ESC022 LAB #3: Investigation of Mechanical Properties in Modern Materials

Dear New Employee,

Welcome to AH Materials, Inc. As part of your new-hire orientation, you are given this assignment to learn about specific mechanical properties of various types of materials. These properties will help you focus on future project designs of products you will be manufacturing for AH Materials, Inc.

On the table is a collection of common and maybe not-so-common objects and materials that have interesting mechanical properties. You will be investigating the mechanical behavior of each of these items. It is a good idea to read through the entire set of directions for each object or material before beginning your experimental work. It is important for you to carefully observe experimental events and record your observations in your lab notebook. Both verbal (written words) and non-verbal (figures, drawings) are important here. You are required to turn in a memorandum reporting the materials and properties investigated, the possible applications for the properties examined, and the significant conclusions you made from this exercise.

President,
AH Materials, Inc.

An Orientation of Mechanical Properties

Take your time as you work through each of these tests. Work with one other person if there aren't enough materials for individual testing. Have fun – this is a low-stress, high-enjoyment lab!

Elasticity, Plasticity, and Fatigue of Metal Paper Clips

In the kit on the table there is an assortment of paper clips. Find the metal ones and the vinyl-covered metal ones.

a) Take one of the metal paper clips and bend the inner loop slightly away from the outer loop so that it will return to its original shape (as you would if you were about to slip the clip around a few pieces of paper). Take special note that you cannot apply too much bending force here. Notice and describe what happens.

What you have demonstrated here is an example of ***elastic deformation*** – a type of deformation in which the object returns to its original shape after the forces have been removed. This type of deformation is unique in the realm of mechanical behavior because all materials undergo elastic deformation. This cannot be said of any of the other types of material deformation that we will cover.

b) Draw a stress-strain curve, and label the axes and the modulus of elasticity. Describe the loading and unloading as it applies to bending your metal paper clip. What are the factors involved in ensuring elasticity with these metal clips (or, what makes the paper clip **not** return back to its original form)?

c) Now take the inner loop of each clip and bend it 180º backwards so that each clip now looks like a funny-shaped "S". Notice and record what happens. Take a careful look at the area in the middle of the "S", with a magnifying glass. Notice anything there? Draw and describe it.

d) Grab the two ends of the "S" and bend them back and force relative to each other. Count the number of times you bend the paper clip until it breaks. When it breaks, quickly put the middle of the "S" up to your upper lip. What do you feel? What do you think has happened? Examine the fracture surface area under the magnifying glass. Draw and describe what you see.

What you have just demonstrated is ***plastic deformation*** – a type of deformation in which the object undergoes a permanent shape change. When a material is capable of undergoing plastic deformation, it is said to have ***ductility***. Many materials will deform plastically; many materials will not.

a) What would be the case if the metal paper clips had no ductility? Sketch the stress vs. number of bends curve for a brittle paper clip that fractures at its first bend and for your metal paper clip.
b) Now count the number of bends it takes to break your vinyl-covered metal clip. What role does the vinyl (a polymer) play in the ductility or toughness of the metal clip?

Metals – A Very Versatile Engineering Material

We will be spending a good deal of time discussing the elastic and plastic deformation of metals. We focus on metals for two reasons: (1) They are well understood with respect to their mechanical response and properties, and (2) They are crystalline so that plastic deformation is relatively straightforward.

Elasticity, Plasticity, and Fatigue of Polymer Paper Clips

Now locate the many different colored plastic paper clips in the kit on the table.

a) Repeat what you did for metal paper clips in part (a) with the polymeric paper clips. How would you compare the elastic deformation of these polymers to that of metals? What similarities and differences do you see?
b) Try to repeat parts (b & c) from above with each size of the plastic clips. What happens? Does the polymer show any ductility?
c) Examine the fracture surfaces and the regions surrounding the fracture with and without the aid of a magnifying glass. What kinds of things do you see? Draw a picture. How is what you see either similar to or different from what happened in the metallic case?

