ME254: Materials Engineering
Second Midterm Exam
1^{st} semester 1436-1437
December 10, 2015
Time: 2 hrs

Problem 1: *(24 points)*

$A_o = \pi/4 * D_o^2 = \pi/4 * 17^2 = 227\ mm^2$
$L_o = 32\ mm$

a) Determine the following properties:

- The modulus of elasticity:
  Take any point in the initial elastic region. For example:
  $\Delta L = 0.15\ mm$
  $F = 76\ kN$
  Then, calculate the corresponding stress and strain:
  $\sigma = F / A_o = 335\ MPa$
  $\varepsilon = \Delta L / L_o = 0.00468$
  $\rightarrow E = \sigma / \varepsilon = 71.6\ GPa$

- The yield strength using 0.2% offset method:
  The load at yielding is about 90 KN $\rightarrow \sigma_y \sim F/Ao \sim 396\ MPa$

- The ultimate tensile strength:
  The load at yielding is about 160 KN $\rightarrow \sigma_{ult} \sim F/Ao \sim 705\ MPa$

- The ductility:
  Ductility $\sim \varepsilon_f = 18.3\ \%$

b) **At an applied load of 140 KN, find the following**:

- Will the specimen experience elastic and/or plastic deformation? Why?
  The deformation is elastic-plastic since the current stress is larger than the yield strength.

- Engineering strain
  From the figure, the elongation at this load is $\Delta L = 1.55\ mm$
  $\varepsilon = \Delta L / L_o = 0.048438$

- True strain: $\varepsilon_t = \ln(1 + \varepsilon) = 0.047301$

- Current length: $L = \Delta L + L_o = 33.5\ mm$

- True stress
  $\sigma_t = \sigma(1 + \varepsilon)$
  where $\sigma = F / A_o = 140 \times 10^3 / A_o = 617\ MPa$

⇨ $\sigma_t = \sigma\,(1 + \varepsilon) = 617\,(1 + 0.048438) = 647$ MPa

- Change in diameter

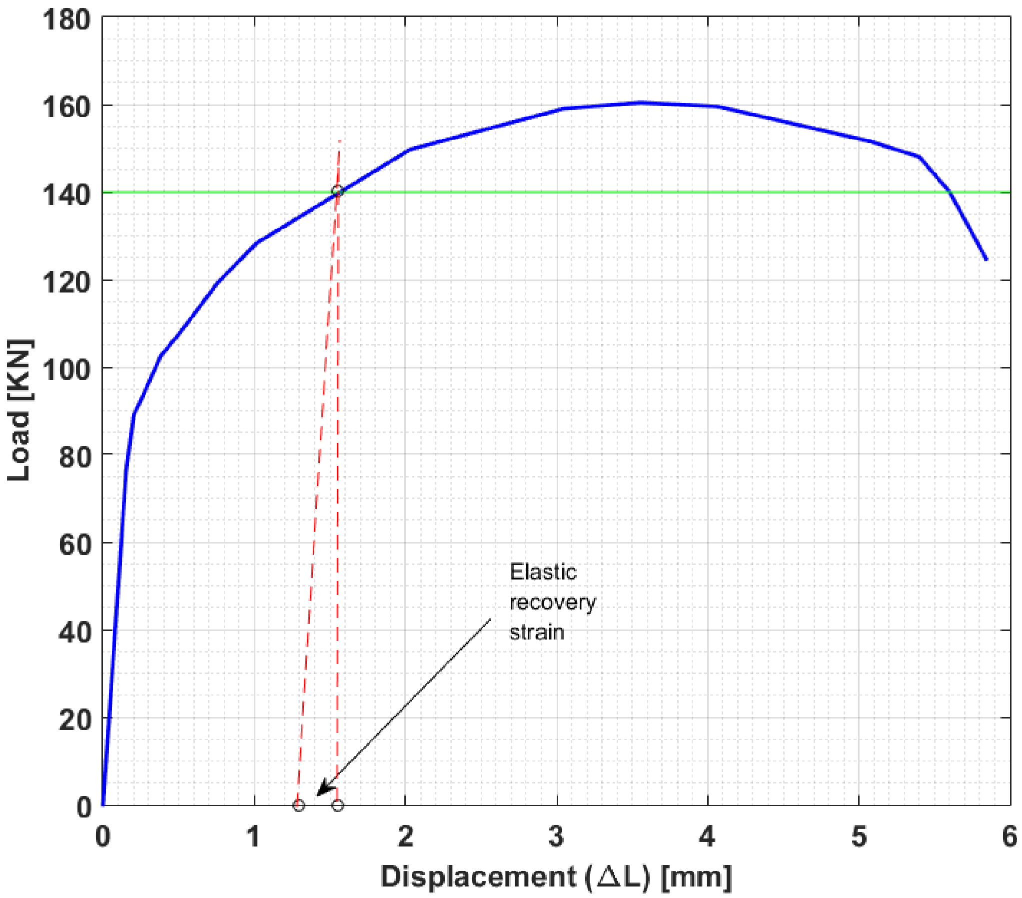
  $\sigma_t = F / A_i \rightarrow A_i = F / \sigma_t = 140 \times 10^3 / 647 = 216.5\ mm^2$

