Donald P. Shiley School of Engineering
EGR 221 Materials Science
Assignment 8, Fall 2015
SOLUTIONS

NOTE: various graphs, some from your textbook, have been included at the end of this assignment. They may or may not be useful. If you do use them in your work, be sure to CITE them (eg. "from Figure 8-11 in the textbook…").

1. Briefly cite the differences between recovery and recrystallization processes.

ANS: For recovery, there is some relief of internal strain energy by dislocation motion and annihilation; however, there are virtually no changes in either the grain structure or mechanical characteristics. During recrystallization, on the other hand, a new set of small strain-free grains forms, and the material becomes softer and more ductile.

2. Explain the differences in grain structure for a metal that has been cold worked and one that has been cold worked and then recrystallized.

ANS: During cold-working, the grain structure of the metal becomes distorted to accommodate the deformation. Recrystallization produces grains that are equiaxed and smaller than the parent grains.

3. (a) What is the driving force for recrystallization?
   (b) What is the driving force for grain growth?

ANS: (a) The driving force for recrystallization is the difference in internal energy between the strained and unstrained material. The internal energy is in the form of strain energy associated with dislocations.
(b) The driving force for grain growth is the reduction in grain boundary energy as the total grain boundary area decreases.

4. You are a design engineer responsible for determining appropriate degree of cold working of copper that best meets the following design criteria:

Criteria	**Importance**
Minimum yield strength of 40kpsi	Very important
Minimum ductility of 10%EL	Very important
Final thickness of 0.250 +/- 0.010 inch	Very important

   Fully annealed copper has a yield strength of about 20kpsi and 30%EL. What range cold working (%CW) would produce acceptable properties? What range of pre-cold worked thicknesses would be acceptable?

ANS: based on the chart provided, to achieve 40kpsi yield strength in commercially pure copper requires about 15% CW, minimum. To maintain 10%EL, 32% CW (maximum) is allowable. Therefore, to achieve the desired strength and ductility, the acceptable range of cold working is between 15% and 32%. The following determines the acceptable range of pre-cold worked thickness.

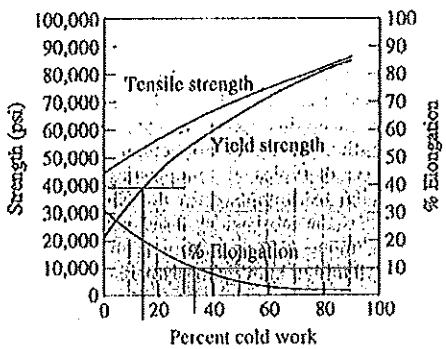
Assume: the majority of the geometric change that will occur will be thickness change. Therefore, %CW = orig thickness – final thickness / orig thickness X 100%.

$\%CW = \frac{t_o - t_f}{t_o} \times 100\%$ If $\%CW = 15\%$ & $t_f = 0.250$ in.;

$15\% = \frac{t_o - 0.25}{t_o} \times 100\% \Rightarrow 0.15 = \frac{t_o - 0.25}{t_o} \Rightarrow t_o = 0.294$ in

If $\%CW = 32\%$, then $t_o = 0.368''$

$0.294 \text{ in} < t_o < 0.368''$

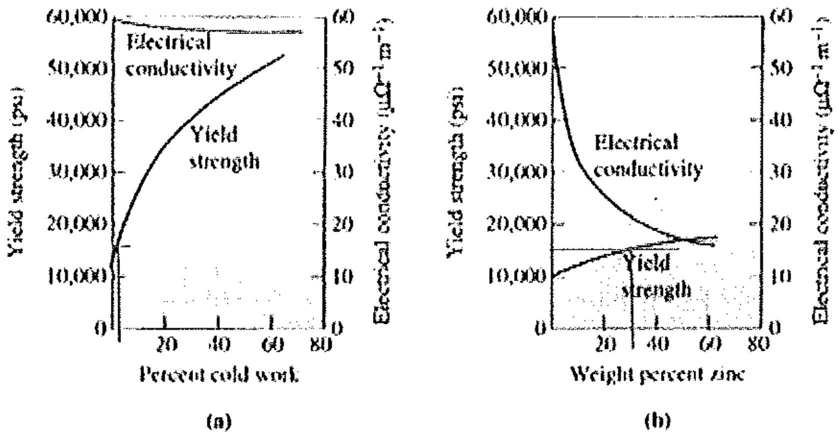


5. You are a design engineer responsible for selecting a material that best meets the following design criteria:

Criteria	Importance
Minimum yield strength of 15kpsi	Very important
Carry electrical current with minimal heating (therefore, good conduction)	Important

Your lead engineer is recommending you consider either brass or commercially pure copper. Select a material (if it's an alloy, describe its composition) and briefly justify (explain) your decision.

ANS: In order to achieve 15kpsi yield strength by alloying copper with zinc, the alloy must contain at least 30% zinc (approximately. Adding zinc greatly decreases conductivity. Therefore, in order to maintain high conductivity, cold working is the best option. To achieve 15kspi yield strength only minimal (less than 5%) cold working is required (based on the charts provided).



