy}}{2}\right)^2} = 2R$$

$\gamma_{\text{abs max}}$ = $|$largest $\varepsilon_p|$ or $|\varepsilon_1 - \varepsilon_2|$ if opposite signs

= radius of large circle ($\times 2$ to go from ε to γ)



moore's circle θ positive, x is on bottom, ccw rotation from x to principal



$p = \rho g h$

$\tau_{xy} = 0$ for pressure vessel

τ_{xy} corresponds to $\frac{\gamma_{xy}}{2}$

$\varepsilon_a = \varepsilon_x \cos^2\theta_a + \varepsilon_y \sin^2\theta_a + \gamma_{xy}\cos\theta \sin\theta_a$

$\cancel{\varepsilon_x \cos^2\theta - \varepsilon_y \sin^2\theta} - \gamma_{xy}\cos\theta\sin\theta$

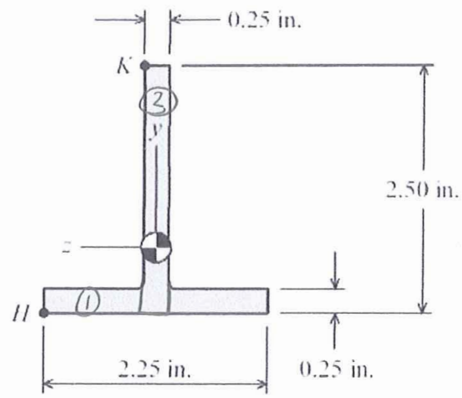
Quiz 4 practice

IDE 110 S08 Test 4 Name: ____________________

1. A cross section of a beam is shown. For any moment M about the z-axis, which point will have the greater bending stress magnitude (either tension or compression)?

   __X__ Point K

   ______ Point H



2. If the beam in Problem 1 is subjected to a negative moment about the z-axis, which bending stress will have the greater magnitude?

   ______ Compression bending stress

   __X__ Tension bending stress

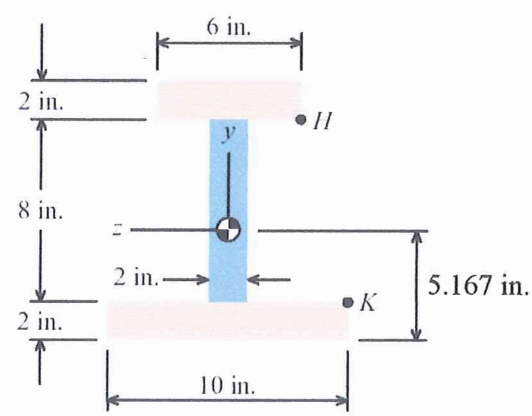
3. Determine the distance from the bottom of the cross section in Problem 1 to the centroid.

y from bottom = .75 in.

$$\frac{\overset{A_1}{2(.25)}\overset{\bar{y}}{(.125)} + \overset{A_2}{(2.5)(.25)}\overset{\bar{y}}{(1.25)}}{(45)(.25)}$$

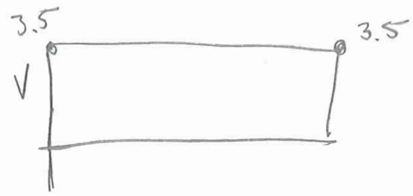
4. Determine the moment of inertia about the z-axis for the cross section shown. Note that the centroid is 5.167 in. from the bottom.

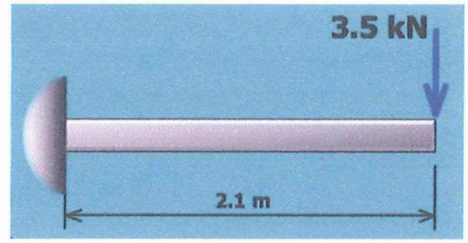
I_z = ____________ in.^{4}



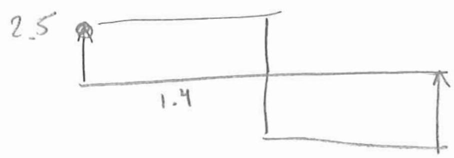
5. Determine the maximum bending moment in the following beams.

