National Exams December 2017

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.
   One of two calculators is permitted - any Casio or Sharp approved model.
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 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 2: (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 3: (20 Marks)

(a) Briefly explain why HCP metals are typically more brittle than FCC and BCC metals. ***(6 marks)***

(b) Explain what is meant by Hall-Petch strengthening of a metal alloy. ***(8 marks)***

(c) Differentiate the mechanisms of solid-solution strengthening and precipitation hardening in a metal alloy. ***(6 marks)***

Question 4: (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) 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)***

Question 5: (20 Marks)

(a) A large thin-walled cylindrical vessel is to be designed to contain a gas whose pressure produces a stress in the vessel wall of 460 MPa. The vessel will be made from a steel alloy whose fracture toughness is 98.9 MPa $\sqrt{m}$. Determine the maximum thickness of the vessel wall (t) such that the structure would leak before it catastrophically fails by fast crack growth. Assume the configuration correction factor for stress-intensity is unity. ***(5 marks)***

(b) Consider a structural component containing surface cracks as large as 0.1 mm in length. The component is exposed to cyclic tensile stresses, which reach a maximum of 310 MPa per cycle. The material 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 4 respectively (for ΔK in MPa$\sqrt{m}$ and a in m). Assume the configuration correction factor for stress-intensity is unity. If the fatigue lifetime must be a minimum of 2.7×10^4 cycles to failure, calculate the required fracture toughness of the material. ***(15 marks)***

Question 6: (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)***

Question 7: (20 Marks)

(a) In the fracture of engineering materials, it is usually possible to determine the cause of failure upon inspection of the fracture surfaces. By considering micromechanisms of fast fracture, briefly discuss the differences in fracture characteristics between a ductile material under static loading as compared to the same material under cyclic loading conditions. ***(10 marks)***

(b) 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)***

Question 8: (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)***