CARLETON UNIVERSITY

Department of Civil and Environmental Engineering

Civil Engineering Materials – CIVE 2700

Midterm Examination

February 16, 2006

Instructor: Professor George Hadjisophocleous

Duration: 2 hours

Exam type: Closed book (drafting tools and calculators allowed)

Student Name: SOLUTIONS

Student I.D. ______________________________

Instructions:
1. Write all your answers on the examination paper only.
2. Use a dark pencil or a pen and write succinctly, clearly and legibly.
3. If a question has missing information, make an engineering assumption (e.g. assume a reasonable value for a missing parameter) and proceed to answer.
4. This examination question paper **MAY NOT** be taken from the examination room.

Problem	Mark
1	/30
2	/6
3	/6
4	/6
5	/12
6	/12
7	/16
8	/12

Civil Engineering Materials – CIVE 2700 – Midterm Examination, February 16, 2006.

Problem 1. Fill in the blanks. Each correct answer is worth 1%.

1. Name four main groups that materials are classified into:

a) Metals, b) Ceramics,
c) Polymers, d) Composites.

2. Name four types of properties of engineering materials:

a) Mechanical, b) Electrical, c) Thermal, and d) Chemical.

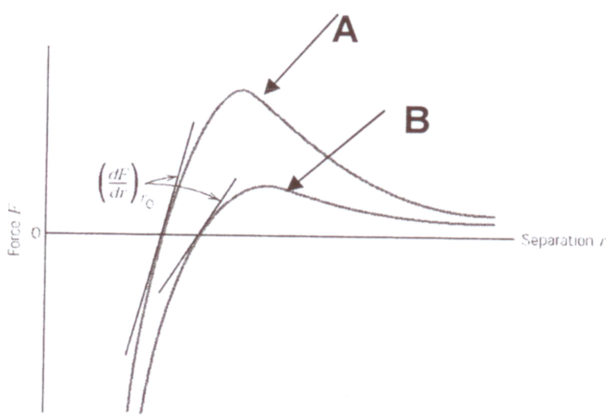
3. Small reversible deformations of materials due to external loading are called elastic deformations.

4. Poisson's ratio is the ratio of the lateral strain to the axial strain

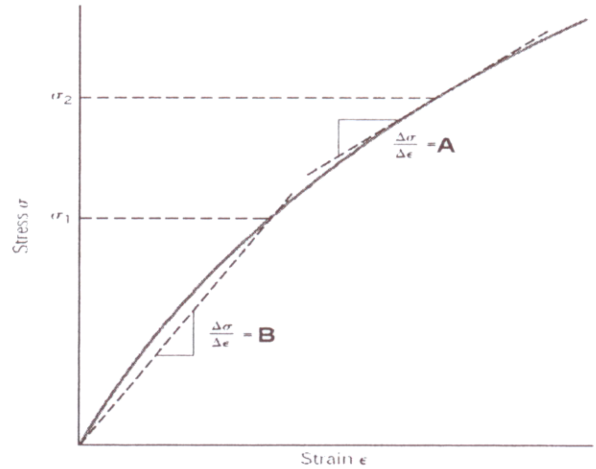
5. Ductility is the measure of the degree of plastic deformation that a specimen undergoing a tensile strength tests has been sustained at fracture.

6. Hardness is a measure of a materials resistance to localized plastic deformation.

7. The figure below shows a force versus interatomic separation for two materials. The atoms of material B are weakly bonded and the atoms of material A are strongly bonded.



8 In the figure below A is the tangent modulus and B the secant modulus.



9. Polymorphism is the phenomenon of the existence of more than one crystal structure in the same element or compound. When found in elemental solids the condition is called allotropy.

10. Coefficient of thermal expansion is a material property that is indicative of the extend to which a material expands upon heating.

11. The property that characterizes a material's ability to transfer heat is the thermal conductivity.

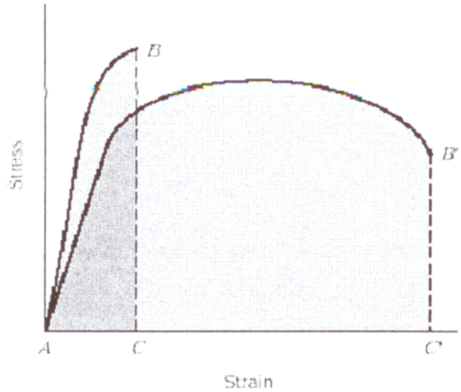
12. Cubic unit cells with atoms located at each of the corners and the centres of all its cube faces are called FCC

13. The atomic packing factor (APF) is the ratio of the volume occupied by the unit cell atoms to the volume of the unit cell.

