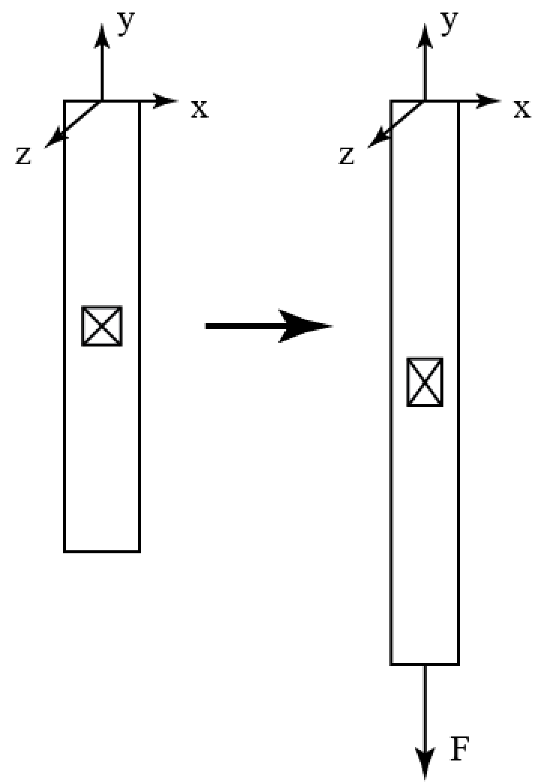
Fall 2013: Profs. Christian Franck, Jennifer Franck
TAs: Jon Estrada (jonathan_estrada at brown dot edu)
Alireza Khorshidi (alireza_khorshidi at brown dot edu)

ENGN0310 – Mechanics of Solids and Structures

Lab 1 – (In) Strain in the Membrane



In class, we talked about finding the strain ϵ for a sample undergoing uniaxial loading. You have seen graphs for the entire stress-strain curve for different materials. In this lab, your job is to take a large sample of points for a variety of loads and displacements applied to the silicone sheet (included in your kit) and translate this into a stress-strain curve. You should make sure to capture enough points to see both linear and non-linear material behavior. Try getting data for stretch ratios of $\lambda_y = 1$ to $\lambda_y = 3$, where λ_y is defined as $\lambda_y = L/L_0$, i.e., the stretched length, L, divided by the original length, L_0.

Note that the dimensions ($w \times L_0 \times t$) of the strip are 1"×6"×0.02".

1.1 The Experiment

(a) **Determine a way to accurately measure displacements** on the rubber sheet given to you. This may involve drawing points or shapes on the sheet, using a ruler, or some other clever methods. You will later record displacements from near the top clamp and near the middle, so pick your design wisely.

(b) **Clamp the two sheet ends with binder clips**. You may want to put paper or some other material in the clip with the rubber to reduce localized stress at the clamp locations. Fix one binder clip, perhaps by threading a rod through the handles.

(c) **Fix a camera** at a certain distance from the sheet. You can choose any camera you'd like as long as you can transfer the images to your computer. Next to your membrane place a ruler or an object of known length, make sure that both the membrane and your ruler or object are **in focus** on your camera. (You will use the image of the ruler or object later to calibrate your pixel to mm conversion).

Take a picture of the membrane before loading, i.e., before you hang any weights on it. What strain does this correspond to?

Proceed to **hang weights of known mass** from the other clip. Take a **picture for each step**. For each step calculate $\lambda_y = L/L_0$. Try to get stretches from $\lambda_y = 1$ to 3. Take **at least 11 pictures**—1 for control (no weight), and 10 additional data points (with hanging weights).

(d) Now that you have pictures for each weight you applied, you can analyze the data. **Download and open ImageJ**[1]. Open your first image. Click **Analyze** in the dropdown menu, followed by **Set Scale**. You can put in the scale to convert pixels to mm or cm—use a fixed object for the scale conversion.

(e) From here, draw lines on your image using the **line segment** (5th) icon. Hit **Measure** under Analyze after drawing a line to find out the **length, angle**, etc. of the segment **using the measurement scale** you specified in **(d)**.