  $A_i = 216.5 = \pi/4 * D_i^2 \rightarrow D_i = 16.6$ mm

  ⇨ $\Delta D = D - D_o = 16.6 - 17 = -0.4$ mm

- Elastic strain recovery

  The elastic strain recovery can be directly determined from the figure by drawing a line at the given load and parallel to the initial linear segment as shown below:



⇨ The elastic recovery strain = $\varepsilon_{elastic} = (1.55 - 1.3) / L_o = 0.0078125$

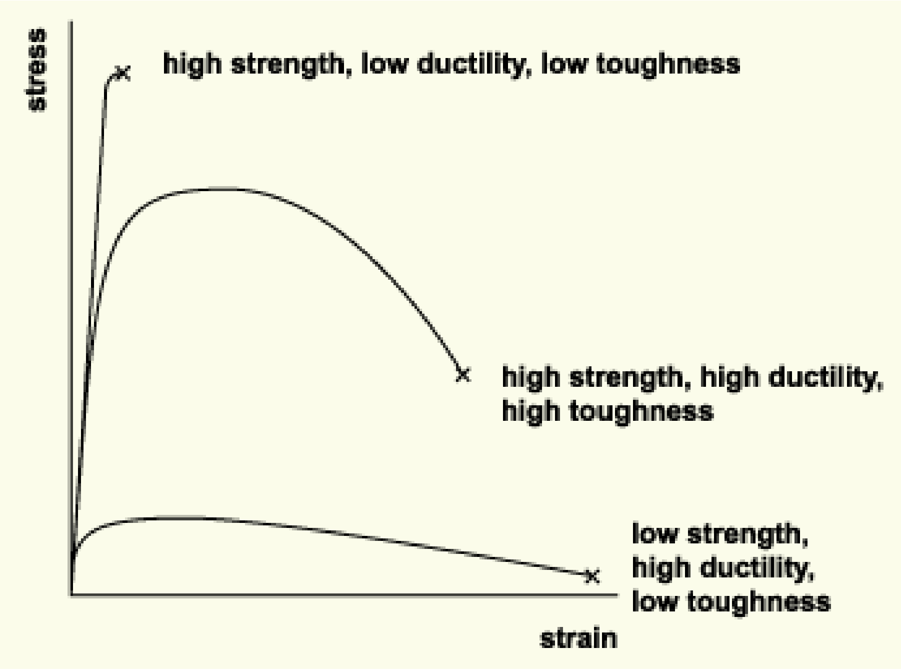
- **Note:**

  The elastic recovery strain can be also computed using Hook's law as follow:

  $\varepsilon_{elastic} = \sigma / E = 617 / 71.6 \times 10^3 = 0.008$

Problem 2: *(15 points)*

a) Explain the differences between these three materials in terms of **strength, ductility, and toughness**.



b) Give examples of materials that have the shape of these stress-strain curves (i.e. suggest a name of a material for A, B, and C)

Examples:

- Material A: Ceramic
- Material B: Metal
- Material C: Polymer

c) If a tensile stress of 400 MPa is applied, explain how each material will deform?

