

National Exams December 2002

98-MET-A5: Mechanical Behaviour & Processing & Performing of Materials

3 hours duration

Notes:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.
2. Candidates may use one of two calculators, the Casio or Sharp approved models. This is a closed book exam.
3. Any five (5) questions constitute a complete paper (100 marks total). Only the first five questions as they appear in your answer book will be marked.
4. All questions are of equal value.

Question 1: (20 Marks)

- (a) Single crystals of pure metals are not very useful for most mechanical design applications. Based on the above statement, describe in sufficient detail two methods by which a specific metal of your choice can be strengthened for improved mechanical strength. *(10 marks)*
- (b) Explain why nickel-based superalloy turbine blades for jet engine applications are produced in single crystalline form by directional solidification. (N.B. Your answer must consider microstructural aspects of the relevant structure-property relationship). *(10 marks)*

Question 2: (20 marks)

- (a) The nominal stress-strain curve for a metal, as obtained from a tensile test for example, defines the stresses for the onset of yield (σ_y) and final fracture (σ_f). However it is known that metals can deform plastically at stresses, $\sigma < \sigma_y$ by creep and fracture at stresses $\sigma < \sigma_f$ by fatigue. Under what conditions can metals be made to: (i) creep and (ii) fatigue? *(5 marks)*
- (b) Using a microstructural description discuss in sufficient detail one mechanism by which creep deformation can occur at stresses $\sigma < \sigma_y$. *(8 marks)*
- (c) Why are materials whose yield stresses are highly strain-rate dependent more susceptible to brittle fracture than those materials whose yield stresses do not exhibit marked strain-rate dependence? *(7 marks)*

Question 3: (20 marks)

- (a) "Tough" materials are usually best suited for mechanical design. Define "toughness" for the case of: (i) elastic deformation, (ii) plastic deformation and (iii) fast fracture. (10 marks)
- (b) Consider a large, flat plate of aluminum alloy which is to be exposed to reversed tensile-compressive loading cycles (N) with a stress amplitude ($\Delta\sigma$) of 150 MPa. The aluminum alloy experiences fatigue crack growth under steady-state conditions as given by: $\frac{da}{dN} = A(\Delta K)^n$, where ΔK is the cyclic stress-intensity factor range and the values of A and n are 2×10^{-12} and 2.5 respectively (for $\Delta\sigma$ in MPa and a in m). If initially the length (a_0) of the largest surface crack in the specimen is 0.75 mm and the fracture toughness (K_{Ic}) is 35 MPa m^{1/2}, calculate the number of cycles to failure (N_f) (i.e. fatigue life). (10 marks)

Question 4: (20 marks)

In light of the fact that the *strength* of a material is sometimes a poor indicator of materials performance, materials *toughness* has become a much more useful parameter. Describe in sufficient detail why and how one can process the following materials to achieve a significant increase in toughness:

- (a) aluminum alloy-based sheet for aircraft applications (5 marks)
- (b) zirconia (ZrO₂)-based ceramic engine blocks (5 marks)
- (c) low-density polyethylene (LDPE) for structural beams (5 marks)
- (d) high impact strength polymer-composites for a Formula 1 racing car chassis (5 marks)

Question 5: (20 marks)

- (a) Briefly describe the mechanical test procedures for creep and fatigue testing of a material of your choice and schematically illustrate how the mechanical property data is represented (i.e. compare a typical “creep curve” with a typical “fatigue curve”). *(10 marks)*
- (b) A steel part can be made by powder metallurgy or by machining from a solid block. Which part is expected to have the higher toughness? Explain. *(10 marks)*.

Question 6: (20 marks)

- (a) Using a single set of axes compare the *nominal* stress-strain curves for the following two engineering materials: (i) a tough polycrystalline metallic alloy and (ii) a semicrystalline polymer. Using sketches where appropriate, describe the changes in microstructure for each material type during stressing from the elastic limit to the ultimate tensile stress. **(10 marks)**
- (b) The development of composite structures has led to dramatic improvements in toughness, stiffness and strength of polymer-based materials. Briefly explain why a ceramic fibre-reinforced plastic (e.g. CFRP) leads to greater (i) stiffness, (ii) strength relative to the polymer matrix and greater fracture toughness relative to both the ceramic and polymer phases. **(10 marks)**

Question 7: (20 marks)

Upon considering the various deformation processing techniques used in industry today (e.g. rolling, forging, drawing, extrusion, deep drawing, stretch forming and bending), briefly describe a method to produce each of the following products. Should the process you select include hot working, cold working, annealing or some combination of these? Explain your decisions.

- (a) I-beams that will be welded to produce a section of a bridge (*5 marks*).
- (b) a head for a carpenter's hammer formed from round rod (*5 marks*).
- (c) paper clips (*5 marks*).
- (d) aluminum drink cans (*5 marks*).

Question 8: (20 marks)

Using materials examples of your choice, briefly describe the difference between the following types of environmental degradation. (Note: Your answer should consider the condition(s) responsible for each type of attack and the expected appearance of the material (i.e. microstructure) during or following failure).

- (a) stress-corrosion cracking (*5 marks*)
- (b) hydrogen embrittlement (*5 marks*)
- (c) corrosion fatigue (*5 marks*)
- (d) cavitation erosion (*5 marks*)