

Plastic S T R E T C H

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Abstract

This demonstration/lab provides students with a real, hands-on understanding of plastic deformation in a common material, polyethylene. Polyethylene is a common polymeric material found in plastic sheets, bags, etc. The material contains long chain molecules that are mostly randomly dispersed. Stretching causes the molecules to align, and the material becomes stronger. A “neck” will form where the material becomes cloudy, indicating the presence of order among the molecules—that is the polyethylene becomes “crystalline” in these areas. Large specimens may be prepared from polyethylene sheet and a whole class can observe and participate in stretching the materials.

Objectives: The student will be able to
Participate in plastic deformation of a polymer
Observe “necking” in the materials and its effect on strength
Relate necking of the sample to crystallization
Observe effects of defects on failure of the material

MatEd core competencies addressed (most important in bold)

0B Prepare tests and analyze data
4A Demonstrate effective work with teams
7B Explain the general nature of plastics
16A Distinguish effects of processing and manufacturing variations on material properties

Key words: polyethylene, plastic, deformation, necking, failure

Type: Class demonstration laboratory

Time required: 5 to 10 minutes plus discussion

Grade Levels

This class demonstration works at any level, elementary to college. To have the students do the stretching, the students must be strong enough to do so; at lower grades, adults may need to do the stretching.

Equipment and supplies needed

Polyethylene sheet (available at hardware stores) or large plastic bags, cut into “dog bone” shape (see instructor notes). The sample(s) must be large enough to grab on to and pull to failure

Same, but with a built-in flaw in the “dog bone” (e.g. a non-uniform area)

Instructor background and notes

Polyethylene consists of long-chain polymeric molecules that are randomly dispersed in the plastic material. When it is stretched, the molecules move so that they become more and more aligned in the direction in which they are being pulled. (An example is spaghetti being boiled in a pot: The spaghetti “molecules” are tangled up but if you put in a fork, you can align them.) Sufficient stretching causes a nearly complete alignment, and when this happens in polyethylene, the material forms a neck, and the neck propagates through the materials. The neck area is nearly crystalline, that is, it has sufficient alignment of the molecules that the x-ray diffraction pattern shows long range order. The development of the crystalline alignment also increases the strength, since the crystalline polymer is stronger than the non-crystalline material. The non-deformed, as received polyethylene is mostly random and thus not crystalline.

Making the ‘dog bone’ specimens can be done with scissors. Try to make the center section as straight as possible. Flaws in the straight section will cause premature failure (that is part of the demonstration as well). Leave large sections at the ends to hold on to when stretching the plastic. The thicker the polyethylene, the stronger it is and the more force is needed to stretch. A piece with a straight section 2 inches wide and 2 ft long will elongate to 5 to 8 feet, and a whole class easily sees the effect. It is best to make the end pieces about 3 or 4 times wider so the students can get a good grip when pulling. Smaller sections also work but are harder to grip.

Amount of elongation (also called amount of deformation) is measured by $(\text{change in length})/(\text{original length})$ and should be calculated using the test section of the sample (not the grips).

Necking occurs after some deformation has occurred. The neck area will be narrower and more opaque and may look like it has horizontal lines.

Failure can occur at flaws in the material—including non-uniform areas of the sample and any nicks or scratches. This is because stress is measured as $(\text{force})/(\text{area})$ so that the stress will be highest where the cross sectional area is lowest. Of course, failure will also occur when the stress exceeds the strength of the material.

This module is an excellent one to teach students why polymers are called “plastic.” Plastic refers to the ability of a material to be easily shaped or molded. Metals can also be plastic (they deform as noted in the MatEd module, “Work Hardening and Annealing of Copper”) but polymers in general deform most easily of materials, thus are referred to as “plastic.”

Experimental process

1. Choose a team of students or adults for the stretching process
2. Measure the initial length of the dog bone area of the specimen
3. Give careful instructions to
 - Pull slowly and steadily
 - Be patient, don't rush
 - Once necking is observed, keep pulling to failure
 - Measure the final length of the dog bone area of the specimen
4. If the specimen fails, try again with another specimen
5. Once a specimen fails without necking, discuss what could have gone wrong— discuss the effects of defects in the material or in the preparation that effect properties
6. Once a necked specimen is obtained, examine the necked area and note the differences between the necked and original material
7. Calculate the percentage of elongation (change of length/original length), usually defined as a percentage (e.g., 100% elongation if the test section doubles in length)
8. Note and discuss the strength of the material before and after necking
9. Discuss the premature failure of one of the specimens that failed early. Explain the concept of stress and focus on non-uniformities and flaws.
10. Discuss why polyethylene is called a "plastic"?

Further study

1. Investigate the structure of polyethylene; explain the structure of crystalline vs. non-crystalline polyethylene.
2. Find references that talk about necking in metals, and research the differences in necking between plastics and metals
3. Find information on what kinds of defects affect the strength of materials

References

1. Introductory site on polymers: <http://www.pslc.ws/mactest/maindir.htm>
2. Polyethylene background: <http://www.personal.rdg.ac.uk/~spsolley/pe.html>
3. Chemistry of polyethylene: <http://www.pslc.ws/mactest/pe.htm>
4. More on polymer properties and differences is included in the MatEd module "Property Differences in Polymers: Happy/Sad Balls"

Evaluation

Student evaluation questions (discussion or quiz):

1. Define polyethylene and give some examples of everyday materials the are made from polyethylene
2. Why is polyethylene called a "plastic?"
3. Why does the necked area of the specimen appear cloudy?
4. Why do variations in thickness or other irregularities in the sample section cause failure of the material?
5. What would you do to prevent such failures?

Instructor evaluation questions:

1. At what grade level was this module used?
2. Was the level and rigor of the module what you expected? If not, how can it be improved?
3. Did the activity work as presented? Did they add to student learning? Please note any problems or suggestions.
4. Was the background material sufficient for your background? Sufficient for your discussion with the students? Comments?
5. Did the activity generate interest among the students? Explain.
6. Please provide your input on how this module can be improved, including comments or suggestions concerning the approach, focus and effectiveness of this activity in your context.

Course evaluation questions (for the students)

1. Was the activity clear and understandable?
2. Was the instructor's explanation comprehensive and thorough?
3. Was the instructor interested in your questions?
4. Was the instructor able to answer your questions?
5. Was the importance of materials testing made clear?
6. What was the most interesting thing that you learned?