

Do all Problems  
 (105/100 Total Points)  
 (1 extra credit for 10 points)

Exam 2a  
 MSEG 302

Name: Key

Write your answers below the question on this paper. If extra room is required use the back of the page on which a specific question resides.

8-1 (10 pts) a) Using a stress-strain diagram, explain what “strain hardening means.

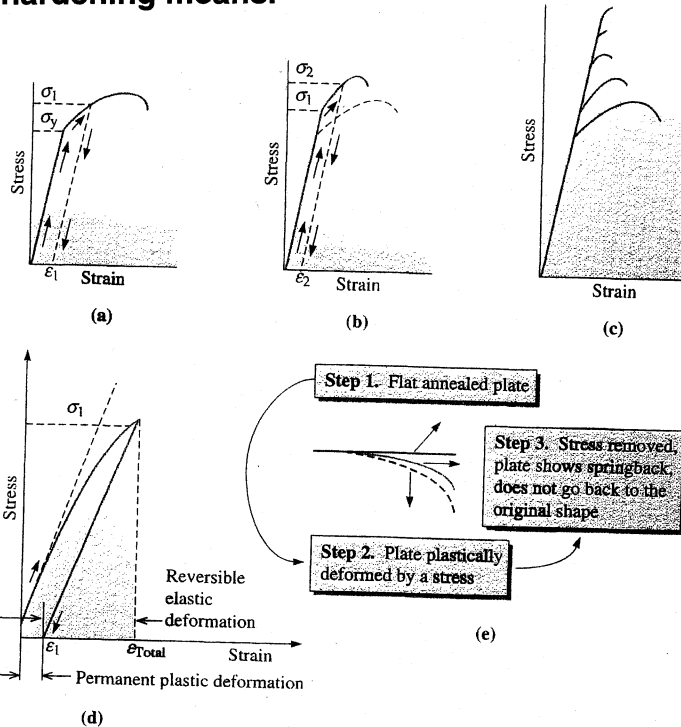


Figure 8-1 Development of strain hardening from the stress-strain diagram. (a) A specimen is stressed beyond the yield strength before the stress is removed. (b) Now the specimen has a higher yield strength and tensile strength, but lower ductility. (c) By repeating the procedure, the strength continues to increase and the ductility continues to decrease until the alloy becomes very brittle. (d) Note the total strain and the elastic strain recovery lead to remnant plastic strain and (e) illustration of springback. (Source: Reprinted from Engineering Materials I, Second Edition, M.F. Ashbey, and D.R.H. Jones, 1996. Copyright © 1996 Butterworth-Heinemann. Reprinted with permission from Elsevier Science.)

b) Explain why many metallic materials exhibit strain hardening.

We obtain strengthening during deformation of a metallic material by increasing the number of dislocations. Before deformation, the dislocation density is about  $10^6$  cm of dislocation line per cubic centimeter of metal – a relatively small concentration of dislocations. When stress that is greater than the yield strength is applied, dislocations begin to slip. The dislocation density may increase to about  $10^{12}$  cm of dislocation line per cubic centimeter of metal during strain hardening. The result is an increased strength, but reduced ductility, for metallic materials that have undergone cold working or work hardening.

9-2 (10 pts) Suppose that liquid nickel is undercooled until homogeneous nucleation occurs. Calculate

- (a) the critical radius of the nucleus required, and  
 (b) the number of nickel atoms in the nucleus.

Assume that the lattice parameter of the solid FCC nickel is 0.356 nm.

$$\Delta T_{\max} = 480^\circ\text{C}$$

$$r^* = \frac{2(255 \times 10^{-7} \text{ J/cm}^2)(1453 + 273)}{(2756 \text{ J/cm}^3)(480)} = \boxed{6.65 \times 10^{-8} \text{ cm}}$$

$$a_0 = 0.356 \text{ nm}$$

$$V = a_0^3 = 4.5118 \times 10^{-23} \text{ cm}^3$$

$$V_{\text{nucleus}} = (4\pi/3)(6.65 \times 10^{-8} \text{ cm})^3 = 1.232 \times 10^{-21} \text{ cm}^3$$

$$\text{Number of unit cells} = (1.232 \times 10^{-21}) / (4.5118 \times 10^{-23}) = 27.3$$

$$\text{Atoms per nucleus} = (4 \text{ atoms/cell})(27.3 \text{ cells}) = \boxed{109 \text{ atoms}}$$

$$r^* = [2 \sigma_{sl} T_m] / [\Delta H_f \Delta T]$$

$$T_m (\text{K}) = 273 + T_m (\text{C})$$

TABLE 8-1 ■ Values for freezing temperature, latent heat of fusion, surface energy, and maximum undercooling for selected materials