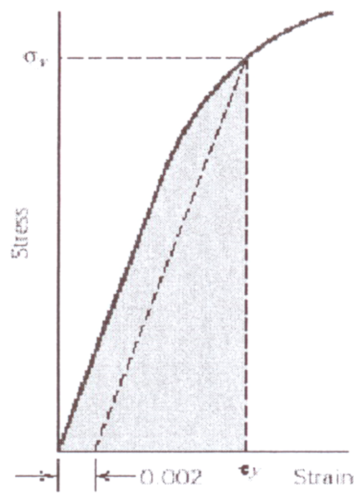
14. Name two types of point defects in crystals and two types of line defects:

a. Point defects: a) vacancies, b) interstitial
b. Line defects: a) edge dislocation, b) screw dislocation

15. In the Figure below material with the curve A-B is a brittle material, while material with A-B' curve is a ductile material. The area under the curves represents the toughness.



16. The shaded area in the Figure below is the modulus of resilience.



Keywords: (Please note that there may be more keywords than used in question 1-16. Some keywords may be used twice and some may be redundant.)

Allotropy ,amorphous materials, anisotropic, atomic packing factor (APF), BCC, brittle, ceramics, chord modulus, chemical, coefficient of thermal expansion, composites, coordination number, covalent, ductility, ductile, edge dislocation, elastic, electrical, FCC, Frenkel defect, hardness, heat capacity, heterogeneous, interstitial, ionic, materials engineering, materials science, mechanical, metallic, metals, metastable state, phase, plastic, polymers, polymorphism, resilience, Schottky defect, screw dislocation, secant modulus, stiffness, strength, tangent modulus, tensile strength, thermal, thermal conductivity, thermal inertia, toughness, vacancy, yield strength, Young modulus.

Problem 2. (6%)

Calculate the APF of a BCC unit cell.

Number of atoms in BCC unit cell = 2

$$APF = \frac{\text{volume of atoms in cell}}{\text{volume of cell}}$$

Volume of atoms = $2 \times \frac{4}{3} \pi R^3$

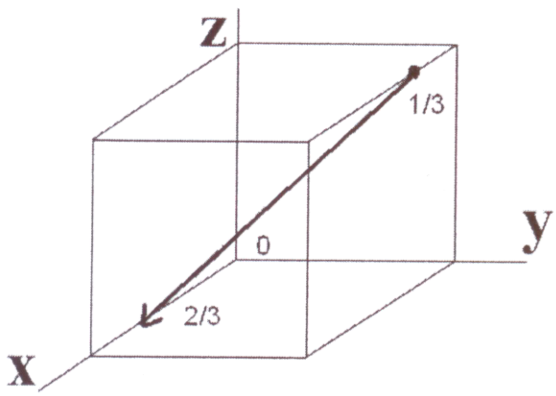
$a = \frac{4}{\sqrt{3}} R$

Volume of cell = $a^3 = \left(\frac{4}{\sqrt{3}} R\right)^3$

$$APF = \frac{2 \times \frac{4}{3} \pi R^3 (\sqrt{3})^3}{4^3 R^3} = \underline{\underline{0.68}}$$

Problem 3. (6%)

Determine the indices for the directions shown in the following cubic unit cells:



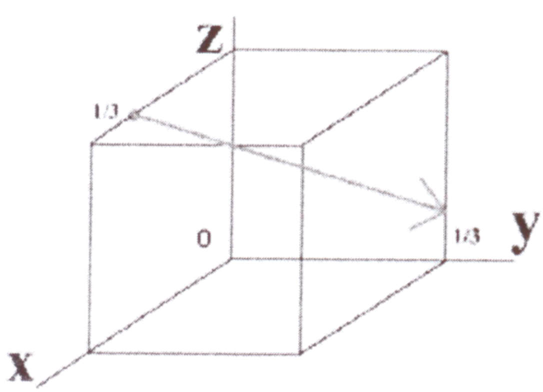
Head coordinates $\frac{2}{3}, 0, 0$

Tail coordinates $\frac{1}{3}, 1, 1$

$\frac{1}{3}, -1, -1$

eliminate fractions $1, -3, -3$

$[1\bar{3}\bar{3}]$



Head: $0, 1, \frac{1}{3}$

Tail $\frac{2}{3}, 0, 1$

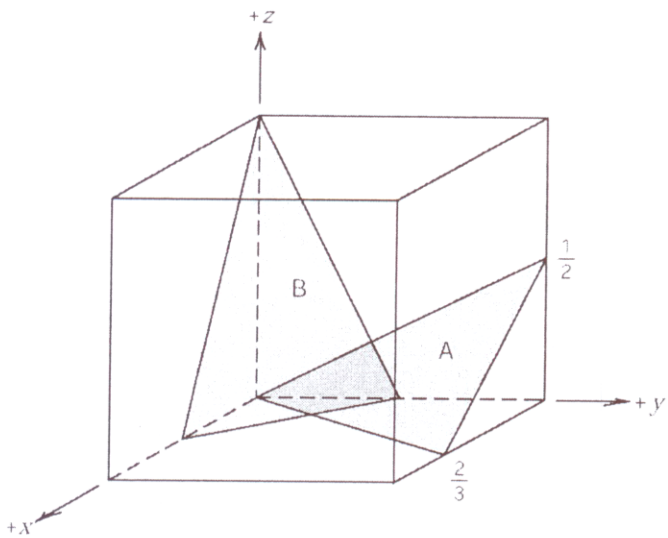
$-\frac{2}{3}, 1, -\frac{2}{3}$

$-2, 3, -2$

$[\bar{2}3\bar{2}]$

Problem 4. (6%)

Determine the Miller Indices of the two planes shown in the following cubic unit cell.



Plane A

Intersepts $\frac{2}{3}$ -1 $\frac{1}{2}$

Reciprocal $\frac{3}{2}$ -1 2

Reduction 3 -2 4

$(3\bar{2}4)$

Plane B

Intersepts $\frac{1}{2}$ $\frac{1}{2}$ 1

Reciprocals 2 2 1

(221)

Problem 5 (12%)

a) Consider the impurity diffusion of gallium into silicon wafer. If gallium is diffused into a silicon wafer with no previous gallium in it at a temperature of 1100°C for 3 h, what is the depth below the surface at which the concentration is 10^{22} atoms/m^3 if the surface concentration is 10^{24} atoms/m^3? ($D_{1100°C}=7.0 \times 10^{-17}$ m^2/s)

$$\frac{C_x - C_0}{C_s - C_0} = 1 - \text{erf}\left(\frac{x}{2\sqrt{Dt}}\right)$$

$$\frac{10^{22} - 0}{10^{24} - 0} = 1 - \text{erf}\left(\frac{x}{2 * \sqrt{7 \times 10^{-17} \times 3600 \times 3}}\right)$$

$$0{,}99 = \text{erf}\left(\frac{x}{1.74 \times 10^{-6}}\right)$$

$\text{erf}(z) = 0{,}99$

Interpolate to find z.

1.8	0.9891
z	0.99
1.9	0.9928

$$\frac{z - 1.8}{0.99 - 0.9891} = \frac{1.9 - 1.8}{0.9928 - 0.9891}$$

$z = 1{,}824$

$$\frac{x}{1.74 \times 10^{-6}} = 1.824 \Rightarrow x = 3.17 \times 10^{-6}\ \text{m}$$

Problem 6 (12%)

a) Determine the number of vacancies (vacancies/cm^3) needed for BCC iron crystal to have a density of 7.87 g/cm^3. The lattice parameter of the iron is 2.866 x 10^{-8} cm. The atomic mass of iron is 55.847 g/mol.

b) At what temperature do we have to heat treat iron to produce the vacancies found in (a) if 30,000 cal are required to produce a mole of vacancies in iron?

$$\rho = \frac{n A}{V_c N_A} = \frac{2 \times 55.847}{6.023 \times 10^{23} \times 2.354 \times 10^{-23}} = 7.877$$

$$V_c = (2.866 \times 10^{-8})^3 \text{ cm}^3 = 2.354 \times 10^{-23} \text{ cm}^3$$

$$7.87 = \frac{n \times 55.847}{2.354 \times 10^{-23} \times 6.023 \times 10^{23}}$$

$n = 1.998$ (number of atoms in unit cell instead of 2)

$$n_v = \frac{2 - 1.998}{V_c} = \frac{2.006 \times 10^{-3}}{2.354 \times 10^{-23}} = 8.52 \times 10^{19} \left(\frac{\text{vacancies}}{\text{cm}^3}\right)$$

$$N_v = N \exp\left(\frac{-Q_v}{RT}\right)$$

$$2 \times 10^{-3} = 2 \exp\left(\frac{-30{,}000}{1.987 \times T}\right)$$

$$-6.908 = -\frac{15{,}098.1}{T} \Rightarrow T = 2{,}185 \text{ K}$$

$$= 1912\ ^\circ\text{C}$$

Problem 7 (16%)

