500.101.02
19 September 2002 **23 September 2002 update**
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Spaghetti Materials Lab

Objective

You need to know how spaghetti behaves (as a building material, not as a meal) so that you can gain a better appreciation of mechanics of materials and develop specific data to be used in the design of your spaghetti dome.

Warning

Warning! This lab is longer than typical and you need the data for later in the course – so it is important that you ask questions as we go and get everything clarified. This is a busy, but important lab!

Overview

You will perform 3 tests (you may want a team member in charge of each test, but you will compare data at the end.).

- **Compression**: Here you will learn about buckling, and we will also find a nifty way to back-calculate what the Young's Modulus is for your spaghetti.
- **Tension**: Here you will learn about tension failure in spaghetti and determine the stress at which spaghetti fractures by direct measurement, you need to do some prep. work before lab for this one!
- **Bending**: Here you will learn about bending and the flexibility of spaghetti. As you bend spaghetti it eventually fractures due to tension. So in this lab we get another measure of the tension fracture stress. If we measure the deflections as we bend the spaghetti we can also get a second way to get at Young's Modulus.

UNITS!

For comparison across the class – let's use metric units this time. ($N=kg\ m/s^2$)

Overall Report

From the compression test report E*
From the bending test report E**
Theoretically there is only one E, compare E* and E**, and recommend an E value.
(NOTE, E ~ $?\cdot 10^9$ Pa or ?,000 MPa, where MPa = $1\cdot 10^6$ N/m^2 = 1 N/mm^2)

From the tension test report σ_{f1}
From the bending test report σ_{f2}
Theoretically there is only one σ_f, compare σ_{f1} and σ_{f2}, and recommend a σ_f value
(NOTE, σ_f ~ ??0 MPa, where MPa = $1\cdot 10^6$ N/m^2 = 1 N/mm^2)

Compression Testing

THE BIG EQUATION

$$P_{cr} = \frac{\pi^2 EI}{(KL)^2}$$

P_{cr}	= buckling load (you observe this in your test)
E	= Young's modulus (you can back-calculate this from your tests)
I	= moment of inertia
	= $\frac{\pi r^4}{4}$, where r is the radius of the spag. (which you know)
K	= effective length factor, accounts for end conditions
	= 1.0 (is for pinned ends, which is close to what you have)
L	= length (of your spaghetti)

THE APPARATUS AND WHAT YOU DO IN LAB

You squash dry spaghetti with a concentric axial compressive load until it buckles and you record the load at which the buckling occurs.

In the lab you will record for each test
d = diameter of spaghetti
L = length of spaghetti
m_{cr} = mass reading from the postal scale when it buckles
convert that data to
r = d/2 , L, and $P_{cr}=m_{cr}g$, where g=gravity 9.81m/s^2

Complete your buckling tests for at least three different diameters of spaghetti. Try to use at least 20 different lengths of spaghetti and to get a relatively even distribution of buckling loads over the lengths you test.

POST-PROCESSING THE DATA

Enter your recorded data into a spreadsheet.
Scatter plot (for each diameter) the length (x-axis) versus the buckling load (y-axis).

For each test use the "big equation" and back-calculate E. (units for E is F/L^2). Theoretically, E should be dependent on only the material, so calculate the average of all your tests and call that your "best-fit" E value (E*).

Now we want to compare our new model for buckling (where we use the best-fit, E*) in the big equation and compare with the tested P_{cr}. So, determine P^*_{cr} for each test.

$$P^*_{cr} = \frac{\pi^2 E^* I}{(KL)^2}$$

Now you have two predictions of P_{cr}, what you measured (P_{cr}) and what you estimated based on the best-fit E (P^*_{cr}). So, add to your earlier scatter plot your new predictions – that is for each diameter add plots of length (x-axis) vs. predicted buckling load, P^*_{cr}, (y-axis). ****Discuss, discuss, discuss, errors, the big equation E^*, P^*_{cr}, etc.****