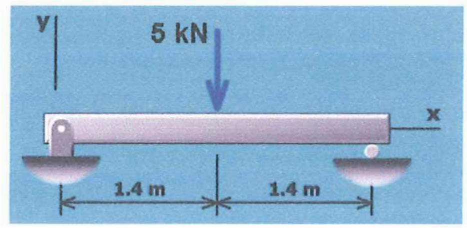
M_{max} = 7.35 kN-m



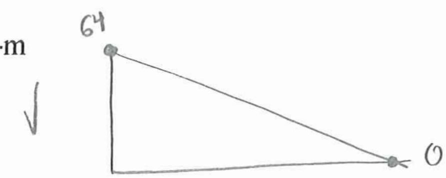


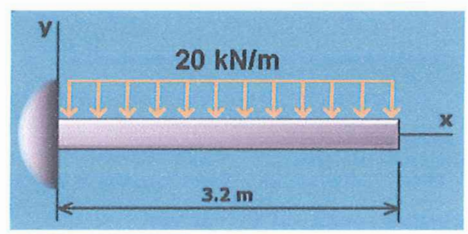
M_{max} = 3.5 kN-m



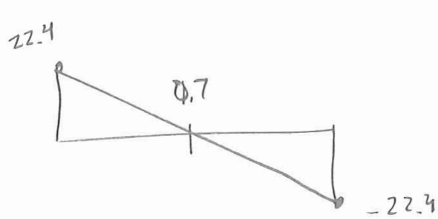


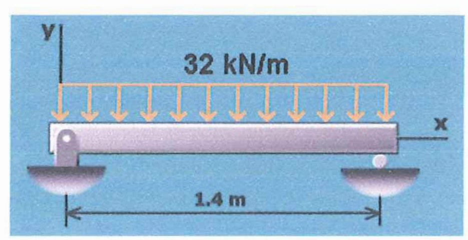
M_{max} = 102.4 kN-m



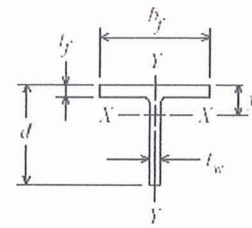


M_{max} = 7.84 kN-m





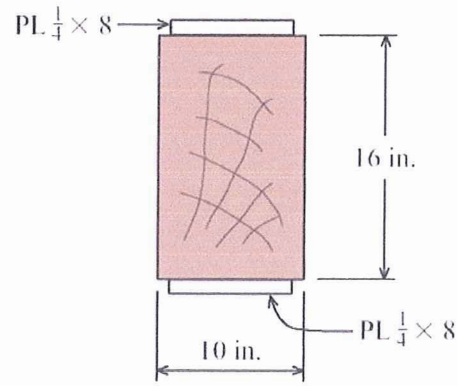
9. Circle the most economical WT beam in the following table if a section modulus $S_x \geq 8$ in.^{3} is required.



Shapes Cut from Wide-Flange Sections or WT Shapes

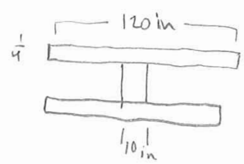
Designation	Area A	Depth d	Web thickness t_w	Flange width b_f	Flange thickness t_f	Centroid $\bar{y}$	I_x	S_x	r_x	I_y	S_y	r_y
	in.^{2}	in.	in.	in.	in.	in.	in.^{4}	in.^{3}	in.	in.^{4}	in.^{3}	in.
WT12×47	13.8	12.2	0.515	9.07	0.875	2.99	186	20.3	3.67	54.5	12.0	1.98
WT12×38	11.2	12.0	0.440	8.99	0.680	3.00	151	16.9	3.68	41.3	9.18	1.92
WT12×34	10.0	11.9	0.415	8.97	0.585	3.06	137	15.6	3.70	35.2	7.85	1.87
WT12×27.5	8.10	11.8	0.395	7.01	0.505	3.50	117	14.1	3.80	14.5	4.15	1.34
WT10.5×34	10.0	10.6	0.430	8.27	0.685	2.59	103	12.9	3.20	32.4	7.83	1.80
WT10.5×31	9.13	10.5	0.400	8.24	0.615	2.58	93.8	11.9	3.21	28.7	6.97	1.77
WT10.5×25	7.36	10.4	0.380	6.53	0.535	2.93	80.3	10.7	3.30	12.5	3.82	1.30
WT10.5×22	6.49	10.3	0.350	6.50	0.450	2.98	71.1	9.68	3.31	10.3	3.18	1.26
WT9×27.5	8.10	9.06	0.390	7.53	0.630	2.16	59.5	8.63	2.71	22.5	5.97	1.67
WT9×25	7.33	9.00	0.355	7.50	0.570	2.12	53.5	7.79	2.70	20.0	5.35	1.65
WT9×20	5.88	8.95	0.315	6.02	0.525	2.29	44.8	6.73	2.76	9.55	3.17	1.27
WT9×17.5	5.15	8.85	0.300	6.00	0.425	2.39	40.1	6.21	2.79	7.67	2.56	1.22
WT8×28.5	8.39	8.22	0.430	7.12	0.715	1.94	48.7	7.77	2.41	21.6	6.06	1.60
WT8×25	7.37	8.13	0.380	7.07	0.630	1.89	42.3	6.78	2.40	18.6	5.26	1.59
WT8×20	5.89	8.01	0.305	7.00	0.505	1.81	33.1	5.35	2.37	14.4	4.12	1.56
WT8×15.5	4.56	7.94	0.275	5.53	0.440	2.02	27.5	4.64	2.45	6.2	2.24	1.17