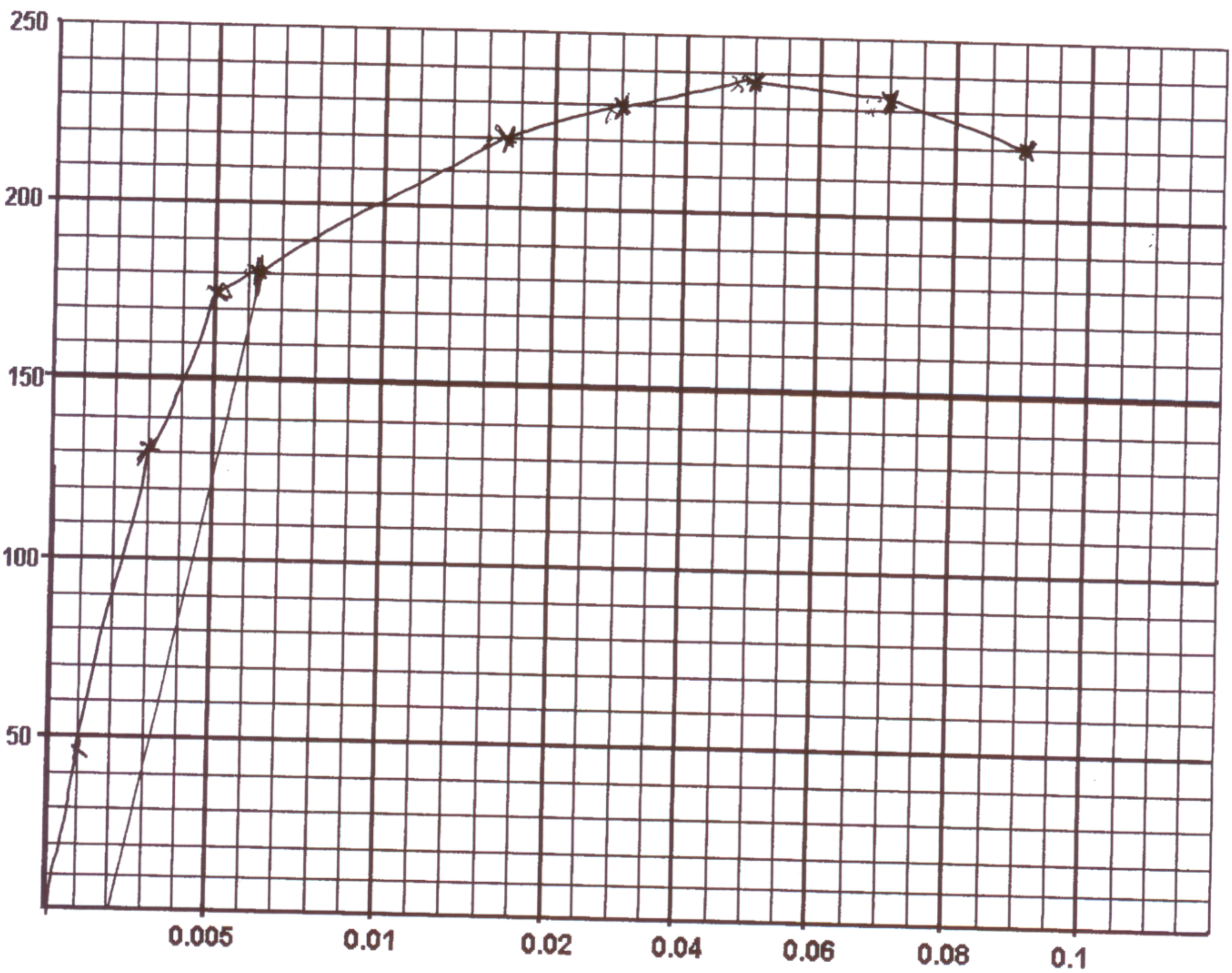
The following data were collected from a 12-mm-diameter test specimen of magnesium having an initial length l_0 of 30-mm.

MPa	0	44.2	88.46	132.7	177	221	230	239	234	221
Load (N)	**0**	**5,000**	**10,000**	**15,000**	**20,000**	**25,000**	**26,000**	**27,000**	**26,500**	**25,000**
Δl (mm)	**0.0000**	**0.0296**	**0.0592**	**0.0888**	**0.15**	**0.51**	**0.90**	**1.50**	**2.10**	**2.79**
$\Delta l / l_0$	0	0.001	0.002	0.003	0.005	0.017	0.03	0.05	0.07	0.093

After the fracture the total length was 32.61 mm and the diameter was 11.74 mm. Plot the data and calculate:

a) the 0.2% offset yield strength
b) the proportionality limit
c) the tensile strength
d) the modulus of elasticity
e) the % elongation
f) the % reduction in area
g) the modulus of resilience.

