HOMEWORK 1.

Hello, and welcome to the first homework in materials science. You can think of the homework documents as a laundry list of course activities for the week. In a typical homework assignment, I will provide a short blurb on your ongoing project work, assignments for the week, a set of materials science readings related to a specific materials theme, a summary of key theoretical concepts from yours truly, and some problems tied to the readings.

PROJECT WORK

DUE DATE: Proposal due Wednesday, January 21, end of class

This week, you will begin your project planning, and possibly some materials research and laboratory experimentation. You'll select a consumer product, explore the product's materials and performance requirements, and start to think about the ways in which the material structure, composition, and properties relate to your product's purpose and impacts. The big goals for the first week of the project are to establish some goals for yourself and your team, develop experimental strategies that will help you attain your goals (and that are reasonable in scope), and identify some information sources to support your work. You'll also need to get to know your project team partners, and begin to figure out how you all will communicate with each other, plan schedules, use meeting times, etc.

To support your project planning effort, you may consider skimming your textbook for concepts related to the experiments your team wants to run. Grab a materials science textbook, and quickly identify sections that might be useful in your project work. Don't get bogged down in details, unless you see something interesting and you can't help yourself. Move quickly, but with an eye toward things that are relevant to your consumer product analysis. If you see sections of the book that you're fairly confident are relevant to your project, mark these in some way, e.g., a Post-it Note or digital highlighting. Jot down any new ideas or questions that arise as you flip through your book.

SET YOUR OWN GOALS ACTIVITY (S-YOGA)

DUE DATE: Friday, January 23, 6 pm

One of the goals of this course is for you to further develop your self-directed learning skills. For each course project, I will ask you to set goals, identify learning strategies, manage your time and effort, etc. In this assignment, you will take the concept of student self-direction one huge step further, by setting your own learning goals for the entire course.

Read over the course syllabus and project one overview, and think about how the course is designed. Think about what you want to accomplish this term in the project-based materials science course. By Friday, September 12 at 6 pm, please submit an email to me with "personal goals" as the subject line. In this email, provide a statement or statements of your **learning goal(s)** in this course. Remember that these are *your* goals, and as such could be just about anything that is connected in some way to what we're doing in this class. You'll have a chance to reconsider and modify these goals as we progress through the course, but give it your best shot now. What do you want to learn? What do you want to improve about yourself – master some skills, gain some new knowledge, become more aware in some area, develop a new identity or sense of competency? These are *your* personal goals, not mine or anyone else's, so make them work for you.

Next, outline some **strategies** that you make take to achieve your goals. What specific things will you do? For example, if you want to develop better teaming skills, what actions can you take, or how may you adjust the ways you interact with your teammates? For this assignment you should write at least a couple sentences for each of your three goals.

This submission doesn't need to be too formal, but it should be clear enough for me to understand, and for you to revisit later in the semester. Give it some thought, and help me make the class work for you!

R E A D I N G

DUE DATE: Tuesday, January 27, start of class

- Mechanical properties. These readings cover the basic stress-strain behavior and temperature-dependence of mechanical properties of materials.
  - o Ashby *Engineering Materials 1*: Chapter 3, pp. 29-41; Chapter 6, pp. 83-87; Chapter 8, pp. 115-125; Chapter 14, pp. 205-209.
  - o Callister 6th, 7th, 8th, and 9th editions: Chapter 6; Sections 8.2-8.4; Section 12.8; and Sections 15.1-15.8.

- Look over "Stolk's Take on the MatSci Readings" in this document, if you're interested in your instructor's perspective on the mechanical property readings.

The big questions for this week are...

What type(s) of loading do your product components experience, e.g., tension, bending, compression, etc.?
How do the components of your product respond to mechanical stress?
How would the components of your product fail?

