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Human-Powered Tensile Tests: an Experiential Introduction to the Concepts of Stress, Strain, and Elastic Modulus

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The concepts of stress and strain are foundational for many engineering disciplines, typically taught to engineering students in their first or second years of college. These concepts are key to proper understanding of characteristic material properties such as elastic modulus and fracture strength. While the formal definitions of both stress and strain are straightforward and can be taught in a few minutes' worth of lecture, deeper understanding of these concepts is hindered by the ease with which they are confused with the more intuitive and tangible measurements (force and displacement) from which they are calculated. For example, a naïve student may conclude that a block of aluminum has a higher strength than a piece of aluminum foil, because a small force can easily tear the foil but has no effect on the block. Therefore, it can be valuable to take an active learning approach to teaching these key concepts, so that students can formulate an intuitive understanding of stress and strain that can carry forward as they encounter more advanced engineering concepts.

Here, we present a discovery-based approach to introduce students to these concepts through the use of crude tensile tests. The students are provided with elastomeric strips which are easy to deform using human strength and have the added advantage of being highly reusable due to their elasticity.

The classroom approach is as follows:

1) Introduce the concept of a tensile test as a way that engineers can probe the behavior of materials when they are subjected to large forces.
2) Distribute identical "baseline" elastomeric strips to each student group. Direct students to conduct human-powered tensile tests by carefully gripping the ends of the strips and pulling in a controlled manner. Prompt students to recognize that the deformation happens uniformly by having them draw evenly-spaced dots on the strips and observe the change in spacing as the strip is stretched.
3) Prompt students to identify appropriate metrics (i.e. "how hard" and "how far" or force and displacement) to express what happens during these tests, and to construct a graph of the behavior they observe. The instructor takes a couple minutes to explain to the class that the strips' behavior is similar to that of a spring, and to emphasize the importance of the slope of the graph that results.
4) Introduce a dilemma by presenting elastomeric strips of different sizes and shapes, which yield obviously different force-displacement graphs despite being the same material. The strips consisted of all combinations of the following dimensions (12 strips total):
   - (Red-colored) high-temperature silicone rubber[1]
     Thicknesses: [1/32", 1/16", 1/8"]; Widths: [½", 1"]; Lengths: [2", 4"]

Students are instructed to compare pairs of strips that are identical in two of the three dimensions (e.g. same thickness, same length, different width).

5) Prompt students to identify the relationships between geometric dimensions and observed force-displacement slopes. For example, a thicker strip yields a steeper line. Call on individual groups to report their conclusions out to the class (allowing the instructor to correct any misapprehensions that may have arisen).
6) Show how these observed geometric relationships can be used to "modify" force into stress. Since the goal is to define a parameter that is independent of geometry, and since both width and thickness cause force to increase (all else remaining constant), the parameter we define should cancel this effect by *dividing* force by both width and thickness – which is the same as saying it should be divided by the cross-sectional area.
$$\sigma = \frac{F}{w * t} = \frac{F}{A_c} \qquad (1)$$
7) Similarly, show how displacement is "modified" into strain. Since increasing the strip's initial length causes more displacement for the same force, the strain should be defined as the displacement divided by initial length.
$$\varepsilon = \frac{\Delta L}{L_0} \qquad (2)$$
8) Finally, show how the slope of the new resulting graph (stress/strain instead of force/displacement) is now independent of geometry and therefore characteristic of the material.
9) Reinforce this concept by providing students additional elastomer strips of different materials. In this activity, the following materials were used:
   - (Black, softer) multipurpose neoprene (30A Durometer) [2]. This material is available in different thicknesses: [1/32", 1/16", 1/8"], but for this step only a single thickness, width and length were used.
   - (Black, stiffer) multipurpose neoprene (50A Durometer) [2]. The dimensions of this specimen were identical to the softer neoprene.

   It was hoped that the two materials would be visually indistinguishable, but the stiffer elastomer was somewhat more lustrous. Students are asked to determine if the two strips are made of the same material or not, and to justify their conclusions using the knowledge gained from the day's activity.

Because of the relative simplicity of this activity, it is highly adaptable for use in different contexts, or to highlight other foundational aspects of materials engineering:

- The approach described here intersperses student discovery with brief lectures, primarily for effective use of class time. If time permits (such as in a lab course), the discovery aspect could be made more central. For example, students could be provided with samples of a variety of sizes and materials, and asked to develop ways to determine if materials are distinct from each other, perhaps framed as a forensic activity of identifying if the material found at a crime scene was the same as that found in a suspect's suitcase.

- Human-powered tensile tests are also used to investigate the stress-strain behavior of plastic materials by cutting strips of a polyethylene garbage bag. This activity can be used to highlight the elastic region, yield point, elastic recovery, necking, drawing, and fracture that are characteristic of such materials.
- Although students are generally able to qualitatively distinguish relative force magnitudes correctly when performing these hand tests, if an instructor wished for more verifiable or quantifiable results, these same experiments could be done with inexpensive portable tensile testers [3], [4]. This would allow more control over the testing and would provide the opportunity to demonstrate more clearly that all of the force-displacement curves collapse down to a single stress-strain curve.

This activity was originally used as part of a materials selection module within an engineering design course. Some students in the course had been previously exposed to the concepts of stress and strain, but others had not. In 2024, this activity was implemented in an introductory materials engineering course, and adapted into the form presented in this paper. These courses were taught by the same instructor within a general engineering curriculum at a small liberal arts college, with class sizes ranging from 15-25 students. However, the activity should scale fairly easily to larger class sizes due to its lack of specialized equipment. Because of the activity's evolution through different courses and the small number of students involved, measurement of its effectiveness in enhancing student understanding of stress and strain has not been attempted, but is a potential future research pathway.

[1] "McMaster-Carr - High-Temperature Silicone Rubber Sheets, Bars, and Strips." Accessed: Jan. 15, 2025. [Online]. Available: https://www.mcmaster.com/catalog/131/4076

[2] "McMaster-Carr - Multipurpose Neoprene Rubber Sheets and Strips." Accessed: Jan. 15, 2025. [Online]. Available: https://www.mcmaster.com/

[3] "Mxmoonfree Force Gauge Stand Manual Force Test Stand Push Pull Gauge, Hand Wheel Operated, with 250mm/9.8'' Stroke, 2 Pcs Testing Clamp, for Compression and Tension Testing (for ZMF model Force Gauge): Amazon.com: Industrial & Scientific." Accessed: Jan. 15, 2025. [Online]. Available: https://www.amazon.com/Mxmoonfree-Operated-Testing-Compression-Tension/dp/B0BZRV2L2Z?ref_=ast_sto_dp

[4] J. H. Arrizabalaga, A. D. Simmons, and M. U. Nollert, "Fabrication of an Economical Arduino-Based Uniaxial Tensile Tester," *J. Chem. Educ.*, vol. 94, no. 4, pp. 530–533, Apr. 2017, doi: 10.1021/acs.jchemed.6b00639.