A comparison of strengthening copper by (a) cold working and (b) alloying with zinc. Note that cold working produces greater strengthening, yet has little effect on electrical conductivity.

6. Consider the H_2O-NaCl phase diagram.
   a) The solidification temperature is decreased when NaCl (salt) is added to pure H_2O (water). What composition of this liquid solution (saltwater aka brine) results in the lowest solidification temperature? What is that temperature?

ANS: based on the phase diagram provided, a solution of approximately 22% NaCl (78% H_2O) can be as cold as -21°C and remain liquid.

   b) If you add three pound of salt (NaCl) to seven pounds of water (H_2O) at +20°C and stir for a few minutes so that equilibrium is reached, the overall composition will be 30% NaCl and 70% H_2O. At +20°C, this will result in a nearly saturated single solution of brine. What is the composition of the brine (hint, this is a very simple question to answer – no tricks).

ANS: if there is only one phase present, it will have the same composition as the overall solution. Hence, the brine will be composted of 30% NaCl and 70% H_2O. See, it really is an easy question.

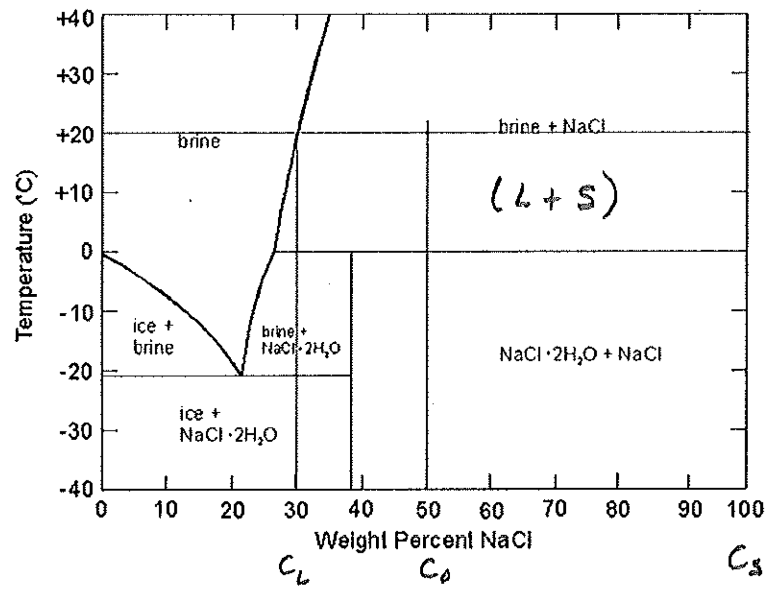
   c) If you add seven pounds of salt (NaCl) to seven pounds of water (H_2O) at +20°C and stir for a few minutes so that equilibrium is reached, the result will be a two phase system composed of liquid (brine aka saltwater) and solid (NaCl). What is the composition of the brine (how much H_2O and how much NaCl)? What is the composition of the solid (hint, this is a very simple question to answer – no tricks – hint #2, the answer is *the composition of the solid is 100% NaCl*).

ANS: The overall composition is 50% NaCl and 50% H_2O (seven pounds of each). Since the solubility limit of NaCl in H_2O at 20°C is about 30%NaCl, once saturated, the liquid phase does not change with additional NaCl. Therefore, the liquid phase will contain 30%NaCl and 70%H_2O. The solid is NaCl (100%NaCl - it contains no H_2O).

   d) If you have a mixture of 5 pounds NaCl and 5 pounds H_2O at +20°C at equilibrium, and then completely separated the liquid (brine) from the solid (NaCl), how much would the liquid weigh? How much would the solid weigh?

ANS: The overall composition is 50% NaCl and 50% H_2O (five pounds of each). At 20C, this puts us in the 2-phase region, so there will be liquid (brine) and solid (NaCl). To determine the *relative amounts of each phase, we draw a tie-line at 20°C spanning the 2-phase region. The following shows the calculations:*

Figure 8-6 The effect of cold work on the mechanical properties of copper.



L: liquid phase

S: solid phase

$C_L = 30\%$ NaCl

$C_0 = 50\%$ NaCl

$C_s = 100\%$ NaCl

At 20°C, if the overall composition (C_0) results in 2 phases (Liquid and Solid):
Composition of the liquid: $C_L = 30\%$ NaCl and 70% H_2O
Composition of the solid: CS = 100% NaCl and 0% H_2O
For this problem, we were given that the overall composition (C_0) is 50%NaCl and 50% H_2O.

The amount of liquid (which itself is composed of NaCl and H_2O – aka brine or saltwater):

$$\% \text{ of } L = \frac{C_s - C_0}{C_s - C_L} \times 100\% = \frac{100 - 50}{100 - 30} \times 100\% = 71\%$$

ANS

Since the total weight is 10 lb, the weight of the liquid will be 7.1 lb and the weight of the solid will be 2.9 lb.