National Exams May 2014

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) Consider a nominal stress-strain curve for a ductile material loaded in tension. At the point of plastic instability the work hardening capability of the material is balanced by the applied stress. The work hardening rate of materials is usually described by a power law of the form: $\sigma = K\varepsilon^n$ where σ and ε are the true stress and true strain respectively, K is a constant and n is the work hardening exponent. Show that plastic instability (i.e. necking) occurs when
$\varepsilon = n$. ***(10 marks)***

(b) A 1.5 mm thick, 80 mm wide sheet of magnesium that is originally 5 m long is to be stretched to a final length of 6.2 m. What should be the length of the sheet before the applied stress is released? (E= 65 GNm^{-2} and σ_y= 200 MNm^{-2}). ***(10 marks)***

Question 2: (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 3: (20 marks)

(a) A relatively large sheet of steel with a fracture toughness, K_c= 25 MPa $\sqrt{m}$ is to be exposed to a cyclic tensile stress of 100 MPa. Prior to testing it has been determined that the component contains surface cracks up to as large as a= 2.0 mm in length. If the cyclic crack growth rate is under steady state conditions where: $\boxed{\frac{da}{dN} = A\,(\Delta K)^n}$, A= 1×10^{-12} $MPa^{-3}m^{-1/2}$ and n= 3, estimate the fatigue life (ie. the number of cycles to failure, N_f). ***(10 marks)***

(b) The nominal stress-strain curve for a tough engineering material, as obtained from a tensile test for example, defines the stresses for the onset of general yielding (σ_y) and final fracture (σ_f). However it is known that materials can catastrophically fail at stresses, $\sigma < \sigma_y$ such that the stress-strain curve becomes a poor measure of the integrity of a material. Describe in sufficient detail <u>two</u> different conditions and the associated mechanisms whereby a tough material can fail at stresses $\sigma < \sigma_y$. **(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) Steel plate is to be used in the construction of a marine vessel. The steel has a fracture toughness (K_C) of 53 MN $m^{-3/2}$ and a yield strength (σ_y) of 950 MN m^{-2}. It is possible that surface cracks may be produced during construction and the *smallest* surface crack depth that can be detected by ultrasonic inspection methods is a= 1.0 mm. Assuming that the plate contains cracks at the limit of detection, determine whether the plate will undergo general yield <u>or</u> will fail by fast fracture before general yielding occurs. ***(10 marks)***

(b) Why are large structures (e.g. ships, bridges and oil rigs) made of steel much more likely to fail in cold winter environments rather than in warm summer climates? ***(5 marks)***

(c) Briefly explain why HCP metals are typically more brittle than FCC and BCC metals. ***(5 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 portion 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)***