Metal	Freezing Temperature ( $T_m$ ) (°C)	Heat of Fusion ( $\Delta H_f$ ) (J/cm <sup>3</sup> )	Solid-Liquid Interfacial Energy ( $\sigma_{sl}$ ) (J/cm <sup>2</sup> )	Typical Undercooling for Homogeneous Nucleation ( $\Delta T$ ) (°C)
Ga	30	488	$56 \times 10^{-7}$	76
Bi	271	543	$54 \times 10^{-7}$	90
Pb	327	237	$33 \times 10^{-7}$	80
Ag	962	965	$126 \times 10^{-7}$	250
Cu	1085	1628	$177 \times 10^{-7}$	236
Ni	1453	2756	$255 \times 10^{-7}$	480
Fe	1538	1737	$204 \times 10^{-7}$	420
NaCl	801			169
CsCl	645			152
H <sub>2</sub> O	0			40

10-3 (10 pts) Write down the Gibbs Phase rule, assuming temperature and pressure are allowed to change. Explain clearly the meaning of each term.

$$2 + C = F + P$$

$C \equiv$  the number of chemically independent components, usually elements or compounds, in the system.

$F \equiv$  the number of degrees of freedom, or the number of variables (such as temperature, pressure or composition), that are allowed to change independently without changing the number of phases in equilibrium.

$P \equiv$  the number of phases present

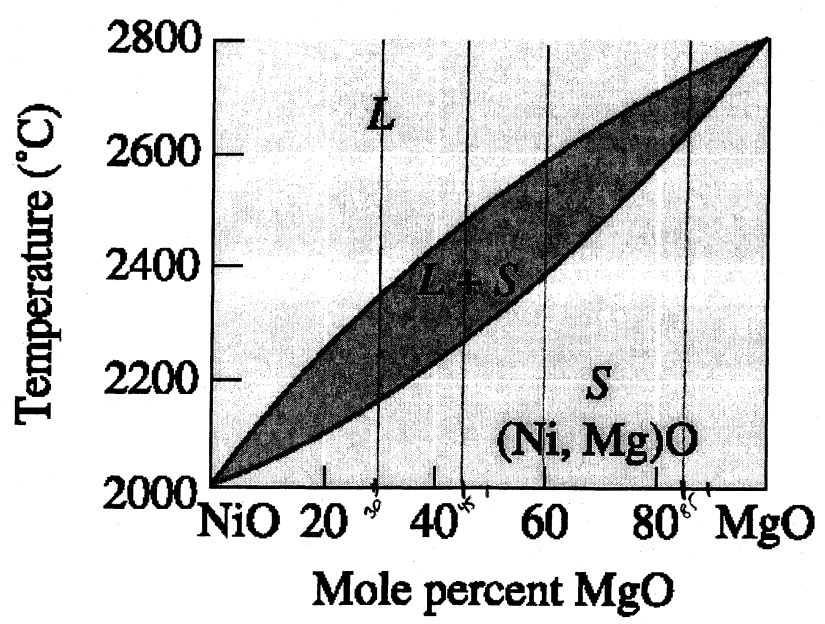
$2 \equiv$  implies that both temperature and pressure are allowed to change

10-4 (10pts) Determine the liquidus temperature, solidus temperature, and freezing range for the following NiO–MgO ceramic compositions.

- (a) NiO–30 mol% MgO
- (b) NiO–45 mol% MgO
- (c) NiO–60 mol% MgO
- (d) NiO–85 mol% MgO

Draw the lines you use to estimate the answers on the figure.

