UNIVERSITY OF TORONTO

FACULTY OF APPLIED SCIENCE AND ENGINEERING

FINAL EXAMINATION, April 17, 2017
DURATION: 2 hrs

First Year

MSE160H1S – Molecules and Materials

Exam Type: A

Calculator type 3

Examiner – B. Hatton

Answer the following questions in the exam booklets.

Put your name clearly below and on all exam booklets to be handed in together.

Total marks: 110

1. [14 marks]

(a) Define directional and non-directional bonding (give examples). [4 marks]

(b) Draw a typical interatomic potential energy curve, and show how you can use it to predict the melting point (T_m), elastic modulus (E), and the coefficient of thermal expansion (α) for a material. [5 marks]

(c) Calculate the fraction of atom sites that are vacant (N_v/N) for copper close to its melting temperature of 1084°C (1357 K). The activation energy for vacancy formation is 0.90 eV/atom. [5 marks]

2. [14 marks]

(a) Draw unit cells for FCC and BCC crystal structures. Illustrate and label a close-packed plane. [5 marks]

(b) Briefly, why are FCC metals softer than BCC metals? [4 marks]

(c) Calculate the density of aluminum, which has an FCC structure (atomic mass = 26.98 g/mol, atomic radius = 0.143 nm). [5 marks]

3. [12 marks]

(a) Derive the Bragg diffraction equation for monochromatic x-rays and parallel atomic planes (use an illustration in your answer). [6 marks]

(b) How does x-ray diffraction prove that materials are crystalline? [2 marks]

(c) A cubic crystal show a diffraction peak from x-ray radiation ($\lambda = 1.54 \times 10^{-10}$ m) at $\theta = 33°$. This peak corresponds to diffraction from (1 3 0). Calculate the lattice parameter for this material. [4 marks]

4. [15 marks]

(a) What are **three** major mechanisms for increasing the strength of metal alloys? [3 marks]

(b) Explain the underlying basis for each mechanism, at the atomic and microstructure scale. Use illustrations where possible to help in your answer. [12 marks]

5. [14 marks]

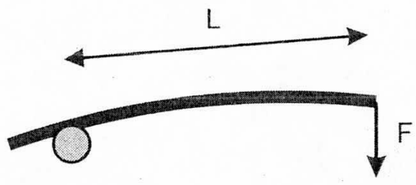
(a) The fracture toughness of an Al_2O_3 panel component is 3.6 MPa $m^{0.5}$. The component design requires the tensile strength to be 350 MPa. If the panel were loaded to this stress without failure, calculate the maximum surface crack that can be present (assume Y=1.0). [4 marks]

(b) How could such a crack be detected in the component? [4 marks]

(c) What would cause a glass window to fracture and fall without warning, after months of service? Where does the stress come from, and what kind of defect could be present? [6 marks].

6. [20 marks]

You are asked to design a high-end **fishing rod** with minimum weight, having a round, solid cross-section (radius **r**). The length (**L**) of the rod is fixed by the design, and it must support an applied load F (weight of the fish) in cantilever bending, without failure.



(a) Why is minimum weight a useful design objective in this case? [2 marks]

(b) Without considering cost, derive a **materials performance index** for the fishing rod. [5 marks]

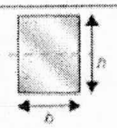
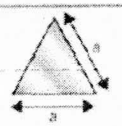
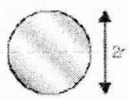
(c) The company wants to compare the following **three materials**; Al alloy, Ti alloy, and carbon fiber reinforced polymer (CFRP). Which **one** material would you recommend? (show your reasoning). [5 marks]

(d) The above materials can also be manufactured as hollow tubes, with different wall thickness. If the maximum shape factor for Al alloy = 2.0, Ti alloy = 3.5, and CFRP = 1.75, then which one material would you recommend? [3 marks]

(e) The company is also considering a **low cost** fishing rod, using either steel alloy 4340 or polycarbonate plastic. Considering cost, which **one** material (of these two choices) would you recommend? [3 marks]

(f) The fracture toughness of polycarbonate is 1.5 MPa $m^{0.5}$ (linear elastic), and steel alloy is 45 MPa $m^{0.5}$ (%EL=12). Would this extra information influence your material choice for (e)? [2 marks]

Name	Density	E	σ_f	Cost
	g/cm^3	GPa	MPa	(\$/kg)
Al alloy (7075)	2.8	71	572	
Ti alloy (Ti6Al4V)	4.3	114	1300	
CFRP	2.7	220	1000	
steel alloy 4340	7.85	207	1760	4.5
polycarbonate	1.2	2.38	121	3.9

Section Shape	Area A m^2	Moment I m^4
	bh	$\frac{bh^3}{12}$
	$\frac{\sqrt{3}}{4}a^2$	$\frac{a^4}{32\sqrt{3}}$
	πr^2	$\frac{\pi}{4}r^4$

Force of failure for a beam in cantilever loading: $F = \dfrac{2I\sigma_f}{y_m L}$

Shape factor, $\varphi = \dfrac{I}{I_o}$

7. [12 marks]

