UNIVERSITY OF CALIFORNIA, MERCED

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ME 021: Engineering Computing
MATLAB® Project

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Preliminary Notes

- **You need to choose one project out of four problem statements** Choose a project that is closest to your interests in "engineering computing" out of the four engineering projects posted as PDF on CatCourses (also available in course Box/MATLAB® Project folder). You must denote your choice in the 2nd MATLAB® project milestone, that is, the 7th project milestone on CatCourses.
- Your solution must be exclusively submitted via CatCourses. Email submission will not be accepted. Pay attention to the posted deadline because **the system automatically stops accepting submissions when the deadline passes.** You can upload one or more `.m` or `.mlx` files for your code.
- **To receive credit, you must also demo your project to your TA, either in your lab or during office hours.** You must show your working program, be prepared to explain your code, and answer other questions that the TA asks about MATLAB® programming. You must demo before the end of your last lab of the semester (that is, before Dec. 8, 2023). **You will get a 0 if you do not demo, even if you made a submission.**
- Four milestones will be released to help you make progress towards the project. However, milestones are simply to push you in the right direction. You need to put in extra effort beyond the milestones to complete the project satisfactorily.
- A short (1-2 page) report in PDF format that consists of main parts of the code, the visualizations, and any mathematical equations must be submitted for the final project submission along with the MATLAB® script files.
- The grading rubric for all milestones, demo, and the report submission will be posted on CatCourses and it will be available for the students to read through to prepare their submissions.

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ME 021: Engineering Computing
MATLAB® Project – Properties of Materials

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1 Overview

Materials are all around us! Look at your computer – it is a solid and usually sustains high temperatures, whereas a different material may easily bend at such temperatures. The properties that various materials exhibit in differing conditions is nothing short of magic! In this project, you will characterize these physical properties of a diverse set of materials.

2 Preliminaries

2.1 Properties of materials

Common ways to characterize the properties of a material are:

1. stress-strain relationship, a mechanical property, and
2. thermal expansion, a thermal property.

By comparing and contrasting the properties of each class of materials (polymers, ceramics, and metals), we can comprehend their characteristics and differences. More importantly. by studying these properties, we can design new materials customized for our own application!

2.2 Mathematical description

Here are some mathematical relations that you will find useful in this project.

2.2.1 Stress and strain

The stress-strain relationship is given by $\sigma = \epsilon E$, where E is the Young's Modulus, σ is the stress (force per unit area) and axial strain is ϵ. The stress (σ) is measured in MPa and can be computed as

$$\sigma = \frac{F}{t_0 w_0},$$

where F is force in Newtons, t_0, w_0 are the initial thickness and width respectively in mm^2. The linear strain is given as a percentage measure:

$$\epsilon = \frac{l - l_0}{l_0} \times 100,$$

where l is the changed length from initial length l_0.
Note that the Young's modulus is defined as the ratio of the stress applied to the object and the resulting axial strain (displacement or deformation) in the linear elastic region of the material. To compute the Young's modulus, we identify the linear regime in the stress-strain experimental data. The region where strain is proportional to the stress is called the elastic deformation region.

2.2.2 Thermal expansion

Thermal expansion for a material is described by a first order differential equation

$$\alpha = \left(\frac{1}{L}\right)\frac{dL}{dT},$$

where α is the coefficient of thermal expansion, L is the length measurement, and (dL/dT) is the rate of change of length per unit change in temperature, T.

2.2.3 Toughness

Toughness can be determined by integrating the area under the stress-strain curve. It is the energy of mechanical deformation per unit volume prior to fracture. The explicit mathematical description is:

$$\text{toughness} = \int_0^{\epsilon} \sigma d\epsilon$$

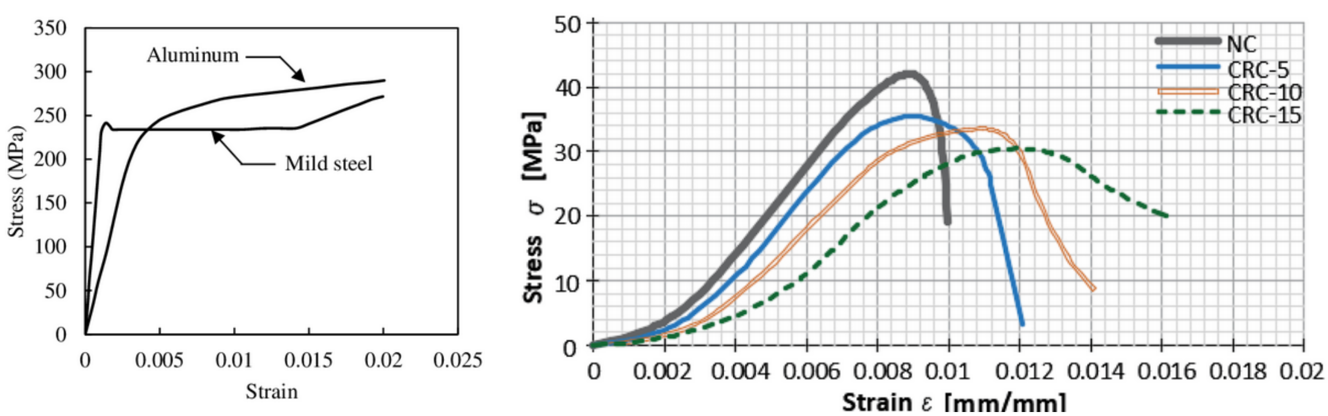

Figure 1: Data for various material types.

3 Computational Tasks

For this project, you will need to work on the following computational tasks,

3.1 The experimental data

Select four different materials from the provided data for materials (see Figure 1, data images available on Box). You can choose four out of the following material types: Metals (Aluminum, Steel), Ceramic

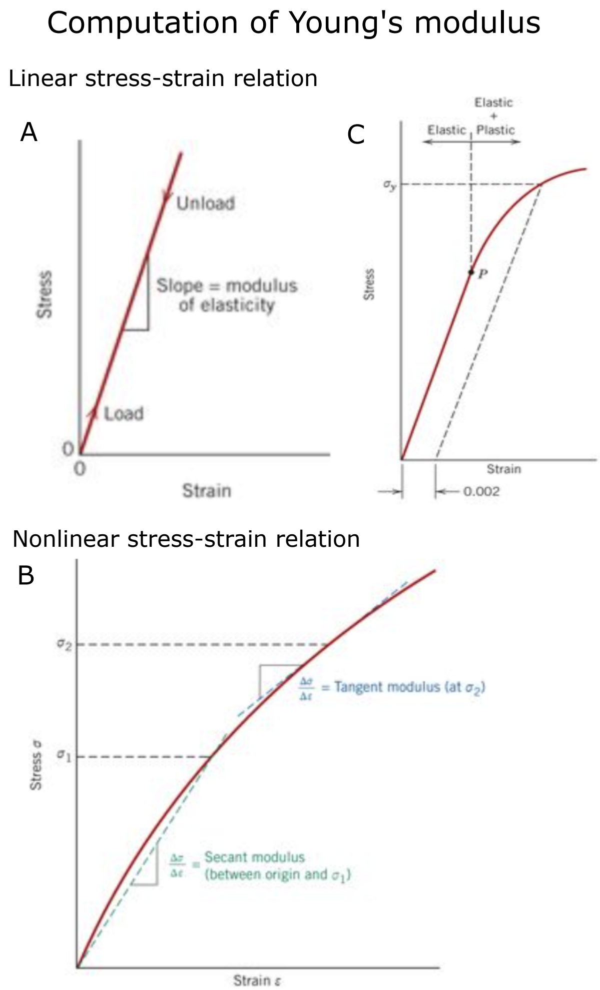

Figure 2: Computation of Young's modules. (A) Linear region in stress-strain data for computation of Young's modulus. (B) Secant modulus of elasticity for nonlinear stress-strain behavior. (C) Computational steps for Young's modulus.

(Concrete *notated NC), Polymers (HDPE or Neat Epoxy). The data for all of these materials are available in the Box folder.
(Updated note. 12/04/2024): Since the given data graphs are all real data from the literature, the names (e.g., CRC-5) in the legend are the notations that the authors put for their own composite materials for comparison between neat material and their composites.

Extract data from the provided graphs that plot the experimental data for each material. You must use the MATLAB® module GRABIT for this purpose. Here is a YouTube tutorial for using GRABIT.