10. Two ¼ in.×8 in. steel [E = 30,000 ksi] plates are securely attached to a pine [E = 2,000 ksi] timber to form a composite beam. Determine the maximum bending stress magnitude in the steel if a moment of 100 kip-ft is applied about the horizontal axis of the beam.



$$n = \frac{E_{st}}{E_t} = 15$$

$\sigma_{\text{max steel}}$ = 20.135 ksi

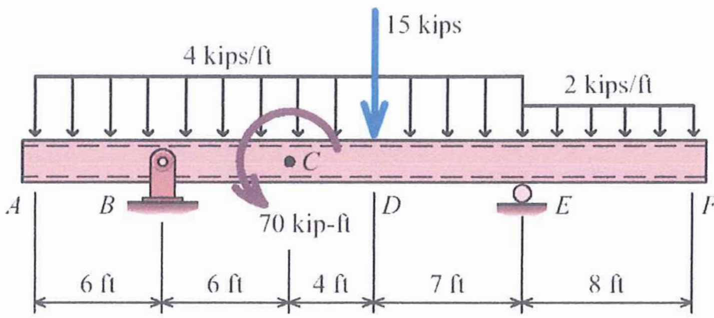


$$I = 2\left[\frac{(.25)^3(120)}{12} + (8.125)^2(.25)(120)\right] + \frac{(10)(16)^3}{12}$$

$$I = 7375 \text{ in}^4$$

$$\frac{My}{I}(n) = \frac{100000(12)(8.25)(15)}{7375}$$

8. A HSS10×4×1/2 standard steel shape is used to support the loads shown on the beam. The shape is oriented so that bending occurs about the strong axis. Determine the magnitude of the maximum bending stress in the beam. Note that the shear-force and bending-moment diagrams have been provided in kips and kip-ft.

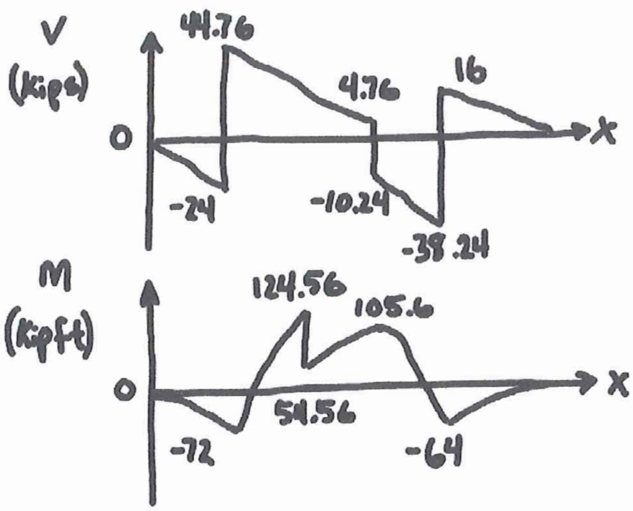


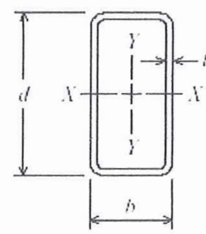
σ_{max} = 57.93 ksi

max bending stress

$$= \frac{My}{I} = \frac{124.56 \text{ kip}\cdot\text{ft}\,(12)(5")}{129 \text{ in}^4}$$