You will likely observe two types of behavior: (1) Some of the clips will definitely undergo plastic deformation before they break. These are examples of ductile polymers. (2) Some of the clips may snap at the first attempt to bend it back! They fracture all at once. These are examples of brittle materials, those that do not undergo plastic deformation. We use many polymers in engineering applications even though they are brittle. We just don't use them as structural materials.

Strain Rate Sensitivity and Creep in Silly Putty

Silly Putty is a fun material to demonstrate mechanical properties. Take a look at the packaging to see all the "amazing" things it can do. Take a minute to play around with your piece of Silly Putty: form it, stretch it, squash it, bounce it...

a) Now make a cylinder about 50 mm long and 10 mm in diameter (this should take about ¼ of your sample). Have a watch/timer ready. Grab the ends *slowly* and pull it apart. Stop when you've about doubled the original length and record the time it took for you to do it. Describe what happened to the Silly Putty.

b) Calculate the rate of pulling.

c) Remake the cylinder. Now, grab onto each end, and as fast as you can, yank your sample apart. Describe what happened this time.

What you have just demonstrated is **strain rate sensitivity** in a material. The rate of deformation (straining) can greatly affect how a material deforms. This is true in many polymers at ambient temperatures, some metals at high and low temperatures, and a few ceramics at high temperatures.

d) This part takes a bit more Silly Putty skill to accomplish… Remake your cylinder. Now, take something like a key that has a thin, flat surface and carefully roll the sample with this "tool" to create a reduced diameter section in the middle of your cylinder sample. Make sure it looks even and is centered. The reduced section should be about 5-10 mm wide. Measure and record its actual width.

e) Now, carefully pick up the sample, holding it horizontally (so there's no force on the reduced section) and attach a round "glob" of Silly Putty to one end. When you are ready, watch your timer, and turn the entire sample so that it is vertical. You are holding one end while the other end has the attached "glob", acting like a weight on the cylinder. Watch carefully what happens – it could take several seconds to get going. Describe/draw what you see. Record the total time it takes for this action to be complete.

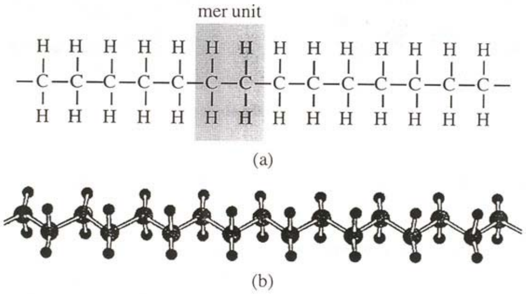
f) To be more accurate about this phenomenon, remake your cylinder, attach the glob, and release the complete sample vertically, watching the time at start. Stop the action by turning your sample horizontally again after every three seconds and measure the amount of elongation per time interval. Then plot elongation as a function of time.

What you have demonstrated here is called **creep**, which is time-dependent plastic (permanent) deformation under a constant stress. Silly Putty creeps pretty easily – it's "creepy". Other engineering materials creep mainly at high temperatures. There is a lot of research on the topic of creep deformation because it is often a design issue that concerns aeronautical, mechanical, metallurgical engineers.

g) Please return your Silly Putty to its egg after you are done. That's its home, you know…

<u>Inhomogeneous Deformation in Polyethylene Beverage Holder Rings</u>

Low-density polyethylene is used to hold 6-packs of soda, beer, and even cans of dog food together. The structure of polyethylene is a linear polymer whose chains are kinked and folded to a great degree. We will look at this structure in more detail in class, but its backbone looks something like this:



(a)

(b)

a) Draw or trace how your polyethylene ring looks like at the start. Grab on each side of one of the loops and gripping tightly, pull the plastic along a horizontal axis away from each other (this is called a tensile test). How is the material deforming? Is the deformation uniform or local? This deformation region continues to grow as you move your hands apart. Notice how much force you need to exert (1) to start the deformation and then (2) to continue the deformation. Is it the same?

