National Exams December 2019

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.
   A Casio or Sharp approved 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) Explain what is meant by slip system and how many independent slip systems exist in FCC metals. ***(5 marks)***

(b) Sketch a standard (100) stereographic projection of a cubic crystal and illustrate one example of how crystallographic texture would be represented. ***(5 marks)***

(c) In FCC metals the twinning plane is {111}. Explain what is meant by a twinning system and how many are possible in an FCC crystal? ***(5 marks)***

(d) In the case of heavily deformed BCC and FCC crystals, what is the maximum number of different twin traces for each type of crystal structure? ***(5 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 <u>one</u> 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)

(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 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 or 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 5: (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 6: (20 marks)

(a) An aircraft accident investigation revealed a high strength titanium alloy component failed by fatigue fracture after 8 years of service (i.e. 228,000 load cycles). If during its service life the component experienced a cyclic stress amplitude of 450 MPa with a tensile mean stress of 200 MPa, determine whether: (i) the suspension component exceeded its safe-life design limit requirements assuming a factor of safety of 2 or (ii) the service life of the component was excessive. [Note: the titanium alloy has a fatigue strength coefficient of 1758 MPa and fatigue strength exponent of -0.0977]. ***(10 marks)***

(b) Consider a component that has failed via a fatigue fracture mode. Explain the difference between fatigue *striations* and *beach marks* in terms of (i) origin, (ii) size, and (iii) detectability. ***(10 marks)***

Question 7: (20 Marks)

(a) Consider a dislocation held up between obstacles spaced at a distance 'L' apart on the slip plane of an engineering alloy. Determine the stress required to move the dislocation past the obstacles. ***(5 marks)***

(b) Determine the magnitude of the Schmid factor for an FCC single crystal oriented with its [100] direction parallel to the loading axis. ***(10 marks)***

(c) Derive the equation for the shear strain rate in terms of the mobile dislocation density and velocity. ***(5 marks)***

Question 8: (20 marks)

(a) You are investigating the collapse of a stressed component that failed at some point during the crash of a commercial aircraft. By considering *modes* and *mechanisms* of fracture, briefly discuss how you would differentiate whether the component failed by: (i) slow crack growth fatigue, (ii) slow crack growth corrosion or (iii) impact with the ground. ***(9 marks)***

(b) Explain why creep rupture occurs along grain boundaries. ***(5 marks)***

(c) Describe the mechanism of formation of intrusions and extrusions during fatigue deformation. ***(6 marks)***