σ_{max} = 57.93 ~~psi~~ ksi

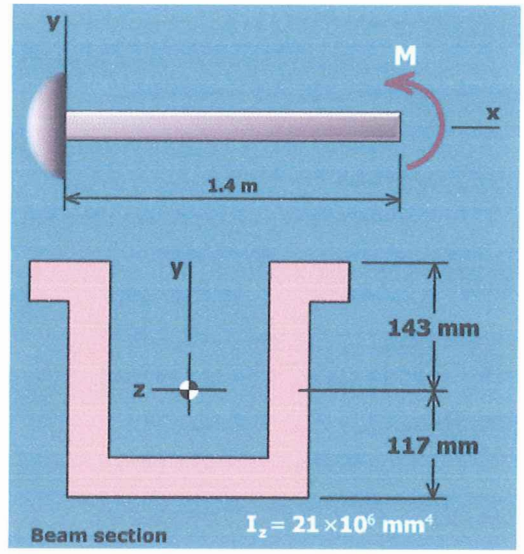




Hollow Structural Sections or HSS Shapes

Designation	Depth d	Width b	Wall thickness (nom.) t	Weight per foot	Area A	I_x	S_x	r_x	I_y	S_y	r_y
	in.	in.	in.	lb/ft	in.^{2}	in.^{4}	in.^{3}	in.	in.^{4}	in.^{3}	in.
HSS12×8×1/2	12	8	0.5	62.3	17.2	333	55.6	4.41	178	44.4	3.21
×8×3/8	12	8	0.375	47.8	13.2	262	43.7	4.47	140	35.1	3.27
×6×1/2	12	6	0.5	55.5	15.3	271	45.2	4.21	91.1	30.4	2.44
×6×3/8	12	6	0.375	42.7	11.8	215	35.9	4.28	72.9	24.3	2.49
HSS10×6×1/2	10	6	0.5	48.7	13.5	171	34.3	3.57	76.8	25.6	2.39
×6×3/8	10	6	0.375	37.6	10.4	137	27.4	3.63	61.8	20.6	2.44
×4×1/2	10	4	0.5	41.9	11.6	129	25.8	3.34	29.5	14.7	1.59
×4×3/8	10	4	0.375	32.5	8.97	104	20.8	3.41	24.3	12.1	1.64
HSS8×4×1/2	8	4	0.5	35.1	9.74	71.8	17.9	2.71	23.6	11.8	1.56
×4×3/8	8	4	0.375	27.4	7.58	58.7	14.7	2.78	19.6	9.80	1.61
×4×1/4	8	4	0.25	19.0	5.24	42.5	10.6	2.85	14.4	7.21	1.66
×4×1/8	8	4	0.125	9.85	2.70	22.9	5.73	2.92	7.90	3.95	1.71
HSS6×4×3/8	6	4	0.375	22.3	6.18	28.3	9.43	2.14	14.9	7.47	1.55
×4×1/4	6	4	0.25	15.6	4.30	20.9	6.96	2.20	11.1	5.56	1.61
×4×1/8	6	4	0.125	8.15	2.23	11.4	3.81	2.26	6.15	3.08	1.66
×3×3/8	6	3	0.375	19.7	5.48	22.7	7.57	2.04	7.48	4.99	1.17
×3×1/4	6	3	0.25	13.9	3.84	17.0	5.66	2.10	5.70	3.80	1.22
×3×1/8	6	3	0.125	7.30	2.00	9.43	3.14	2.17	3.23	2.15	1.27

6. For the beam shown, the allowable compression bending stress is 60 MPa, and the allowable tension bending stress is 70 MPa. Determine the maximum value of *M* that can be applied as shown to the beam.