S T O L K ' S   T A K E   O N   T H E   M A T S C I   R E A D I N G S

Chapter 6 – Mechanical Properties. Why, you may ask, did I assign a chapter that's a third of the way into the textbook as your first reading assignment? The answer is simple, but twofold. First, I wanted to avoid Chapter 2 like the plague, as it is primarily review of some topics that you've probably seen in your chemistry or physics courses. Can you think of a more boring way to start a new class than review? I can't. Second, I wanted to give you access to some concepts that you could immediately sink your teeth into. Most of you are starting to run some mechanical tests on your modern artifact, or you will be starting these soon, and the topics presented in Chapter 6 will provide you with the terminology and definitions that will enable you to describe the mechanical behaviors and responses of your materials in a formal, scientific manner. For example, instead of using words like "durable" to describe your components, you'll be able to define what we mean by "durable" in terms of hardness, toughness, strength, and other real material properties. But wait, that's not all. You'll also be able to explain how each of these is quantitatively measured, e.g., "**toughness** is the area under the stress-strain curve, which indicates the energy required to fracture a material." You can lose the everyday language and start talking like a scientist (or engineer, if you prefer). As you read and consider the concepts in Chapter 6, push yourself to start using the formal materials science terminology when you think about and discuss the properties of your modern objects.

Okay, so what's important in Chapter 6? First off, we have the tensile test, and a long list of properties that we can measure based on a simple tensile test. Tensile tests provide graphs of **engineering stress** vs. **engineering strain**. As we apply a load or displacement to a material (it doesn't matter which one, really, but the Instron applies displacement and measures the load response), we initially get **elastic**, or recoverable deformation. Note that this is a property that may be directly connected to the **atomic level** – it tells us about the strength of bonds between atoms (more on this in our next reading assignment). The measure of how much stress is required to strain a sample by a certain amount is called the **Young's modulus, or modulus of elasticity**. Note that it's also called the elastic modulus. Why does it have so many names? I don't know, but I like it regardless. You can think of the Young's modulus as the same thing as the spring constant you learned about in physics (remember Hooke's law...k = F/x?), except that we materials folks are very clever in their handling of this spring-like response. We like to normalize other people's measurements by sample geometry, give a new name, call it a "material property", and claim it as our own. This seems trivial, but normalizing the spring constant (k) gives us a material property measurement that makes it easy to compare materials, regardless of geometry. This means that a 6 mm bar of copper will have the same Young's modulus as a 6000 mm bar of copper. It also means that we can easily compare the "stiffness" of different materials. I forgot to mention this earlier, but we do the same thing with engineering stress (load over original cross-sectional area) and strain (displacement over original length). Loads and deflections can't be easily compared across different geometries, but stresses and strains travel well from geometry to geometry and from material to material. Are you feeling the power of materials science? If not, take a moment to stand up, take a deep breadth, and flex your muscles (not your cognitive muscles, the other ones). Also take a moment to consider how the Young's moduli of different materials compare. For

example, how does steel compare to titanium? How does titanium compare to nylon? How do the Thompson Twins compare to Modern English?

Now let's get back to our tensile test. If we release the load on our specimen while it is undergoing elastic deformation, it snaps back like a rubber band (**elastic recovery**). After we've pushed a material beyond its elastic limit, it begins to plastically (permanently) deform, or **yield**. We use the term **yield strength** to define the point that sorta kinda indicates the transition from elastic deformation to plastic deformation – "sorta kinda" because this transition isn't always easy to identify, so we use the **0.2% strain offset** as a standard method to find the yield strength value. Here's a question for you: does this 0.2% strain offset method work for determining the yield strength of polymers? Why or why not? By the way, have I mentioned that when I use the word "strength," I'm talking about a stress, not a load? Yield strength = yield stress, tensile strength = tensile stress, etc. Not to change the subject, but do you happen to be looking for a material that's going to absorb a lot of energy during loading, but then give it all back upon unloading, i.e., a very "springy" material? If so, you want a material with a high **modulus of resilience**, This property is a measure of the area under the elastic portion of the stress-strain curve. Like resilient people, resilient materials can take a lot of applied stress or strain, but then return to their original, unstressed state. [Stretch Armstrong](#) – now that's one resilient dude, as evidenced by this YouTube video.

After the yield point comes **uniform plastic deformation**, during which the entire reduced section of the test specimen deforms in the same way. This continues up to the highest point on the stress-strain curve, the **tensile strength** or **ultimate tensile strength (UTS)**. It just so happens that the tensile strength correlates very well to material **hardness**, which is defined as a measure of the resistance to surface indentation or abrasion. I hear that Stephen Sass' biceps are exceptionally hard, but I don't have any evidence to support this. When materials are pushed beyond the tensile strength, **non-uniform plastic deformation**, or "necking" begins. Necking occurs in a localized region of the specimen, and this region will continue to get smaller and smaller until the **true stress** gets too high for the material to bear, at which point it will POP! Fracture. At the end of the test, we can glean one more important material property from our specimen: **ductility**. This is usually accomplished by measuring the **percent elongation** in the test specimen, which is simply the total engineering strain multiplied by 100%.