3.2 The material properties

Compute the stress and strain (directly by indexing the data) to plot curves for different materials (as shown in the data in Figure 1). Find the Young's Modulus and tensile strength of each material. Remember that the Young's modulus is computed using the slope of the linear region in the stress-strain data. The illustration in Figure. 2A visually depicts this computation. However, some materials do not exhibit this elastic deformation property. For example, concrete and many polymers have an elastic portion of the stress–strain curve that is not linear (see Figure 2B); hence, it is not possible to determine a modulus of elasticity as described previously. For this nonlinear behavior, either the tangent or secant modulus is normally used. The tangent modulus is taken as the slope of the stress–strain curve at some specified level of stress, whereas the secant modulus represents the slope of a secant drawn from the origin to some given point of the $\sigma - \epsilon$ curve. In this project, you should find the secant modulus.

Then, which point do we choose to calculate the Young's modulus? (how do we determine if the chosen point is within the elastic deformation region?). We need to find the onset point of plastic deformation, which is called a Proportional limit, P that is, you need to pick a point before the point P shown in Figure 2C.

As the material is deformed beyond this point P, the stress is no longer proportional to strain, and permanent, nonrecoverable, or plastic deformation occurs.

3.3 Tensile strength and toughness

The tensile strength of a material is defined as the maximum stress in the stress-strain curve. You can use built-in MATLAB functions to compute the tensile strength of each material. Mark the tensile strength on the stress-strain curve and on the y-axis to visualize.

The toughness of a material is defined as the area under the curve of a stress-strain curve. Ideally, you would compute the integration to find out the area under the curve. You can use built-in MATLAB functions to compute the area. Note that since you have data as discrete points, the number of points that you have will determine the accuracy of your computation (more points will lead to a better area under curve computation). In engineering research, we need a high number of data points to plot a single graph! You must plot the shaded area between the stress-strain curve and the X-axis to show the computation visually.

3.4 Thermal expansion

Evaluate how different materials expand or contract for a given temperature change. Use the values of alpha provided for your material type on this URL. To compute the change in length, you can solve the ordinary differential equation in MATLAB. Here is how to get started with understanding the solution of a differential equation in MATLAB (you can read up more on Wikipedia to refresh your memory on differential equations):

1. The most common ODE solver in MATLAB is `ode45`.
2. You must define the ODE as a function at the bottom of your code. Remember that MATLAB functions are either defined as their own files (to make them global) or defined at the bottom of the file (to make them local). This function should have a signature required by the ODE solver module in MATLAB. You could also do this with the "@" character to define an inline function when calling the ODE solver, as described in the documentation.
3. Before you are ready to use the ODE solver, you need to specify 1) the initial length of the material (we are considering 1-dimensional materials), 2) the range of temperature values over which to solve the ODE, and 3) the value of the thermal expansion coefficient α. Make sure to include the reasons for your choice.

4. Store the solution from the ODE solver in a variable. Then, you can look at the last value for the length, or even plot the length with varying temperature values. You should use the solution of the ODE to study the thermal expansion for each material. Analyze and explain your final values.

Once you have analyzed the thermal expansion for each material by solving the ODEs, you must compare the different materials that you chose on this property. This leads you to the last task — choosing your own material. [hint 1: you can do error-checking with your final number. Does it match the significance of the thermal expansion coefficient? If the coefficient is a positive number, the final length should increase, and vice versa.] [hint2: Don't forget to include the labels and title for your plots]

4 Open-ended questions

You may explore one or more of the following open-ended ideas in your project.

1. Design your own new material by composing more than one material together. Report a stress-strain curve for your new material, its Young's modulus, and properties that the material exhibits.
2. What are the main differences that you observe between materials? Explore the possible reasons.
3. In the context of the mechanical behavior of composites, describe (in details and with reasons) the characteristics of the ideal individual materials. Note that "ideal" will depend on the intended application of the material.

For the open-ended problems, include justifications for each of your choices, that is, explain your reasoning and thought process. Discuss the potential trade-offs (advantages and disadvantages) and how you address them. Take the open-ended questions as an opportunity to explore data/system design/visualization that interests you the most!