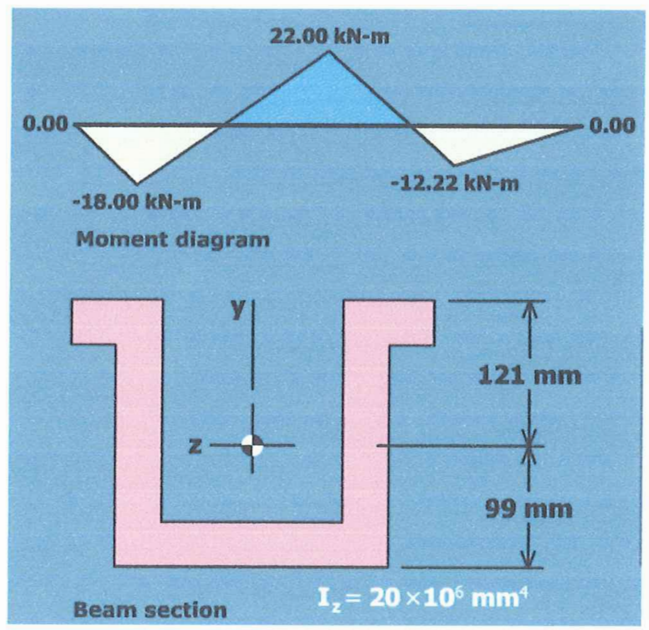
$M =$ 8.811 kN-m

$\sigma_t = \frac{My}{I} > 70\text{MPa}$

$\frac{M\ .117}{21(10^{-6})} > 70$ $M < 12.564$

$\sigma_c = \frac{M\ .143}{21(10^{-6})} > 60$ $M < 8.811$

7. For the moment diagram and cross section shown, compute the maximum tension and compression bending stresses produced at any location along the beam span.



σ max tension = 108.9 MPa

σ max compression = 133.1 MPa

$$\frac{\begin{pmatrix} 22{,}000 \\ -18{,}000 \end{pmatrix}\begin{pmatrix} .121 \\ -.099 \end{pmatrix}}{20(10^{-6})\ m^4}$$

$22 \begin{cases} 133.1 \\ -109.0 \end{cases}$

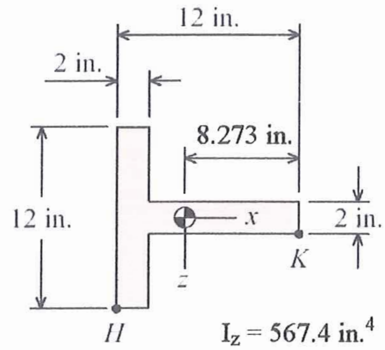
$-18 \begin{cases} -108.9 \\ 89.1 \end{cases}$

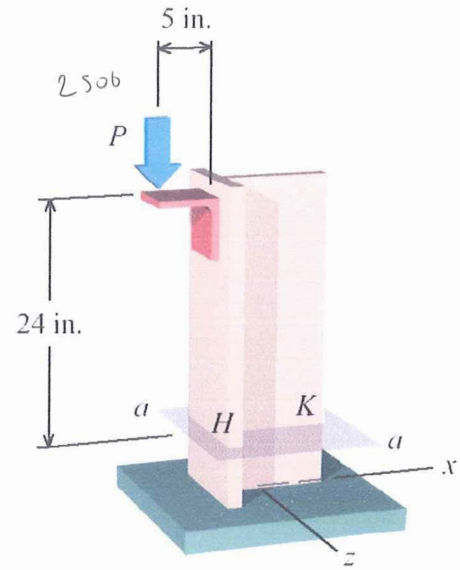
11. The tee shape is used as a short post to support a load of $P = 2{,}500$ lb. The load P is applied at a distance of 5 in. from the surface of the flange. Determine the normal force and bending moment located at section *a-a*. Also determine the magnitude of the bending stress at point *K*. Note that the centroid location and moment of inertia are provided.

N= 2500 lb

M_z= 21,800 lb-in.

σ_K= 261.04 psi (t)