During plastic deformation, we observe a fascinating property in metallic materials: **strain hardening**. Why is it so fascinating? It means that we can make a metal stronger simply by beating on it. Some Oliners think the same holds true for our first-year students (I'm thinking about the "suck it up, you're at Olin" t-shirts from a few years ago), but I'm not so sure. Why does this happen (the metal strain hardening, not the first-year student strain hardening)? It turns out that beating on (or rolling, drawing, extruding, etc.) a metal introduces a particular type of defect that makes it more resistant to further deformation. That's right – we can make some materials stronger by creating defects in them! Different materials have different strain hardening responses: some only show a small increase in strength, while some can double, triple, even quadruple their yield strength as a result of this effect. Think you can harness this power to manipulate materials to suit your needs? I think you can. We'll see more on this topic in later readings.

Another topic of note in Chapter 6 (or Chapter 7 or 8, depending on your textbook) is that different types of failure produce different looking fracture features. **Brittle failures** tend to be relatively flat and show very little sign of plastic deformation, while **ductile failures** are described by obvious stretching, bending, twisting, etc. in the fractured part. We see these differences in features both at the macroscopic level (e.g., visual examination) and microscopic level (e.g., scanning electron microscopy). Have you fractured any of your artifacts as part of your project experiments? If so, how would you characterize the mode of failure? Can you provide evidence to support your conclusion? Could Wang Chung offer any advice in this situation?

Polymers sections. Everything I just told you is a lie. Well, actually, it's only partially true. All that Hooke's law and elastic deformation stuff would be completely true if we lived in a world made entirely of metals. And though this may seem a utopia to some, including perhaps your textbook authors, I'm not sure I could live in a world devoid of Kenneth Cole boots, Alain Mikli eyeglasses, and Aveda hair gel. Besides being noteworthy form a personal style perspective, these items are also fascinating from a materials science perspective. They are all composed primarily of polymers, and polymers do not play by the same rules that the metallurgists of old have come to know and love. Polymers are **viscoelastic**, which means that their mechanical response combines aspects of viscous behavior (like a jar of honey) and elastic behavior (like a spring). Viscoelastic materials can provide some interesting and very different responses to load depending on the rate of loading or strain, and depending on the temperature of testing. Generally, high strain rates or lower temperatures provide a more brittle, higher stress response in polymers. Of course, the other thing that dramatically affects a polymer's viscoelastic response is the material structure, both at a molecular level (polymer chain

composition, polarity, "bulkiness" of the functional groups in the chain), and at a microscopic level, where things like crystallinity, interchain bonding (crosslinking), molecular weight, and chain branching can make huge differences in the mechanical behavior of the polymer. Which of these factors play into determining the properties of the polymers you're examining in your project work?

Ceramics and inorganic glasses. Crystalline ceramic materials act pretty much like metals, but without all that plastic deformation. Stress-strain curves for ceramics are incredibly boring. Their mechanical response tends to be primarily elastic, unless we heat them to an elevated temperature. Inorganic glasses like window glass or Pyrex behave similarly, except that their viscosity gradually decreases with increasing temperature, which is an incredibly useful effect as it enables us to shape glasses while they are in a semi-solid state (glassblowing!). Perhaps the most important thing to remember with ceramics and glasses is that **defects** play a huge role in determining the material strength. Although ceramics and inorganic glasses are theoretically extremely strong, defects in these materials can cause them to catastrophically fail at stresses that are much, much lower than we expect, especially if we're loading in tension. So be careful when you're designing mechanically loaded ceramic or glass components!

In thinking about applying all of these terms, it may be helpful for you to create some graphs or tables that show the expected stress-strain behaviors of different types of solids – polymers (brittle, semicrystalline, and elastomeric), metals (ductile, brittle, stiff, strong, weak, etc.), ceramics, etc – that were used for the components of your modern artifact.