- a)  $T_L = 2330^\circ\text{C}$      $T_S = 2150^\circ\text{C}$      $FR = 180^\circ\text{C}$
- b)  $T_L = 2460^\circ\text{C}$      $T_S = 2250^\circ\text{C}$      $FR = 210^\circ\text{C}$
- c)  $T_L = 2570^\circ\text{C}$      $T_S = 2380^\circ\text{C}$      $FR = 190^\circ\text{C}$
- d)  $T_L = 2720^\circ\text{C}$      $T_S = 2610^\circ\text{C}$      $FR = 110^\circ\text{C}$



(b)

11-5 (20 pts) Consider a Pb-15% Sn alloy. During solidification, determine:

- a) the composition of the first solid to form
- b) the liquidus temperature, solidus temperature, solvus temperature, and freezing range of the alloy
- c) the amounts and compositions of each phase at 260°C
- d) the amounts and compositions of each phase at 183°C
- e) the amounts and compositions of each phase at 25°C

a) 8% Sn

b) liquidus = 290°C

solidus = 240°C

solvus = 170°C

freezing range = 50°C

c) L: 30% Sn  $\alpha$ : 12% Sn

$$\%L = \frac{15-12}{30-12} \times 100\% = 17\%$$

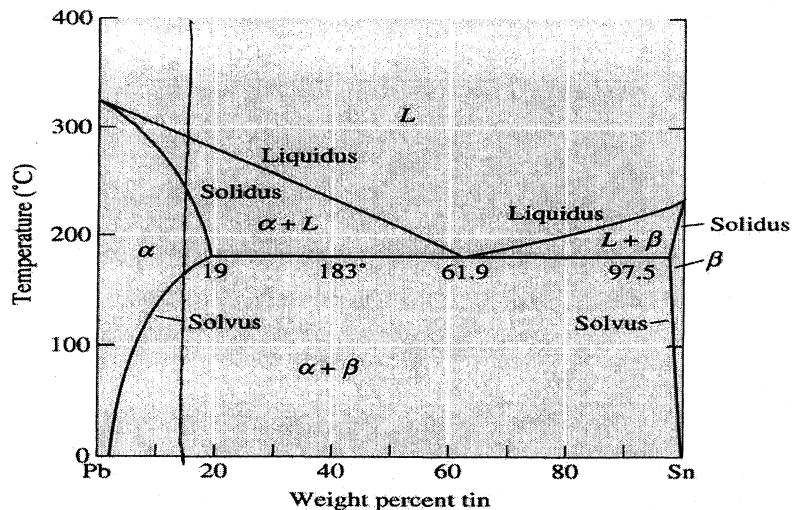
$$\% \alpha = 83\%$$

d)  $\alpha$ : 15% Sn 100%  $\alpha$

e)  $\alpha$ : 2% Sn  $\beta$ : 100% Sn

$$\% \alpha = \frac{100-15}{100-2} \times 100 = 87\%$$

$$\% \beta = 13\%$$



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11-6 (10 pts) Consider the binary phase diagram in the figure. Identify all of the three-phase eutectic and eutectoid reactions that occur. Give temperature, reaction and type.