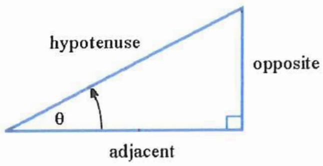




$$\sigma_K = \frac{N}{A} + \frac{My}{I}$$

$$\frac{2500 \text{ lb}}{44 \text{ in}^2} + \frac{-21{,}800\,(8.273)}{567.4}$$

TRIGONOMETRY

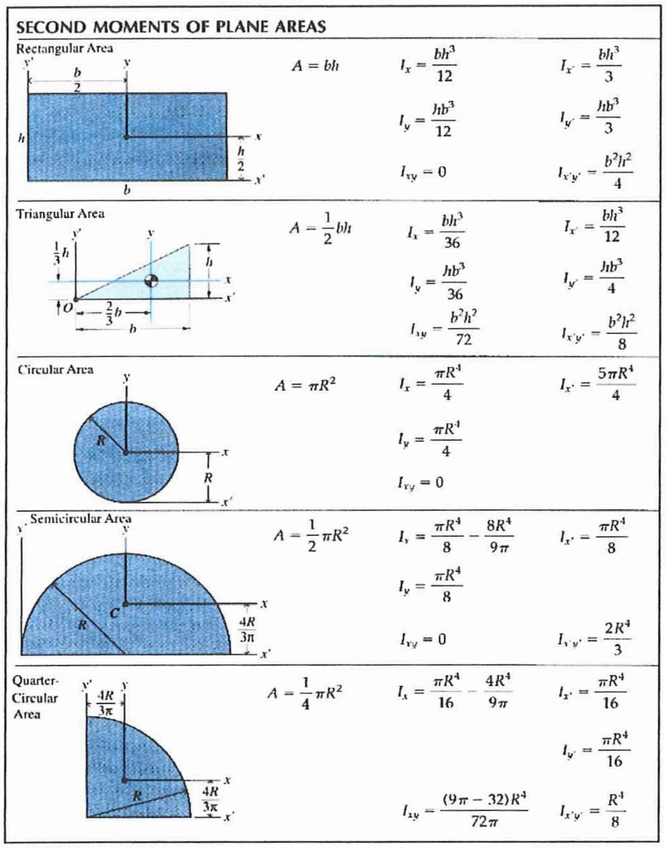


$\sin\theta = $ opp / hyp
$\cos\theta = $ adj / hyp
$\tan\theta = $ opp / adj

1 hp = 550 ft.lb/s
power through gears stays same (Torque x rpm)

STATICS

Symbol	Meaning	Equation	Units
$\bar{x}, \bar{y}, \bar{z}$	centroid position	$\bar{y} = \Sigma \bar{y}_i A_i / \Sigma A_i$	in, m
I	moment of inertia	$I = \Sigma(I_i + d_i^2 A_i)$	in^4, m^4
J	polar moment of inertia	$J_{\text{solid circular shaft}} = \pi d^4/32$ $J_{\text{hollow circular shaft}} = \pi(d_o^4 - d_i^4)/32$	in^4, m^4
N	normal force		lb, N
V	shear force	$V = \int -w(x)\,dx$	lb, N
M	bending moment	$M = \int V(x)\,dx$	in-lb, Nm
equilibrium		$\Sigma \mathbf{F} = \mathbf{0}$ $\Sigma \mathbf{M}_{(\text{any point})} = \mathbf{0}$	lb, N in-lb, Nm



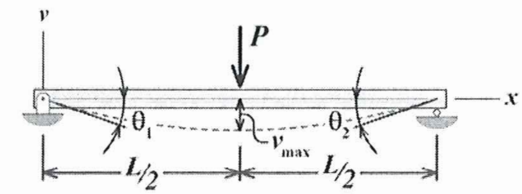
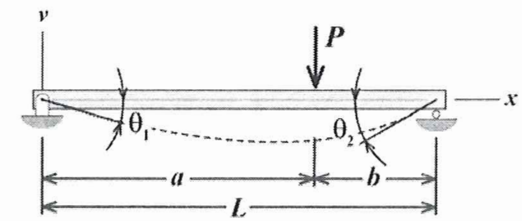
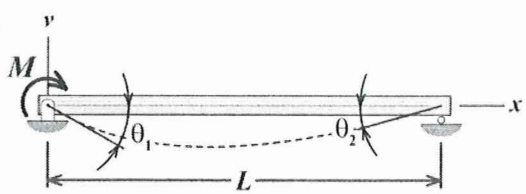
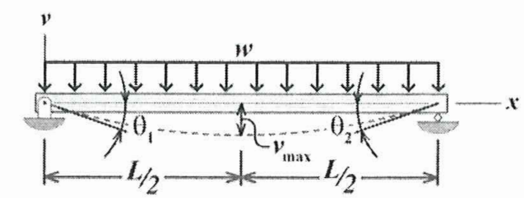
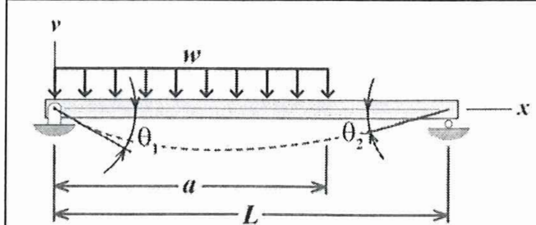
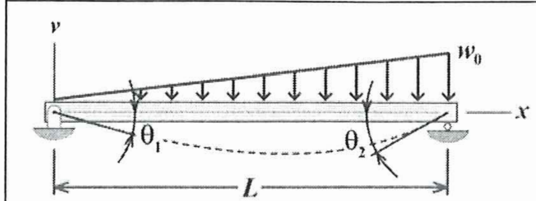
SECOND MOMENTS OF PLANE AREAS