M A T   S C I   P R A C T I C E   P R O B L E M S

As noted in the syllabus, the homework assignments will include two types of problems: textbook-style practice problems aimed at comprehension and application of concepts, and open-ended problems aimed at development of more advanced abilities in synthesis, analysis, design, and evaluation. When you work through the practice problems, consider how the concepts may apply to your analysis of the modern objects.

Textbook Problems (do as many of these as you think is helpful to your learning)

1. Given the engineering stress-engineering strain diagram for an aluminum alloy initially 11 mm in diameter and 50 mm in length, calculate the following:
    a. Percent elongation at the moment the aluminum part fractures
    b. Percent elongation after fracture (hint: think about how some strain is recovered after the sample breaks)
    c. True stress at an engineering strain of 0.04
    d. True strain at an engineering strain of 0.04
    e. Elongation (Δl) when a load of 25 kN is applied.
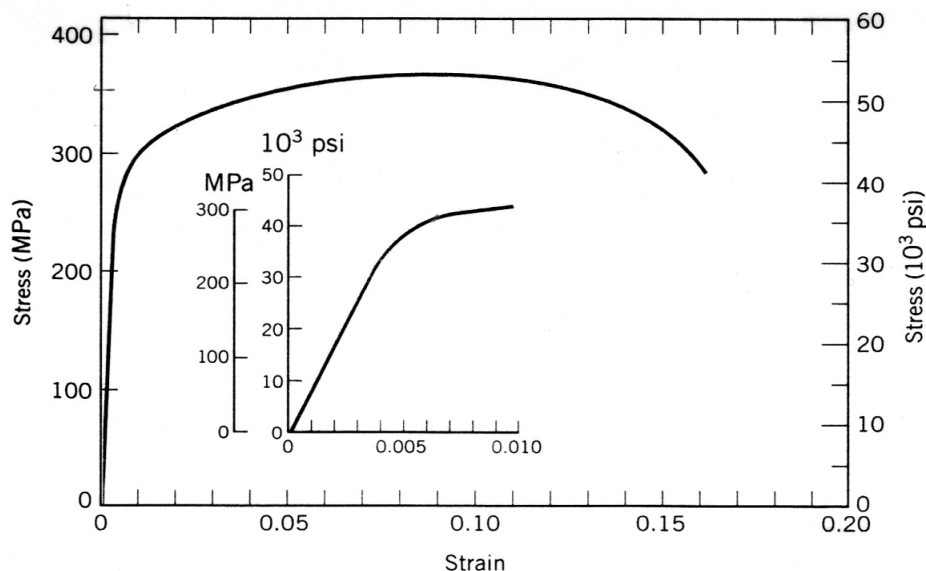
2. Askeland (4th ed.) 6-9. Why does silly putty break when you stretch it very quickly?

3. Askeland (4th ed.) 6-25. A force of 100,000 N is applied to a 10 mm x 20 mm iron bar having a yield strength of 400 MPa and a tensile strength of 480 MPa. Determine (a) whether the bar will plastically deform and (b) whether the bar will experience necking.

4. Askeland (4th ed.) 6-25 (yes, there are two 6-25 problems in the older edition). Calculate the maximum force that a 0.2 in. diameter rod of Al_2O_3, having a yield strength of 35,000 psi, can withstand with no plastic deformation. Express your answer in pounds and Newtons.

5. Askeland (4th ed.) 6-42. A three point bend test is performed on a block of silicon carbide that is 10 cm long, 1.5 cm wide, and 0.6 cm thick and is resting on two supports 7.5 cm apart. The sample breaks when a deflection of 0.09 mm is recorded. Calculate (a) the force that caused the fracture and (b) the flexural strength. The flexural modulus for silicon carbide is 480 GPa. Assume that no plastic deformation occurs.

6. Askeland (4th ed.) 6-47. What determines or controls the strength of ceramics and glasses?

Open-Ended Problem (give this a try)

1. **Liquidmetal.** Go to www.liquidmetal.com, and watch the video (upper left of the screen). Alternatively, check out the physical Liquidmetal demo in the materials science lab. Click on the "The Technology" tab, and read about this incredible material's structure and properties.

   Based on your observations of the behavior of the Liquidmetal and stainless steel cylinders in response to the bearing ball loading, sketch stress-strain curve for both materials (on one set of axes).