(a) On one graph, draw typical tensile stress-strain curves for a ceramic material, a ductile metal and a ductile polymer. [4 marks]

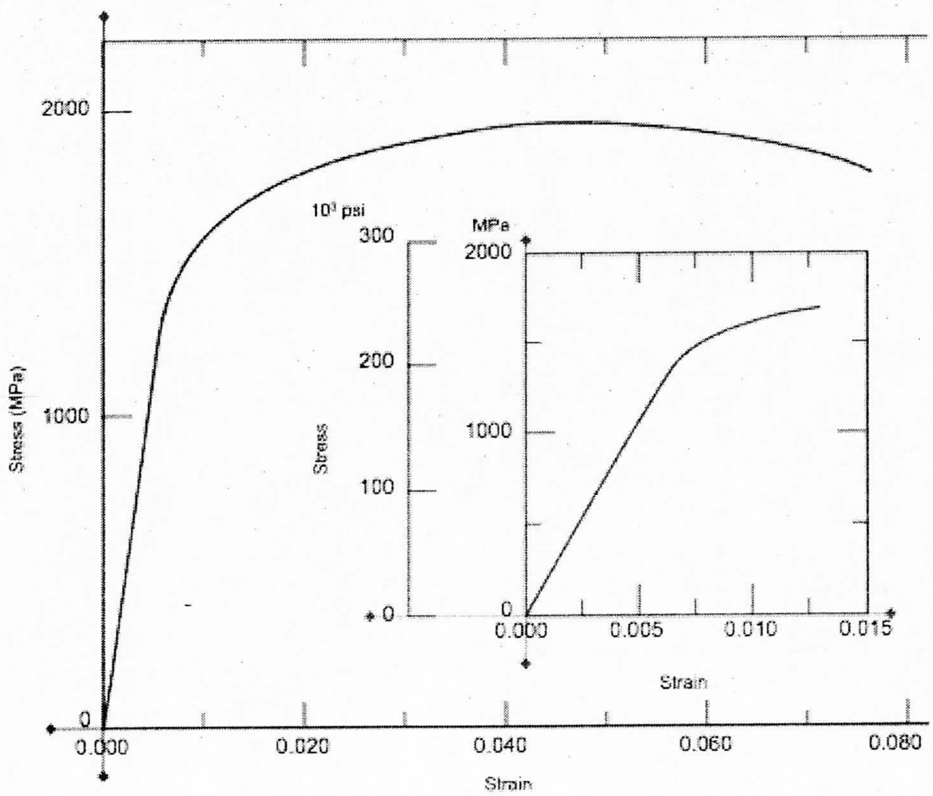
(b) How is toughness calculated with respect to a stress-strain curve? [2 marks]

(c) How do dislocations cause plastic deformation of metals, and why does this not work in covalent or ionically-bonded materials? [6 marks]

8. [9 marks]

(d) A steel alloy specimen (E = 207 GPa) having a rectangular cross section of dimensions 19 mm × 3.2 mm has the stress–strain behavior shown in the graph below. This specimen is subjected to a tensile force of 110,000 N. Determine the elastic and plastic strain values. [5 marks]

(e) If the specimen of (d) has original length is 610 mm, what will be its final length after the load is released? [4 marks]



$$d_{hkl} = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$$

$$n\lambda = 2d\ sin\theta$$

$$\sigma_T = \sigma(1 + \epsilon)$$

$$\tau_R = \sigma \cos\phi \cos\lambda$$

$$\sigma_y = \sigma_o + k_y d^{-1/2}$$

$$\epsilon_T = \ln(1 + \epsilon)$$

$$\text{\% ionic character} = \left(1 - e^{-\frac{(X_A - X_B)^2}{4}}\right) \text{x}\,(100\%)$$

$$\rho = \frac{n\,A}{V_C N_A}$$

$$K_c = Y\sigma\sqrt{\pi a}$$

$$U_r = \int_0^{\epsilon_y} \sigma\, d\epsilon$$

$$\sigma_c = \left[\frac{2E\gamma_s}{\pi a}\right]^{1/2}$$

$$\sigma_m = 2\sigma_o\left(\frac{a}{\rho_t}\right)^{1/2} = K_t\sigma_o$$

$$\frac{\Delta L}{L} = \alpha_L \Delta T$$

$$\frac{N_v}{N} = \exp\left[\frac{-Q_v}{kT}\right]$$

$$\sigma_T = K(e_T)^n$$

$$\%CW = \frac{A_o - A_d}{A_o}(100)$$

$$\frac{dA}{dN} = \left(\Delta\sigma\sqrt{a}\right)^m$$

Constants

k = 1.38 x 10^{-23} J/atom-K

k = 8.62 x 10^{-5} eV/atom-K

R = 8.31 J/mol-K

N_A = 6.022 x 10^{23}

Radius Ratio	CN	Coordination
1.0	12	Cubic closest packed (CCP) Hexagonal closest packed (HCCP)
1.0–0.732	8	Cubic
0.732–0.414	6	Octahedral
0.414–0.225	4	Tetragonal
0.225–0.155	3	Triangular
<0.155	2	Linear