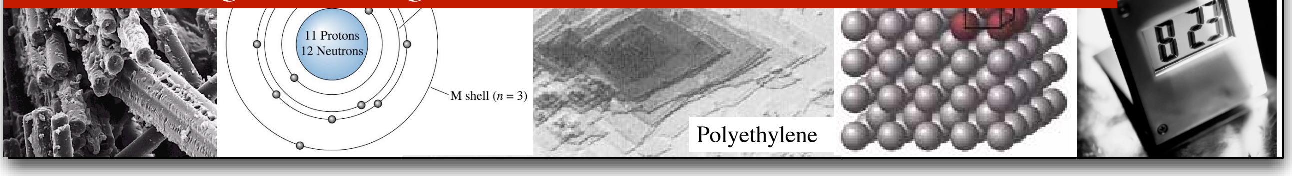
Spring 2006 **Engineering Material**



Final Exam

Monday, August 18, 2006

Duration: 2 hrs

Open **Book** Exam (Book and Class Slides only)

Write clearly your derivations and answers on the question sheet

Instructions:

1. Do not open this exam until instructed to do so.

2. Complete the name and identification portion on your sheet.

3. Put all answers on the this question sheet.

4. No questions are allowed during the duration of the exam. If you feel that assumptions are needed to solve a certain problem, state these assumption clearly in your answer.

Name:

ID#:

Problem 1 [20 Points]

1. Regarding steels, a larger carbon content generally means that: (1 point)

a. The steel will not be as expensive.

b. Ductility will probably be unaffected.

c. The strength will be larger.

d. a and c.

e. all of the above.

2. When quenching a piece of steel in water, for example, the surface portions of the steel piece will generally: (1 point)

a. cool faster than interior portions

b. have more ductility than interior portions

c. have a smaller hardness than interior portions

d. be unusable.

3. Suppose that Li_2O is added as an impurity to MgO. If Li^+ substitutes for Mg^{2+}, what defects would you expect to form if several Li_2O molecules are added? (1 point)

a. Li vacancies

b. Mg vacancies

c. O vacancies.

4. You want to increase the tensile strength of a semi-crystalline polymer such as polyethylene. Which of the following will increase tensile strength? (1 point)

a. a decrease in molecular weight

b. an increase in % crystallinity

c. fatigue loading of the polymer

d. a decrease in cross linking.

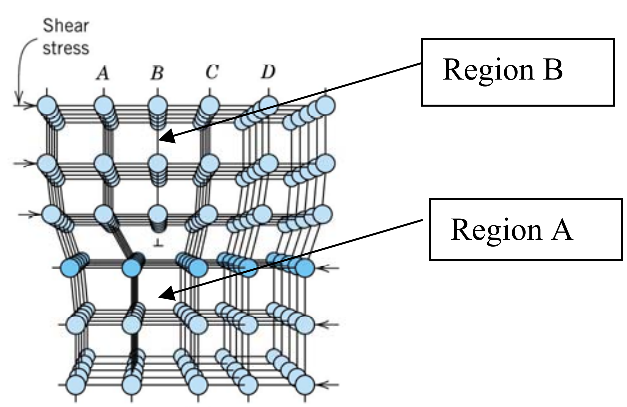
5. Below is a diagram of an edge dislocation. State which region in the diagram is expected to have a tensile stress. (1 point)

a. region A

b. region B

c. both A and B

d. none of the above.



6. Which of the following will NOT result in an increase in yield strength? (1 point)

a. reducing the grain size

b. adding impurity atoms to form a solid solution

c. cold working

d. re-crystallization.

7. A polycrystalline specimen with randomly oriented crystals is loaded in simple tension and yield is observed. True or false: The individual crystals in the specimen all yield at the same time during the test. (1 point)

a. true

b. false

8. What is a likely outcome of using a metal alloy at a higher temperature? (1 point)

a. The ductility is likely to decrease.

b. Dislocations may not be able to move.

c. The yield strength and tensile strength are likely to decrease.