- Material A: The deformation will be purely elastic since the applied stress is in the initial elastic region.

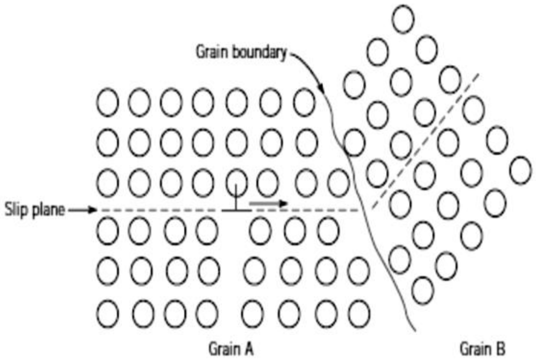
- Material B: The deformation will be elastic-plastic since the applied stress is higher than the yield strength and below the tensile strength of the material.

- Material C: The material will break since the applied stress is high compared to the strength of this material.

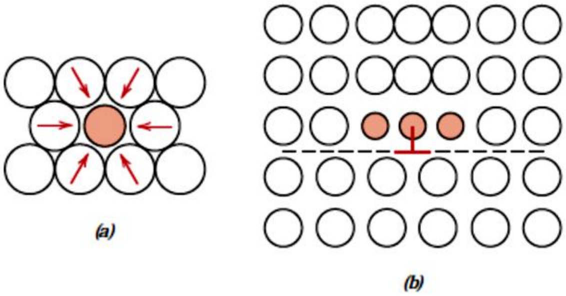
Problem (3): *(15 points)*

Solutions to Problem (3):

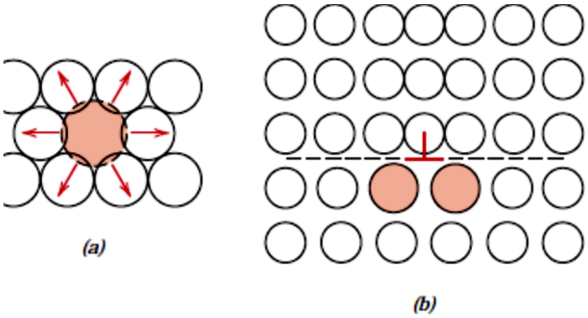
a) STRENGTHENING BY GRAIN SIZE REDUCTION



SOLID-SOLUTION STRENGTHENING



Representation of tensile lattice strains imposed on host atoms by a smaller substitutional impurity atom. (b) Possible locations of smaller impurity atoms relative to an edge dislocation such that there is partial cancellation of impurity–dislocation lattice strains.



Representation of compressive strains imposed on host atoms by a larger substitutional impurity atom. (b) Possible locations of larger impurity atoms relative to an edge dislocation such that there is partial cancellation of impurity–dislocation lattice strains.

STRAIN HARDENING

Strain hardening is the phenomenon whereby a ductile metal becomes harder and stronger as it is plastically deformed. Sometimes it is also called *work hardening.*

$$\%\mathrm{CW} = \left(\frac{A_0 - A_d}{A_0}\right) \times 100$$

b) The slip system with the highest Schmid factor $(cos\lambda\ \cos\Phi)$ will be activated first. Here, we need just to check $\cos\lambda$ since the angle Φ is similar for the two systems.

$$cos\Phi = \frac{1}{\sqrt{3}}$$

$$cos\lambda_1 = \frac{\vec{LD}\cdot\vec{SD}_1}{|\vec{LD}\,|\,|\vec{SD}_1|} = \frac{[1\ 0\ \ 0]\cdot[1\ 0\ -1]}{\sqrt{1}\,\sqrt{2}} = \frac{1}{\sqrt{2}}$$

$$cos\lambda_2 = \frac{\vec{LD}\cdot\vec{SD}_2}{|\vec{LD}\,||\vec{SD}_2|} = \frac{[1\ 0\ \ 0]\cdot[0\ \ 1\ -1]}{\sqrt{1}\,\sqrt{2}} = 0$$

$$cos\Phi\ *\ cos\lambda_1 = \frac{1}{\sqrt{3}} * \frac{1}{\sqrt{2}} = 0.4$$

$$cos\Phi\ *\ cos\lambda_2 = \frac{1}{\sqrt{3}} * 0 = 0$$

⇨ So, the slip system (111) [10 -1] will be activated first.