Continue pulling until the plastic breaks. What happened? Describe and draw your observations. Think about what might be happening to the structure of this polymer during its deformation. Try to give an explanation for this behavior based on the structure of the material.

What you have just demonstrated is a kind of **inhomogeneous deformation** – one part of the sample deforms locally and this local deformation continues to move throughout the entire sample before fracture. In polymers, this is called *cold drawing*; in metals, this is called *local necking* or *Luders band formation*. This type of deformation happens in many polymers. It also happens in certain steels with low carbon content, but we would need an Instron tensile testing machine to demonstrate it, instead of our simple "manual tensile test" method here.

Polymers

Polymers represent an important class of structural materials and understanding their mechanical behavior will be important to your position. Their deformation is more complex than that of metals since polymers are often noncrystalline or amorphous-crystalline materials. Polymers are significantly less stiff than metals. We take advantage of this in numerous engineering applications.

Anelasticity in Twizzlers®

Twizzlers®, as you probably already know, are a kind of licorice.

a) Grab hold of the opposite ends of one of your licorice sticks and *gently* pull it then release. You will notice that the licorice will deform a bit and then almost immediately return to its original length. What type of behavior is this again? This is further evidence that all materials – even licorice – undergo that type of deformation.
b) Now we want to pull a little harder. Don't pull too hard, but definitely use more force than in part (a). What do you notice now? What can you conclude about the element of time in deformation of materials?

What you have just demonstrated is **anelastic deformation**. This is a time-dependent elastic-type response in which once the loads have been removed (zero applied stress), the strain on the sample returns to zero over a period of time. In other words, the strain on the sample *lags* the stress. This is important because it can lead to **dampening** in materials. Dampening is a form of energy absorption, kind of like a sponge soaking up water. For now, remember that elasticity is instantaneous; there is no time element involved at all. Anelasticity is time-dependent.

c) Take your licorice stick now and pull even harder until you start to notice plastic deformation. Now when you release, the sample no longer returns to its original shape. Continue pulling your piece of licorice until you can easily break it. Since a good deal of plastic deformation occurred prior to breaking, what we have here is an example of **ductile fracture**. Think about and compare this to the ductile behavior of the metal paper clips way back at the beginning of this lab.

Brittle Fracture in Chalk

When you left college, you may have thought that you saw the last of chalk. It is actually a really good demonstration tool to illustrate mechanical behavior of ceramic materials.

a) Take a piece of chalk from the kit on the table and examine it closely for any small cracks or deformities on its surface. Grab the chalk tightly at each end. Without producing any bending or twisting, pull the chalk and see if you can break it. You may be able to do this – it depends if your piece of chalk has some flaw in it or not. Most likely, however, you will not be able to break it. Don't worry, you do not need to rush to the gym and start pumping iron! Even though chalk is a relatively weak ceramic, it is difficult for us to generate enough **normal stress in tension** to break it with our bare hands.

b) Take a small file or knife and make a notch in the diameter, at the center of your chalk specimen. It will be perpendicular to the long axis of the chalk. Now try to pull it apart again as you did in part (a). Describe what happened. Were you able to break it this time?

What you have just demonstrated is the important property of notch sensitivity in ceramic materials. Ceramics cannot plastically deform at room temperatures because they are brittle materials, so notches act as stress concentration regions. The regions near the notch reach the breaking strength with little overall stress on the sample. Once a crack forms at the notch, it propagates through the ceramic quickly.

c) Take a new piece of chalk and perform a 3-point bend test by hand, by putting your thumbs underneath the middle of the chalk, and your index fingers on the outside, and then bending. What happens? Why does it break so easily? Does any plastic deformation occur?

d) Notice that the fracture in (b) and (c) was straight across the sample. This is because the maximum tensile stress was parallel to the long axes of the chalk in both loading modes (it acts on a plane perpendicular to the long axis). Now, in torsion, or twisting, the maximum tensile stress is at 45° to the axis of twisting. So, take another piece of chalk and be careful not to induce any bending. Carefully twist the chalk – it should break at a 45° angle. Does it? Use the magnifying glass to look at the fracture region. Draw any interesting observations.