Area	A		
Rectangular Area	$A = bh$	$I_x = \frac{bh^3}{12}$, $I_y = \frac{hb^3}{12}$, $I_{xy} = 0$	$I_{x'} = \frac{bh^3}{3}$, $I_{y'} = \frac{hb^3}{3}$, $I_{x'y'} = \frac{b^2h^2}{4}$
Triangular Area	$A = \frac{1}{2}bh$	$I_x = \frac{bh^3}{36}$, $I_y = \frac{hb^3}{36}$, $I_{xy} = \frac{b^2h^2}{72}$	$I_{x'} = \frac{bh^3}{12}$, $I_{y'} = \frac{hb^3}{4}$, $I_{x'y'} = \frac{b^2h^2}{8}$
Circular Area	$A = \pi R^2$	$I_x = \frac{\pi R^4}{4}$, $I_y = \frac{\pi R^4}{4}$, $I_{xy} = 0$	$I_{x'} = \frac{5\pi R^4}{4}$
Semicircular Area	$A = \frac{1}{2}\pi R^2$	$I_x = \frac{\pi R^4}{8} - \frac{8R^4}{9\pi}$, $I_y = \frac{\pi R^4}{8}$, $I_{xy} = 0$	$I_{x'} = \frac{\pi R^4}{8}$, $I_{x'y'} = \frac{2R^4}{3}$
Quarter-Circular Area	$A = \frac{1}{4}\pi R^2$	$I_x = \frac{\pi R^4}{16} - \frac{4R^4}{9\pi}$, $I_{xy} = \frac{(9\pi - 32)R^4}{72\pi}$	$I_{x'} = \frac{\pi R^4}{16}$, $I_{y'} = \frac{\pi R^4}{16}$, $I_{x'y'} = \frac{R^4}{8}$

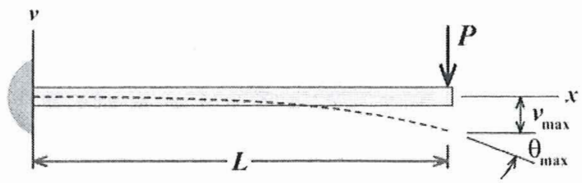
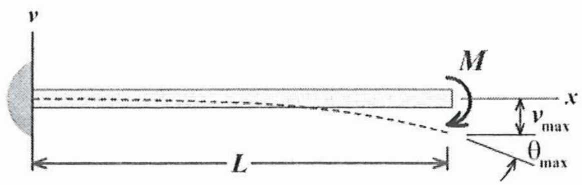
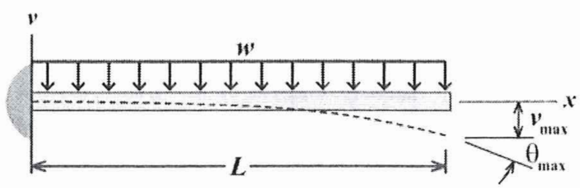
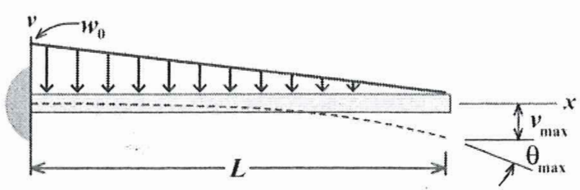
MECHANICS OF MATERIALS

