SCI 1410: materials science & solid state chemistry

HOMEWORK 9.

solutions

PROBLEMS

1. The effects of cold work (strain hardening) on the properties of an aluminum alloy are shown in Figure 7-23. 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.

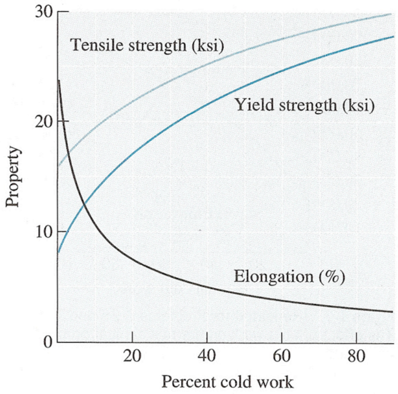
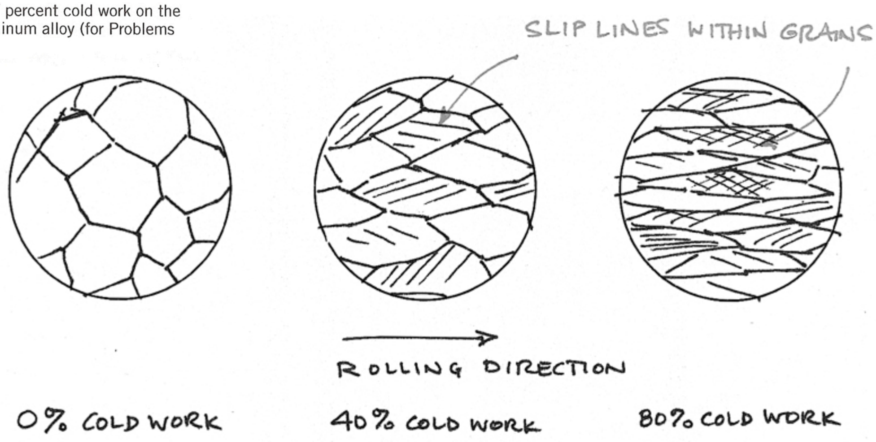
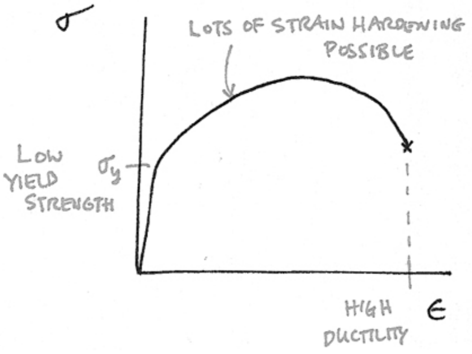
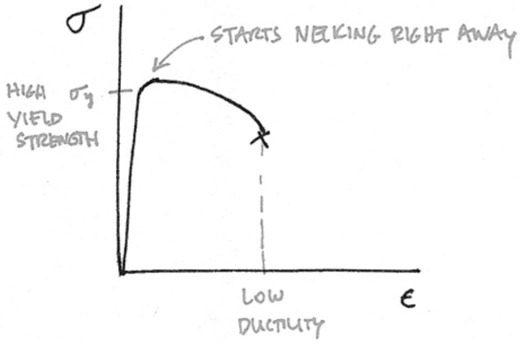


Figure 7-23 The effect of percent cold work on the properties of a 3105 aluminum alloy (for Problems 7-22 and 7-24).

NOTES: I accidentally sketched 40% cold worked instead of 20% cold worked, but I think you'll get the basic concept. Also, I'm assuming unidirectional rolling for the type of cold working.







