National Exams December 2015

10-MET-A5: Mechanical Behaviour and Fracture 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. This is a CLOSED BOOK EXAM.
   Any non-communicating calculator is permitted.

3. FIVE (5) questions constitute a complete exam paper.
   The first five questions as they appear in the answer book will be marked.

4. Each question is of equal value.

5. Some questions require an answer in essay format. Clarity and organization of the answer are important.

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 (σy) and final fracture (σf). 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: $\boxed{\frac{da}{dN} = A(\Delta K)^n}$, 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_o) of the largest surface crack in the specimen is 0.75 mm and the fracture toughness (K_c) 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 (ZrO_2)-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) polymer beams for construction ***(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-induced cracking***(5 marks)***

(c) corrosion fatigue ***(5 marks)***

(d) liquid metal embrittlement ***(5 marks)***