1150°C : This reaction occurs at 15% B



920°C : This reaction occurs at 40% B



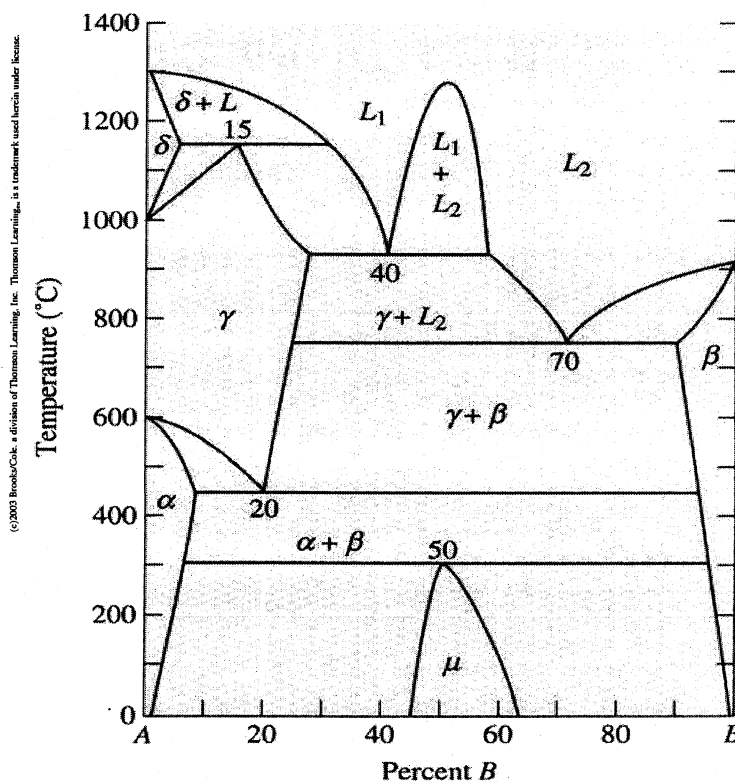
750°C : This reaction occurs at 70% B



450°C : This reaction occurs at 20% B



300°C : This reaction occurs at 50% B



**15-7 (10 pts) Plastic deformation due to dislocation motion is important in metals; however, this is not a very important consideration for the properties of ceramics and glasses. Explain.**

Ceramics contain dislocations and can even be strain-hardened to a small degree. However, dislocations in ceramics are normally not very mobile. Polycrystalline ceramics also contain porosity. As a result, ceramics behave as brittle materials and significant deformation and strengthening by cold working are not possible. Likewise, covalently bonded materials such as silicon (Si) are too brittle to workharden appreciably. Glasses are amorphous and do not contain dislocations and therefore cannot be strain hardened.

**MSD-8 (10 pts): Materials Section for Design Screening and Ranking**

**Describe the 4 basic steps for materials selection**

1. Translation of design requirements into a material specification
2. Screening out materials that fail constraints
3. Ranking by ability to meet objectives; material indices
4. Search for supporting information for promising candidates

**16-9 (15 points)**

**a) Explain why the degree of polymerization is not usually used to characterize thermosetting polymers?**

**b) Explain the term “glass transition” or  $T_g$ . Is this a fixed temperature for a given composition of ceramic or polymer glass?**

- a) Degree of polymerization is the average molecular weight of the polymer divided by the molecular weight of the monomer. However, because thermosetting polymers are crosslinked and therefore have essentially infinite average molecular weight since virtually all the polymer chains are interconnected. Therefore, the degree of polymerization is not usually used to characterize thermosetting polymers.
  
- b) The temperature range below which the amorphous polymer assumes a rigid glassy structure, also known as glass transition temperatures. No the glass transition temperature is not a fixed temperature for a given composition. Depending on how fast the polymer is heated, the glass transition temperature can change.

**16-extra credit (10pts) Match terms with definitions.**

- |                            |           |   |
|----------------------------|-----------|---|
| 1 monomer                  | <u>2</u>  | attaching chains of polymers together to produce a three-dimensional network polymer  |
| 2 cross-linking            | <u>9</u>  | average molecular weight of the polymer divided by the molecular weight of the monomer  |
| 3 elastomers               | <u>6</u>  | low molecular weight molecules, these may contain two (dimers) or three (trimers) mers  |
| 4 degradation temperature  | <u>1</u>  | molecule from which a polymer is produced   |
| 5 glass temperature        | <u>8</u>  | number of sites on a monomer at which polymerization can occur  |
| 6 oligomer                 | <u>3</u>  | polymers (thermoplastics or lightly cross-linked thermosets) that have an elastic deformation >200%   |
| 7 mer                      | <u>4</u>  | temperature at which a polymer burns, chars or decomposes   |
| 8 functionality            | <u>10</u> | temperature at which a polymer will deform a given amount under a standard load   |
| 9 degree of polymerization | <u>5</u>  | temperature range below which the amorphous polymer assumes a rigid glassy structure  |
| 10 deflection temperature  | <u>7</u>  | unit group of atoms and molecules that defines a characteristic arrangement for a polymer. A polymer can be thought off as a material made by combining several mers or units |