2. Askeland 4th ed. Problem 11-36. 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.

   No, not all alloys may be strengthened by precipitation hardening. The alloy must exhibit (i) formation of a single phase solid (dissolved alloying elements) at a higher temperature, (ii) decreasing solubility as temperature decreases below the solvus line, (iii) formation of a **hard** second phase or phases after quenching, (iv) capacity for quenching (no quench cracks or high distortion, and (v) a coherent or semi-coherent precipitate, i.e., a second phase with a crystal structure that is related to the matrix crystal structure. In most cases, precipitation hardening of ceramics or inorganic glasses would not increase strength that much, since the mechanical properties of ceramic materials are determined more by the presence of defects than the motion of dislocations. There are some ceramic materials that are ***toughened*** by the formation of a second phase, but this really isn't the same as precipitation hardening. I suppose something similar to precipitation hardening may be possible in polymeric materials, but since polymer mechanical properties are determined largely by bonding and chain motion, the formation of a second phase would have to impede polymer chain motion rather than the motion of dislocations. If we formed a hard second phase in a polymer upon heat treatment, we'd call the system a copolymer or a polymer blend.

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.

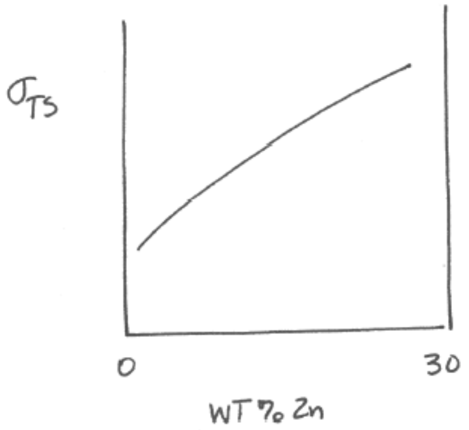
   The HCP crystal structure has a lower degree of symmetry than cubic crystal structures; this lower symmetry provides fewer active slip systems and, in general, lower ductility in HCP structures.

   The BCT structure lacks the symmetry of the BCC and FCC cubic structures and the close-packed arrangement of the FCC structure. We expect the BCT structure to have fewer active slip systems and lower ductility (higher brittleness) compared to BCC and FCC crystals.

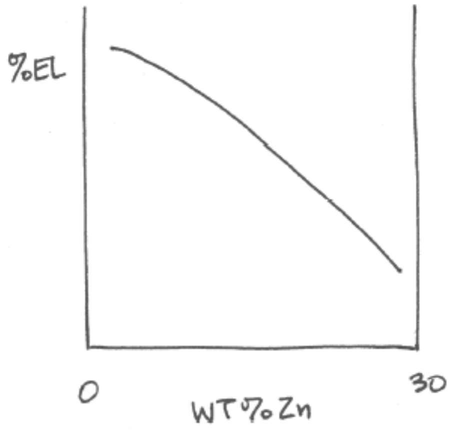
4. Sketch a schematic plot of the effect of zinc content on the (i) tensile strength and (ii) ductility of single-phase brass. The range of compositions for single-phase brass is 0 to about 30 wt.% zinc.

SOLID SOLUTION STRENGTHENING

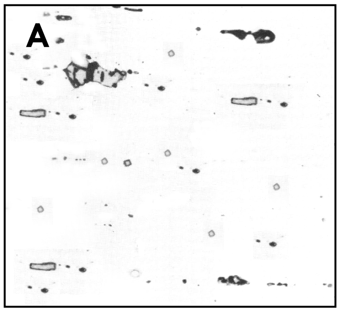
(i) TENSILE STRENGTH

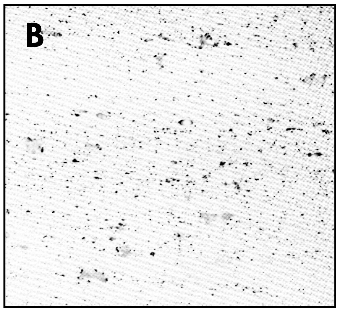


(ii) DUCTILITY



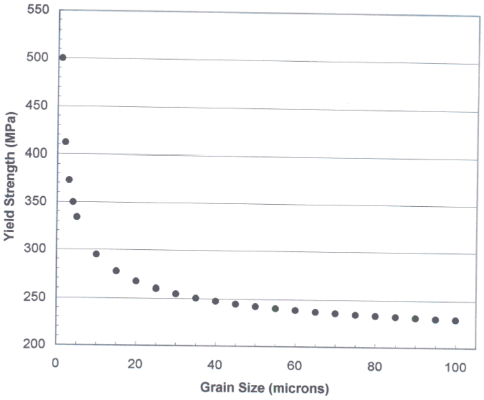
5. The microstructures of two precipitation hardenable aluminum-magnesium specimens of the same composition are shown below. The magnification for both micrographs is about 500x. Which specimen would have higher hardness? Briefly explain your answer.