(f) **Record x and y length changes** between two different sets of points on the rubber sheet—one set near the top clamp and one set near the middle, at each specified weight.

1.2 The Analysis

The raw data you have is length ratio λ_x and λ_y near the top clip and near the middle as a function of applied force F. This must be converted into strain ϵ_x, ϵ_y, and stress σ_y, respectively. Your analysis should convert the length ratio to true strain and the force to a true stress by determining the cross-sectional area.

(a) Although the z length ratio λ_z is not explicitly measured, silicone rubber can be considered "incompressible", meaning the total volume does not change when it is deformed. From uniaxial loading, $\boldsymbol{\lambda_x = \lambda_z}$. **Determine the new area $\boldsymbol{A}$** as a function of $\boldsymbol{\lambda_y}$ and the initial width $\boldsymbol{w}$ and thickness $\boldsymbol{t}$ of the sheet.

(b) **Determine the stress $\boldsymbol{\sigma_y}$** for each force F and area as a function of $\boldsymbol{\lambda_y}$. Also, **what is $\boldsymbol{\sigma_x}$**? Is there shear stress or strain?

(c) From the values λ_x and λ_y, **determine the true strains $\boldsymbol{\epsilon_x}$ and $\boldsymbol{\epsilon_y}$**.

(d) **Plot $\boldsymbol{\sigma_y}$ vs. $\boldsymbol{\epsilon_y}$**. Comment on the differences between your data at the middle and the data from near the top clamp.

(e) Is the data linear? **Make a log-log plot of the data from the middle** of the sheet. Determine the **Young's modulus**.

(f) **Determine an empirical Poisson's ratio $\boldsymbol{\nu}$** for the silicone sheet.

(g) Calculate the **strain energy density** from your **$\boldsymbol{\sigma_y}$ vs. $\boldsymbol{\epsilon_y}$** curve. What is the total amount of work done on the sample at its maximum deflection?

[1] Link: http://rsbweb.nih.gov/ij/download.html

1.3 The Writeup – Guidance and Suggestions

(a) The body of your writeup should contain the following sections: **Introduction, Materials and Methods, Results and Discussion, Conclusions, and Appendix**. The body of the paper **cannot exceed four (4) pages in length**. Additional material past four pages will not be counted. The appendix is not considered part of the body and should contain your raw data and/or any equation derivations (which should be numbered). Your introduction and conclusions should be short, concise and to the point. In your Introduction explain what you are calculating in this lab and why. As part of your Discussion section, you should present a qualitative error analysis, or describe how you would go about estimating the error in your measurements, and identify sources of error.

(b) **There should be a cover page** that contains the title of the lab, name of the author, acknowledgment of anyone who you worked with, date, and the name of the class.

(c) **Regular Text Margins = 1"** (headers/footers can be inside this), with **text size = 11pt font or larger**. Accepted fonts are Times New Roman, Calibri, Arial, Helvetica, Palatino Linotype, and Computer Modern (LaTeX native font).

(d) **Plots should look professional**; there should be no auto-generated Excel plots[2]. Any figures should have a **caption** explaining the purpose of the figure, a **separate title**, and **labeled axes**, all in **readably large text**. Specific things to avoid are shadow on line plots, having grid lines on only one axis, and unnecessary overuse of color. **We will deduct points if your plots do not look professional!**

(e) **Tabulated raw data should be included in the appendix, not in the body of the report**. Representative additional pictures not needed in the body can be put in the appendix as well, such as an example ImageJ analysis picture. Make sure to **cite (refer to) every picture** (appendix and body alike) **in your report**.

(f) Finally, a good resource for writing is the Mayfield Handbook of Technical and Scientific Writing[3]. If you're wondering what exactly goes into each of these sections or how to format certain things, consult this book; it'll save you time writing.

Make sure to take some pride in your work, and give yourself enough time to make it look good!

[2] You guys are Brown students, and are better than that!

[3] Online for free at: http://www.mhhe.com/mayfieldpub/tsw/home.htm