Ceramics

Ceramic materials have great importance in engineering use. Because of their notch sensitivity, we use them mostly in compression when they are used for structural applications. Ceramics are extremely strong in compression and not so in tension. In many ways, we can treat their mechanical properties similar to those of metals since they are both crystalline. The situation becomes more complex with ceramics, however, since ionic bonding means we must take into account charge interactions (+/-) and their crystal structures tend to be more complicated than those of most metals. Still, they are extremely interesting to work with and study.

So, there you have it. This introduction to the mechanical behavior of materials is a "window" to how wide the field of materials engineering can be and the great things that can come about in this company now that you have come onboard. Please have a memo of this study for me at our meeting next week, again at this time.

Writing a Memorandum

A common form of communication in business and academia is the memorandum, or memo for short. Memos are written by everyone from junior executives to professors to engineers to CEOs. It is important that you learn to master this basic communication form. Memos are generally written to solve problems **by informing the reader about new information** or by persuading the reader to take an action. The most important feature about a memo is that it be concise yet complete and informative.

A memorandum is one type of formatted document that can be used to present lab results. The audience is your professor/company president who has asked you to perform some task (i.e. test and observe mechanical properties in different types of materials). She wants you to present key results (i.e., to recommend a certain material for a certain application given the specific mechanical result that you tested). Treat the professor/president as a skeptic, who won't believe your recommendation unless you back it up by carefully explaining your measurement/analysis technique and presenting your data. Your challenge is to present the important and relevant information in two pages – to be able to explain your results clearly in text and with one or two figures. Memos are generally divided into two parts: the heading and the body.

Heading: The heading segment follows this general format:

TO: (readers' names and job titles)
FROM: (your name and job title – authenticate the memo with your signed initials)
DATE: (current date)
SUBJECT: (what the memo is about, be specific and concise. Highlighted the subject line)

Body:

Your memo should be concise and informative. Organization is key to achieving this. Writing a quick outline may help your to organize your thoughts. Develop a list of the main ideas that you wish to present. Use short paragraphs and analyze each paragraph of your memo for its purpose, content, or function. When you find a paragraph that does more than one thing, consider splitting it into two paragraphs. If you find two short separate paragraphs that do the same thing, consider combining them. Writing a memo is *not* easy – shorter does not always means simpler. Use your intellectual creativity. The following are elements generally found in the body of the memo.

Opening: State the main purpose of the correspondence right away. Include the context and problem, the specific assignment or task, and the purpose of the memo. This section should be short (1 paragraph) and used to remind the reader of the issue, problem, or situation that is addressed in the memo.

Recommendation: If your memo is longer than a page, you should include a summary section at the beginning of the memo. This section provides a brief statement of the key results or recommendations you have reached. These will help your reader understand the key points of the memo immediately. (i.e include a statement like "*I recommend that materials with good ductility be used for XXXX " or "I measured the creep rate to be XXXX.")*

Discussion: The discussion section is where you include all the detailed information that you have gathered to support you ideas. Keep these two things in mind:

- Begin with the information that is most important. This may mean that you will start with key findings or recommendations. Think of an inverted pyramid. Start with your most general information and move to your specific or supporting facts.
- Briefly describe any experiments you performed or calculations that you made.
- Provide supporting data to give the reader confidence in your recommendations. Make sure you document your findings or provide detailed information whenever necessary. You may include one or two figures or tables to support your recommendations.
- You may use meaningful subheadings to direct the reader. Try to write subheadings that are short but clarify section content.

Closing: After the reader has absorbed all of your information, you want to close with a courteous ending (i.e., an offer of further assistance) that states what action you want your reader to take.