9. Referring to Figure 7.17, what range of cold working will result in a copper alloy with a minimum yield strength of 290 MPa and a minimum ductility of 5%EL? (1 point)

a. 10-20%CW

b. 20-30%CW

c. 30-40%CW

d. unable to determine from the given information.

10. Real engineering materials rarely reach the strength of perfect materials since (1 point)

a. there is rarely enough ionic bonding

b. engineering materials are not cold worked enough

c. the coordination number is too small

d. flaws cause premature failure.

11. You are given a lead-tin (Pb-Sn) alloy of composition 40 wt% Sn – 60 wt% Pb. The phase diagram is given in figure 9.7. As we cool a sample of the material from an initial temperature of 400˚C, at what temperature will the LAST bit of the liquid solidify? (1 point)

a. 327˚C

b. 250˚C

c. 232˚C

d. 183˚C

e. 20˚C.

12.For the Pb-Sn alloy in question 11, what phases will be present at 150˚C? (1 point)

a. α only

b. β only

c. L only

d. α + β.

13. For the Pb-Sn alloy in question 11, what is the equilibrium mass fraction of α phase at 100˚C? (2 points)

a. 0.27

b. 0.38

c. 0.62

d. 0.73.

14. Austenite at 750˚C is rapidly quenched to 625˚C and held at that temperature for 10 s. Then, it is rapidly cooled to 250˚C and held for an additional 100 s before it is finally quenched to room temperature. What will the final microstructure be? Refer to the isothermal transformation diagram in figure 10.13. (2 points)

a. 50% pearlite + 50% martensite

b. 50% pearlite + 50% austenite

c. martensite with a trace of austenite

d. 100% bainite

15.Which Fe-C product below is expected to have the largest hardness? (2 points)

a. spheroidite

b. pearlite

c. bainite

d. tempered martensite

e. martensite

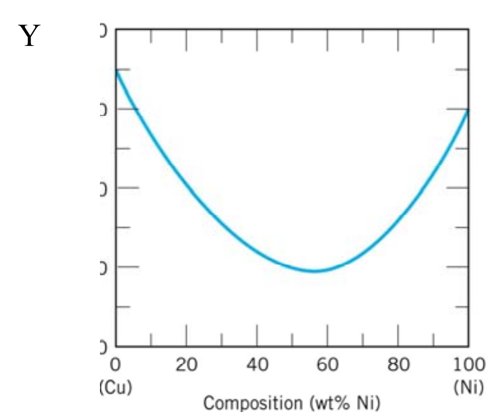
16. Shown is a plot of an engineering property (Y) versus the composition of a Cu-Ni alloy. Unfortunately, the label for Y is missing. What possible engineering property(s) are likely for Y? (2 points)

a. ductility

b. tensile strength

c. yield strength

d. b and c.



Problem 2 [15 Points]

You are designing a turbine engine part made of an FCC single crystal. By using the Schmid law, determine the τ_c necessary for the part to have a uniaxial yield strength of 200 MPa in the [331] crystallographic direction?

You are designing a turbine engine part made of an FCC single crystal. By using the Schmid law, determine the τ_c necessary for the part to have a uniaxial yield strength of 200 MPa in the [331] crystallographic direction?

Let us determine the Schmid factor of a FCC crystal pulled in the [331] direction.

