HOMEWORK 8.

PROJECT WORK

This is it: crunch time. Your project reports and presentations are due soon, so your project two results should be starting to come together. I'm imagining that this week will involve a lot of microstructural analyses for each team, and perhaps some last-minute sample preparation (mounting, grinding and polishing, etching of your cross sections) and property testing. Oh, and there's that whole written report thing. As you begin to generate text and graphics for your report, consider these questions:

- What is the real-world context and motivation for your study? Why do we care about your alloys, and/or your processing approach?
- What questions are you asking, or what hypotheses are you posing, in this project? Based on your phase diagram(s) or materials theory, what do you expect to see?
- What are your experimental methods (how are you trying to answer your questions or support your hypotheses)?
- What are your results? For example, what properties do your various processed alloys exhibit? What microstructures resulted from your different processes (what do you see in the microscope)?
- ***IMPORTANT*** How can you ***explain*** your results using materials science theory? How did your processing variables affect the development of different microstructures? How do the different microstructures give rise to different properties? Why do your samples behave the way they do?
- What's the significance of your findings in the real world? Why do we care?

READING

- **Textbook Reading**
  - Callister 6^{th} – 8^{th} editions: Chapter 7 (Dislocations and Strengthening Mechanisms); Chapter 11 – just read the sections on precipitation hardening
  - Ashby *Engineering Materials 1*: Chapter 9 (Dislocations and Yielding in Crystals); Chapter 10 (Strengthening Methods and Plasticity of Polycrystals)
- **Other readings.** Find other textbook, handbook, or journal readings specific to your project topic. Talk to Jon or Matt if you're having trouble finding what you need to analyze your microstructures and properties.

KEY CONCEPTS IN STRENGTHENING MECHANISMS

There are a few key concepts that are important to understand when trying to figure out how and why compositional and processing variables are affecting properties. As you saw earlier in the semester in the reading about imperfections in solids, materials can have a number of different types of defects, e.g., point defects, line defects, surface defects, and volume defects. It turns out that the line defects, or dislocations, are of critical importance in metallic materials, as dislocations are responsible for the amazing plastic deformation (ductility) that we see in many metals and alloys. Plastic deformation occurs via the motion, or "slip," of millions and millions of dislocations within the grains of solid metals. Imagine a bunch of squiggly lines inside of grains, moving about in different directions in response to applied stresses. In attempting to predict the mechanical properties of alloys, the primary thing we need to consider is how easily dislocations can move in the substance. But here's where things get a little messy. It turns out that there are a ton of different variables that can affect the ease at which dislocations can move. Just thinking about a pure metal, we need to consider the number of dislocations (dislocation density) in the material, the atomic bonding strength within the material, the crystal structure and corresponding number of active “slip systems” in the material, and the grain size and morphology of the material.

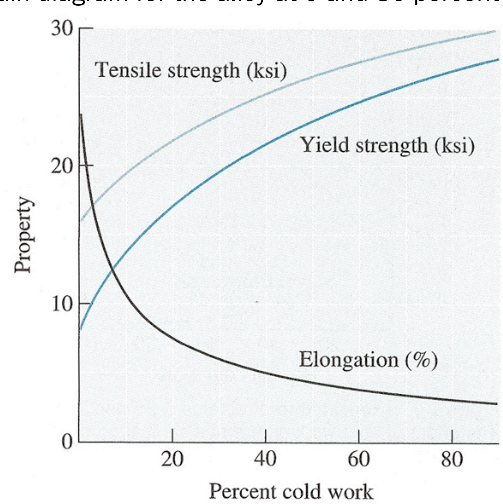
When we add another chemical constituent to the pure metal to make a binary alloy, things get even more complicated. Suddenly we need to think about the role of solute atoms in single-phase solid solutions, the different phases that may be present, the crystal structures of the phases and relationships between the phases at their interfaces, and the grain size and morphology and distribution of these phases. If we start changing the processing of our binary alloy, we can have huge impacts on many of these, e.g., we can change the grain size by slower or faster cooling rates, we can introduce more dislocations by pounding on the material, and we can even promote or prevent the formation of certain phases by adjusting the way we quench or heat the sample. Heck, in some alloys, we can use heat treating to cause metastable phases, which don’t show up on the phase diagram, to appear in our microstructure and have an enormous impact on the properties. It’s your job to figure out what issues are important to consider in your alloy system.