$$A = \frac{\pi (0.012)^2}{4} = 1.1304 \times 10^{-4} \, m^2$$



(2)

a) from graph $\sigma_y = 183$ MPa

b) from graph $\sigma_f = 135$

c) from graph $\sigma_T = 239$ (also from data fa

d) $E = \frac{88.46}{0.002} = 44.23$ GPa

e) $\% EL = \frac{32.61 - 30}{30} \times 100 = 8.7\%$

f) $\% RA = \frac{1.1304 * 10^{-4} - 1.0819 \times 10^{-4}}{1.1304 \times 10^{-4}} \times 100 = 4.3\%$

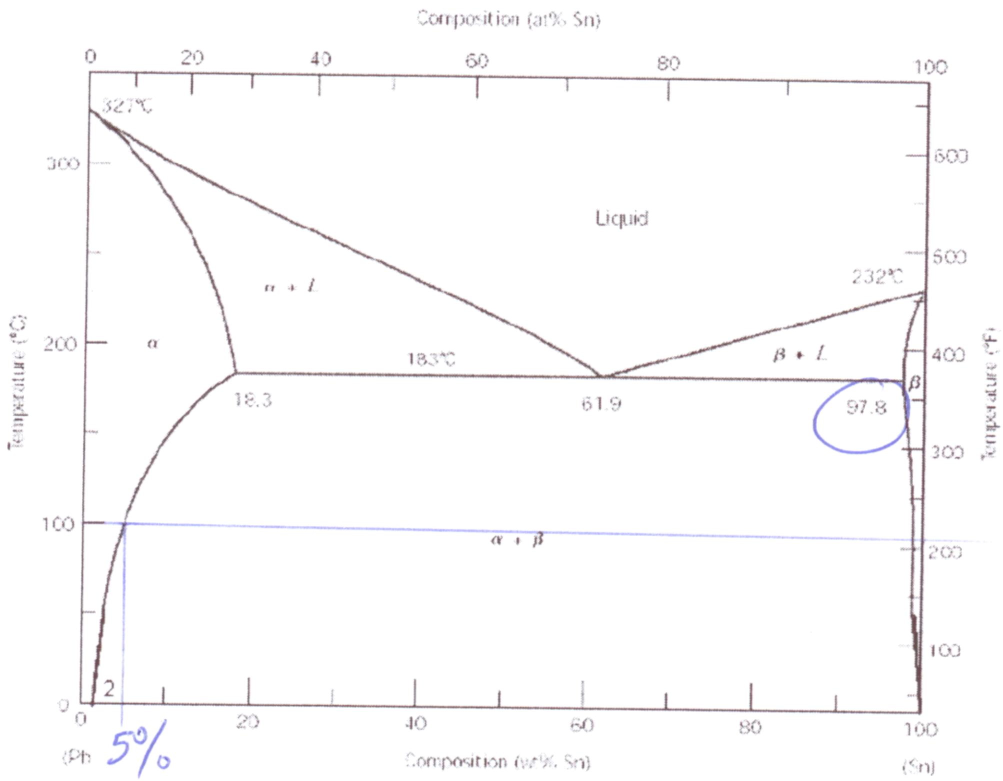
g) Modulus of resilience $= \frac{1}{2} \sigma_y \varepsilon_y = 0.5 * 183 * 0.0063$

$= \underline{\underline{0.6}}$ MPa

Problem 8 (12%)
With the aid of the following phase diagram determine the following:

a. The solubility of tin in solid lead at 100 °C
b. The maximum solubility of lead in tin,
c. The amount of β that forms if a Pb-10% Sn alloy is cooled to 0 °C,
d. The masses of the tin contained in the α, and β phases, and
e. Mass of lead contained in the α, and β phases.

Assume that the total mass of the Pb-10% Sn alloy is 100 grams.



a) At 100°C the solubility of tin (Sn) in lead (Pb) is 5%.

b) The maximum solubility of lead in tin is
$100 - 97.8 = 2.2\%$

c) Amount of β phase in Pb-10%Sn at 0°C.

$$\%\beta = \frac{10-2}{100-2} = 8.2\%$$

$$\%\alpha = 91.8\%$$

d) Mass of tin in α-phase

$$100 \times 91.8\% * 2\% = 1.836\ g$$

Mass of tin in β-phase

$$100 \times 8.2\% * 100\% = 8.2\ gr$$

or $10 - 1.836 = \underline{\underline{8.164\ g}}$

e) Mass of lead in α-phase

$$100 * 91.8\% * 98\% = 90\ g$$

Mass of lead in β-phase = 0. g