Slip		(111)			$(\bar{1}11)$			$(1\bar{1}1)$			$(\bar{1}\bar{1}1)$		
Systems		$[\bar{1}10]$	$[0\bar{1}1]$	$[10\bar{1}]$	$[110]$	$[01\bar{1}]$	$[101]$	$[110]$	$[011]$	$[10\bar{1}]$	$[1\bar{1}0]$	$[011]$	$[101]$
Tensile	$\cos\phi$	$\frac{7}{\sqrt{57}}$	$\frac{7}{\sqrt{57}}$	$\frac{7}{\sqrt{57}}$	$\frac{1}{\sqrt{57}}$	$\frac{1}{\sqrt{57}}$	$\frac{1}{\sqrt{57}}$	$\frac{1}{\sqrt{57}}$	$\frac{1}{\sqrt{57}}$	$\frac{1}{\sqrt{57}}$	$\frac{-5}{\sqrt{57}}$	$\frac{-5}{\sqrt{57}}$	$\frac{-5}{\sqrt{57}}$
Axis	$\cos\lambda$	0	$\frac{-2}{\sqrt{38}}$	$\frac{2}{\sqrt{38}}$	$\frac{6}{\sqrt{38}}$	$\frac{2}{\sqrt{38}}$	$\frac{4}{\sqrt{38}}$	$\frac{6}{\sqrt{38}}$	$\frac{4}{\sqrt{38}}$	$\frac{2}{\sqrt{38}}$	0	$\frac{4}{\sqrt{38}}$	$\frac{4}{\sqrt{38}}$
[331]	M	0	$\frac{-14}{19\sqrt{6}}$	$\frac{14}{19\sqrt{6}}$	$\frac{6}{19\sqrt{6}}$	$\frac{2}{19\sqrt{6}}$	$\frac{4}{19\sqrt{6}}$	$\frac{6}{19\sqrt{6}}$	$\frac{4}{19\sqrt{6}}$	$\frac{2}{19\sqrt{6}}$	0	$\frac{-20}{19\sqrt{6}}$	$\frac{-20}{19\sqrt{6}}$

The Schmid factor is thus $\frac{20}{19\sqrt{6}}$ (tensile test in [331] direction).

So $\boxed{\tau_c = MY = \frac{20}{19\sqrt{6}} \times 200 = 86 \text{ MPa}}$

Problem 3 [30 Points]

Consider the gas carburizing of a gear of 1020 steel at 927˚C (1700˚F).

a. Calculate the diffusivity (diffusion coefficient) at 927˚C

b. Calculate the time in minutes necessary to increase the carbon content to 0.40% at 0.50 mm below the surface.

c. Calculate the carbon content at 0.50 mm beneath the surface of the gear after 5 hrs carburizing time.

Assume that the carbon content of the surface of the gear is 0.9% and that the steel has a nominal carbon content of 0.20%.

$$\frac{C_s - C_x}{C_s - C_0} = \text{erf}\left(\frac{x}{2\sqrt{Dt}}\right) \quad (*)$$

$C_s = 0.90\%$ $\quad x = 0.5 \text{ mm} = 5.0 \times 10^{-4}$ m

$C_0 = 0.20\%$ $\quad D_{927°C} = 1.28 \times 10^{-11}$ m²/s

$C_x = 0.40\%$ $\quad t = ?$ s

Substituting the above values in Eq. (*) gives

$$\frac{0.90 - 0.40}{0.90 - 0.20} = \text{erf}\left[\frac{5.0 \times 10^{-4}\text{ m}}{2\sqrt{(1.28 \times 10^{-11}\text{ m}^2/\text{s})(t)}}\right]$$

$$\frac{0.50}{0.70} = \text{erf}\left(\frac{69\ 88}{\sqrt{t}}\right) = 0.7143$$

Let $\quad Z = \frac{69.88}{\sqrt{t}} \quad$ then $\quad \text{erf } Z = 0.7143$

We need a number Z whose error function (erf) is 0.7143 From Table
5.1 of the text we find this number by interpolation (see below) to be
0.755 :

erf Z	Z
0 7112	0.75
0 7143	x
0 7421	0.80

$$\frac{0.7143 - 0.7112}{0.7421 - 0.7112} = \frac{x - 0.75}{0.80 - 0.75}$$

$$x - 0.75 = (0.1003)(0.05)$$

$$x = 0.75 + 0.005 = 0.755$$

Thus

$$Z = \frac{69.88}{\sqrt{t}} = 0.755$$

$$\sqrt{t} = \frac{69.88}{0.755} = 92.6$$

$$t = 8567 \text{ s} = 143 \text{ min} \blacktriangleleft$$

2.