Problem (4): *(21 points)*

For the Cu-Ni solid solution phase diagram, and for an alloy having a composition of 55wt%Ni – 45 wt% Cu, calculate the following:

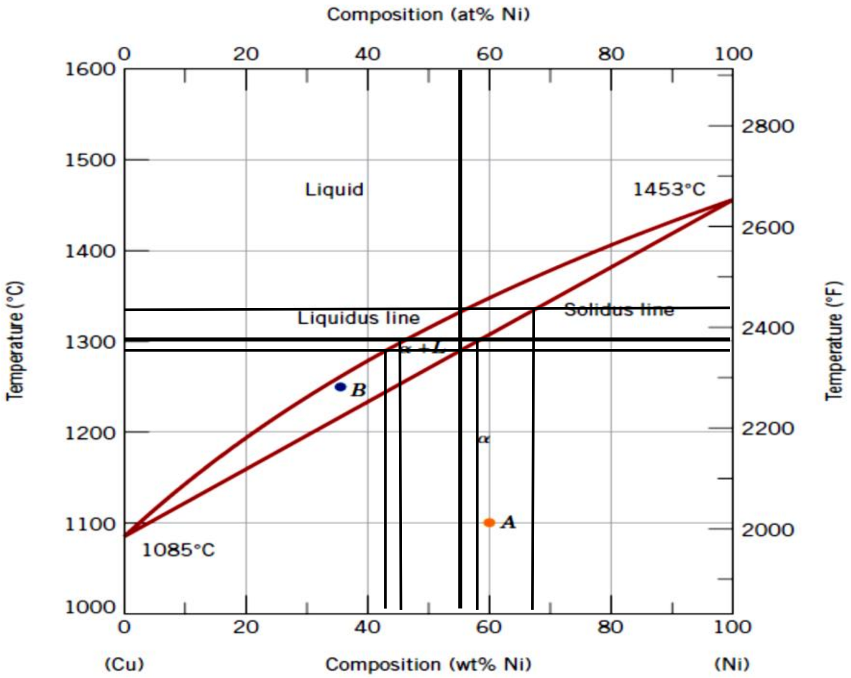
a) At 1300 °C, what are the phases present and weight (mass) fraction of each phase.
   Phases are α + L   %α= (55-43)/(58-43)*100 = 80%   %L= (58-55)/58-43)*100=20%

b) At what temperature does solidification start, and what is the chemical composition of the first solid phase to form?

   1340 °C (68wt% Ni+32wt%Cu)

c) At what temperature does solidification end, and what is the chemical composition of the last liquid prior to complete solidification?

   1290 °C (42wt%Ni + 58wt% Cu)



Problem (5): *(25 points)*

A 2.0-kg specimen of a 15 wt% Sn -85 wt% Pb alloy is heated to 200 °C; at this temperature it is entirely an α phase solid solution. The alloy is to be melted to the extent that 50% of the specimen is liquid, the remainder being α phase. This may be accomplished by heating the alloy or changing its composition while holding the temperature constant.

a. To what temperature must the specimen be heated to achieve this state?

280 °C

b. How much tin (Sn) must be added to the 2.0-kg specimen at 200 °C to achieve this state?

The middle point is (57 – 17)/2 = 20 is amount starts from 17 and it will be 37 when it starts from 0. The original amount of Sn is 15/100 * 2kg = 0.3 kg

The new amount of Sn will be 37/100 * 2kg = 0.74 kg

The amount of Sn should be added is 0.74-0.3= 0.44 kg

c. Write the equation of the eutectic reaction in Pb-Sn phase diagram and draw the microstructure of each phase?

$$L(61.9\text{ wt\% Sn}) \underset{\text{heating}}{\overset{\text{cooling}}{\rightleftharpoons}} \alpha(18.3\text{ wt\% Sn}) + \beta(97.8\text{ wt\% Sn})$$