As you do this week’s reading and think about your particular alloy and process, consider these questions:

- Dislocation density – What is it? What processing factors affect dislocation density in your alloys?
- Dislocation motion, or slip – What is it? How does slip occur? Why is it important? What factors affect it? How does it relate to properties?
- Is slip, or dislocation motion, easier in some crystal structures, e.g., fcc versus bct? If so, why?
- Strain fields around edge dislocations – What are they, and what do they have to do with strength and ductility?
- What are the various ways in which alloys may be strengthened (strengthening mechanisms)? How do these various strengthening mechanisms work, and what do they require in terms of composition and processing?
- Which strengthening mechanisms are possible in your alloy system? Which ones are not possible, and why not?
- What microstructural changes & property changes as a function of cold work and annealing? How do annealing time and temperature affect cold worked alloy microstructures and properties?
- What’s the recrystallization temperature, exactly? Why is it important? What are the effects of amount of cold work, alloying elements, and the material’s absolute melting temperature on the recrystallization temperature?
- What are the recrystallization temperatures of your alloys? Annealing temperatures?
- How does precipitation hardening work? In what alloys is it possible? How and why do properties change as a function of aging time? What’s the effect of precipitate spacing? How does overaging affect properties?
- Could you specify different processes to attain a specific set of desired properties in your alloy? Or, if given a composition and process for your alloy, could you predict microstructure and material properties?
- What type of mechanical or thermal processing is required to attain maximum strength in your alloy(s)? How about maximum ductility? Maximum toughness?

PROBLEMS

1. The effects of cold work (strain hardening) on the properties of an aluminum alloy are shown in the figure below. Assuming this alloy has a single phase microstructure (aluminum solid solution, or (Al)),
   a. Sketch the microstructure of the alloy at 0, 20, and 80 percent cold work.
   b. Sketch a schematic stress-strain diagram for the alloy at 0 and 80 percent cold work.

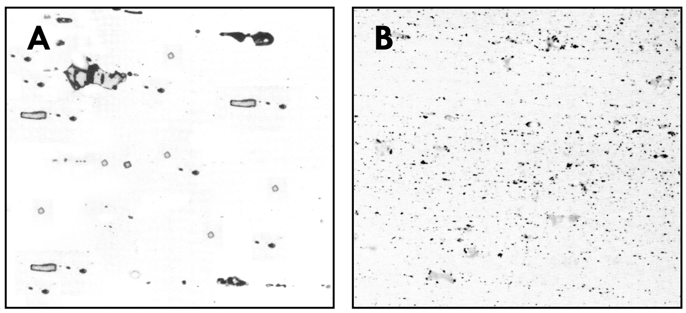


2. Can **all** alloy compositions be strengthened using precipitation hardening? Can we use this mechanism for the strengthening of ceramics, glasses, or polymers? Provide some rationale for your answers.

3. Why are materials with the HCP crystal structure usually more brittle than BCC or FCC metals? How do you think the ductility of BCT (body centered tetragonal) crystals would compare with BCC and FCC crystals? Briefly explain your answer.

4. Sketch a schematic plot of the effect of zinc content on the (i) tensile strength and (ii) ductility of single-phase brass. The range of compositions for single-phase brass is 0 to about 30 wt.% zinc.

5. The microstructures of two precipitation hardenable aluminum-magnesium specimens of the same composition are shown below. The magnification for both micrographs is about 500x. Which specimen would have higher hardness? Briefly explain your answer.



6. Using a graphing program such as Excel or MATLAB, plot yield strength (in MPa) as a function of grain size (in μm) for jewelry bronze (87.5% Cu, 12.5% Zn) for grain sizes of 1 to 100 μm. For strength given in MPa and grain size in μm, the constants σ_o and k for jewelry bronze are 200 MPa and 300, respectively. Do you expect the yield strength trend given by the Hall-Petch equation to hold for extremely small grain sizes (nanoscale materials)? Why or why not?

7. Would you expect the recrystallization temperature for pure Cu be higher or lower than the recrystallization temperature for a Cu-Zn brass alloy? Explain your answer.

8. Is it possible to strengthen lead by cold rolling at room temperature? Why or why not?

9. How does increasing the amount of cold work affect the recrystallization temperature? Briefly explain your answer.