$$D_{927°C} = 1.28 \times 10^{-11} \text{ m}^2/\text{s}$$

$$\frac{C_s - C_x}{C_s - C_0} = \text{erf}\left(\frac{x}{2\sqrt{Dt}}\right)$$

$C_s = 0.90\%$ $\quad x = 0.50 \text{ mm} = 5.0 \times 10^{-4} \text{ m}$

$C_0 = 0.20\%$ $\quad D_{927°C} = 1.28 \times 10^{-11} \text{ m}^2/\text{s}$

$C_x = ?\%$ $\quad t = 5 \text{ h} = 5 \text{ h} \times 3600 \text{ s/h} = 1.8 \times 10^4 \text{ s}$

$$\frac{0.90 - C_x}{0.90 - 0.20} = \text{erf}\left[\frac{5.0 \times 10^{-4} \text{ m}}{2\sqrt{(1.28 \times 10^{-11} \text{ m/s})(1.8 \times 10^4 \text{ s})}}\right]$$

$$\frac{0.90 - C_x}{0.70} = \text{erf } 0.521$$

Let $Z = 0.521$. We need to know what the corresponding error function for the Z value of 0.521 is. To determine this number from Table 4.1, we must interpolate the data as shown in the accompanying table.

Z	erf Z
0.500	0.5205
0.521	x
0.550	0.5633

$$\frac{0.521 - 0.500}{0.550 - 0.500} = \frac{x - 0.5205}{0.5633 - 0.5205}$$

$$0.42 = \frac{x - 0.5205}{0.0428}$$

$$x - 0.5205 = (0.42)(0.0428)$$

$$x = 0.0180 + 0.5205$$

$$= 0.538$$

Therefore

$$\frac{0.90 - C_x}{0.70} = \text{erf } 0.521 = 0.538$$

$$C_x = 0.90 - (0.70)(0.538)$$

$$= 0.52\% \blacktriangleleft$$

(2)

Problem 4 [20 Points]

a. On the basis of microstructure, explain why grey cast irons are recommended for compressive loading conditions and not for tensile loading conditions.

Grey cast irons contain graphite flakes in a ferrite or pearlite matrix. Graphite offers no strength and graphite flakes act as cracks in the matrix of grey cast irons. This makes the alloy very brittle and weak in tension. However, under compression cracks do not open and thus are not effective in reducing the mechanical strength of the material.

b. Can low carbon steels be quench hardened?

No. Quenching hardens steels by forming martensite. The formation of martensite requires a minimum carbon concentration (usually ~ 0.4%C) to cause a reasonable level of lattice distortion. The carbon concentration in low carbon steels is too low to form martensite.

c. How are low carbon steels strengthened?

Low carbon steels are usually strengthened by cold working.

d. "Steel is made hard by quenching." List at least three requirements that must be met to justify this statement.

"Steel is made hard by quenching" because of the formation of martensite. The essential conditions for martensite to form in plain carbon steels are:
(1) high enough carbon concentration (usually >0.4%) to cause lattice distortion,
(2) high enough temperature to form austenite, and
(3) fast enough cooling (quenching) to suppress C diffusion.

Problem 5 [15 Points]

Suppose that CaO is added as an impurity to Li_2O. If Ca2+ substitutes for Li^+, what kind of vacancies would you expect to form? How many of these vacancies are formed for every Ca^{2+} added?

Suppose that CaO is added as an impurity to $CaCl_2$. If the O^{2-} substitutes for Cl^- what kind of vacancies would you expect to form? How many of these vacancies are formed for every O2- added?