Topic	Symbol	Meaning	Equation	Units
axial	σ, sigma	normal stress 	$\sigma_{\text{axial}} = N/A$ $\tau_{\text{cutting}} = V/A$ $\sigma_{\text{bearing}} = F_b/A_b$	psi, Pa
	ε, epsilon	normal strain	$\varepsilon_{\text{axial}} = \Delta L/L_o = \delta/L_o$ $\varepsilon_{\text{transverse}} = \Delta d/d$	in/in, m/m
	γ, gamma	shear strain	γ = change in angle,	rad
	E	Young's modulus, modulus of elasticity	$\sigma = E\varepsilon$ (one-dimensional only)	psi, Pa
	G	shear modulus, modulus of rigidity	$G = \tau/\gamma = E / 2(1+\nu)$	psi, Pa
	ν, nu	Poisson's ratio	$\nu = -\varepsilon'/\varepsilon$	
	δ, delta	deformation, elongation, deflection	$\delta = NL_o/EA + \alpha\Delta T L_o$	in, m
	α, alpha	coefficient of thermal expansion (CTE)		in/inF, m/mC
	F.S.	factor of safety	F.S. = actual strength / design strength	

SIMPLY SUPPORTED BEAMS

Beam	Slope	Deflection	Elastic Curve
	$\theta_1 = -\theta_2 = -\dfrac{PL^2}{16EI}$	$v_{max} = -\dfrac{PL^3}{48EI}$	$v = -\dfrac{Px}{48EI}(3L^2 - 4x^2)$ $for\ 0 \le x \le L/2$
	$\theta_1 = -\dfrac{Pb(L^2 - b^2)}{6LEI}$ $\theta_2 = +\dfrac{Pa(L^2 - a^2)}{6LEI}$	$v\big\rvert_{x=a} = -\dfrac{Pba}{6LEI}(L^2 - b^2 - a^2)$	$v = -\dfrac{Pbx}{6LEI}(L^2 - b^2 - x^2)$ $for\ 0 \le x \le a$
	$\theta_1 = -\dfrac{ML}{3EI}$ $\theta_2 = +\dfrac{ML}{6EI}$	$v_{max} = -\dfrac{ML^2}{9\sqrt{3}EI}$ $@\ x = L\left(1 - \dfrac{\sqrt{3}}{3}\right)$	$v = -\dfrac{Mx}{6LEI}(2L^2 - 3Lx + x^2)$
	$\theta_1 = -\theta_2 = -\dfrac{wL^3}{24EI}$	$v_{max} = -\dfrac{5wL^4}{384EI}$	$v = -\dfrac{wx}{24EI}(L^3 - 2Lx^2 + x^3)$
	$\theta_1 = -\dfrac{wa^2}{24LEI}(2L - a)^2$ $\theta_2 = +\dfrac{wa^2}{24LEI}(2L^2 - a^2)$	$v\big\rvert_{x=a} = -\dfrac{wa^3}{24LEI}(3a^2 - 7aL + 4L^2)$	$v = -\dfrac{wx}{24LEI}(a^4 - 4a^3L + 4a^2L^2 + 2a^2x^2 - 4aLx^2 + Lx^3)$ $for\ 0 \le x \le a$ $v = -\dfrac{wa^2}{24LEI}(-a^2L + 4L^2x + a^2x - 6Lx^2 + 2x^3)$ $for\ a \le x \le L$
	$\theta_1 = -\dfrac{7w_0L^3}{360EI}$ $\theta_2 = +\dfrac{w_0L^3}{45EI}$	$v_{max} = -0.00652\dfrac{w_0L^4}{EI}$ $@\ x = 0.5193L$	$v = -\dfrac{w_0x}{360LEI}(7L^4 - 10L^2x^2 + 3x^4)$

CANTILEVER BEAMS

Beam	Slope	Deflection	Elastic Curve
	$\theta_{\max}=-\dfrac{PL^2}{2EI}$	$v_{\max}=-\dfrac{PL^3}{3EI}$	$v=-\dfrac{Px^2}{6EI}(3L-x)$
	$\theta_{\max}=-\dfrac{ML}{EI}$	$v_{\max}=-\dfrac{ML^2}{2EI}$	$v=-\dfrac{Mx^2}{2EI}$
	$\theta_{\max}=-\dfrac{wL^3}{6EI}$	$v_{\max}=-\dfrac{wL^4}{8EI}$	$v=-\dfrac{wx^2}{24EI}(6L^2-4Lx+x^2)$
	$\theta_{\max}=-\dfrac{w_0L^3}{24EI}$	$v_{\max}=-\dfrac{w_0L^4}{30EI}$	$v=-\dfrac{w_0x^2}{120LEI}(10L^3-10L^2x+5Lx^2-x^3)$