<u>**Tension Testing**</u>

THE BIG EQUATIONS

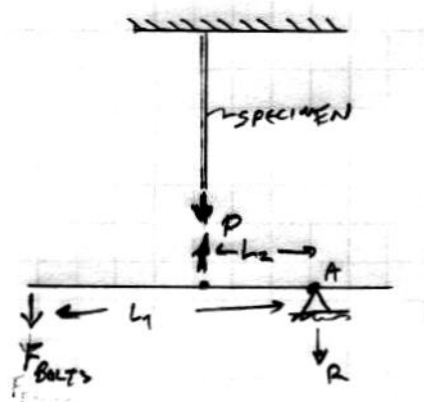
$$\sigma_f = \frac{P_{max}}{A}$$

σ_f = stress at which the spag. breaks (you calculate this)
P_{max} = tension force in the sample
A = cross-sectional area of the sample
= πr^2

$$P_{max} = F_{bolts} \frac{L_1}{L_2}$$

F_{bolts} = weight (load) from the bolts used to add more tension in the sample
L_1 = lever arm to the bolts (weight)
L_2 = lever arm to the tension sample

THE APPARATUS AND WHAT YOU DO IN THE LAB



You take the specimens that you specially prepared for lab and you pull on them in direct tension.

As you add more weight to the end of the apparatus you increase the tension on the sample. You are interested in the weight at which the sample breaks.

Record the diameter of the spaghetti, d, the weight at which it fails, F_{bolts}, and the fulcrum lengths L_1 & L_2.

POST-PROCESSING THE DATA

Calculate the tension load at which each of your specimens fail (P_{max}).
Calculate the stress at which each of your specimens fail (σ_f). Average σ_f is?

You might see a lot of variation in your data (feel free to add to your data from other groups – just make sure you cite the data as theirs).

Discuss the possible sources for variation in your results, you may want to consider: experimental technique, apparatus, bias as a function of material diameter, length…

Flexural Testing

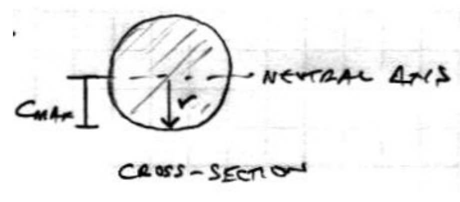
THE BIG EQUATIONS

$$y = \frac{PL^3}{48EI}$$

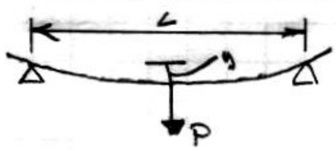
- y = midspan deflection of the spag. beam
- P = midspan load on the spag. beam
- L = span length of the spag beam
- E = Young's modulus of spaghetti
- I = moment of inertia of the spaghetti cross-section
  $= \frac{\pi r^4}{4}$, where r is the radius of the spag. (which you know)

$$\sigma_f = \frac{M_{max} c}{I}$$

- M_{max} = maximum moment in the beam
  $= P_{failure}L/4$
- c_{max} = distance from the neutral axis to the extreme fiber in the cross-section..
  = r



THE APPARATUS AND WHAT YOU DO IN THE LAB



Bend a piece of spaghetti until it breaks measuring the deflection and the loads as you go.

For three spaghetti diameters record the diameter, d, the length, L, the deflection, y, and the load P. Try to record at least 10 points before you fracture the specimens.

POST-PROCESSING THE DATA

Enter your recorded data into a spreadsheet. Scatter plot (for each diameter) the deflection (x-axis) versus the load (y-axis).

For each test use the "big equation" and back-calculate E. (units for E is F/L^2). Theoretically, E should be dependent on only the material, so calculate the average of all your tests and call that your "best-fit" E value (E^{**}).

Now we want to compare our new model for deflection (where we use the best-fit, E^{**}) in the big equation and compare with the tested y. So, determine y^* for each point.

$$y^* = \frac{PL^3}{48E^{**}I}$$

Now you have two predictions of y, what you measured (y) and what you estimated based on the best-fit E (y^*). So, add to your earlier scatter plot your new predictions – that is for each diameter add plots of predicted deflection y* (x-axis) vs. load, P, (y-axis). ****Discuss, discuss, discuss, errors, the big equation E^{**}, y^*, etc.****

You can also use your data to estimate the fracture stress. For each test determine M_{max}, and then use the second big equation to determine σ_f.