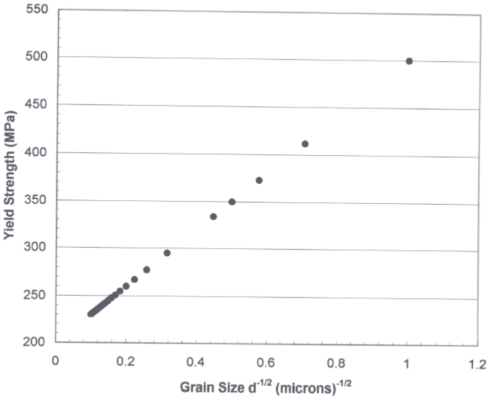




We know that the shear stress to move a dislocation is inversely proportional to the precipitate spacing. We also know that hardness and strength (stress) are generally proportional to each other. Dislocations are very small – atomic scale in width – so it doesn't take a large precipitate to impede their motion, just a tiny little particle. Thus, microstructure B with the closely-spaced precipitates is expected to have higher hardness, higher strength, and lower ductility than microstructure A.

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?





The Hall-Petch equation does not work as well when grain sizes get very small (a few nm or less). At the nanoscale, dislocations can't move well (no large volumes to move through) and phenomena associated with the numerous grain boundaries (e.g., high diffusion rates causing "healing," grain boundary sliding, grain rotation) start to dominate the behavior of the material rather than slip of dislocations that happens within the bulk of larger-grained materials. The mechanical behavior of nanoscale materials is still not well-understood, but plenty of people are busy researching this topic.

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.

If you draw on your knowledge of solid-state diffusion from earlier in the semester (Chapter 5 of your textbook), you may recall that self-diffusivities (e.g., Cu moving within Cu) are generally higher than substitutional impurity (e.g., Zn in Cu) diffusivities. Table 5.2 in Callister shows that for 500 °C, the self-diffusivity of Cu is about an order of magnitude higher than the diffusivity of Zn in Cu. Higher diffusivity or easier atomic motion provides will assist recrystallization (lower energy barrier to the formation of new grains). If solid state atomic motion is easier, we don't need as much thermal activation for diffusion, so the recrystallization in pure materials is expected to occur at a lower temperature than in their alloys.

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

NO. The recrystallization temperature of metals or alloys is typically between 1/3 and ½ of the absolute melting temperature of the metal or alloy. As shown in Table 7.2, the melting temperature and recrystallization temperature for lead are 327 ºC and -4 ºC, respectively. So, unless your rolling mill is in a really cold room, you won't be able to strengthen lead by cold rolling at room temperature.

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

Increasing cold work will decrease the recrystallization temperature. The reason is most easily explained in terms of energy. As you cold work a metal or alloy, you increase the amount of defects in the material and thus the amount of stored strain energy in the lattice. For recrystallization to occur in a cold-worked metal, we need to provide enough energy for atoms to overcome the energy barrier (think of this as an activation energy) for formation of new grains via solid state diffusion. By heating a cold worked metal to its recrystallization temperature, we are increasing the thermal energy enough to get the atoms past the energy barrier for recrystallization. Now, let's go back to the cold work. Again, cold work increases the strain energy in the material, and atoms are more uncomfortable (at a higher energy state) and more ready to do something (recrystallize) the more they are cold worked. With increased strain energy via cold work, we need to provide less thermal energy (lower temperatures) for recrystallization to take place.