ENGINEERING TRIPOS PART IIB
ELECTRICAL AND INFORMATION SCIENCES PART II
ENGINEERING TRIPOS PART IIA

Friday 2 May 2003 2.30 to 4.00

Module 4C1

DEFORMATION AND FRACTURE

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

(TURN OVER

1 (a) Explain the difference between the interaction force between two edge dislocations and that between two screw dislocations on adjacent slip planes, and its significance on the equilibrium configuration of the dislocations. [25%]

(b) The stress field around an edge dislocation expressed in Cartesian coordinates (x, y, z) is

$$\sigma_{xx} = -\frac{Gby}{2\pi(1-\nu)}\frac{3x^2+y^2}{(x^2+y^2)^2}, \quad \sigma_{yy} = \frac{Gby}{2\pi(1-\nu)}\frac{x^2-y^2}{(x^2+y^2)^2}, \quad \sigma_{zz} = \nu(\sigma_{xx}+\sigma_{yy})$$

$$\sigma_{xy} = \frac{Gbx}{2\pi(1-\nu)}\frac{x^2-y^2}{(x^2+y^2)^2}, \quad \sigma_{xz} = \sigma_{yz} = 0$$

where G is shear modulus, ν is Poisson's ratio, and b is Burger's vector. Re-express the above stress field in cylindrical coordinates (r, θ, z). [20%]

(c) Determine the mean stress for an edge dislocation. At what value of θ is the mean stress a maximum? For $r = 10b$, what is the maximum value of this stress (in units of G)? How does this value compare with the yield strength of high strength steel? [30%]

(d) For a screw dislocation, the energy per unit length is approximately

$$U = \frac{Gb^2}{4\pi}$$

and for an edge dislocation, it is approximately

$$U = \frac{Gb^2}{4\pi(1-\nu)}$$

Use these results to determine the energy per unit length of a mixed dislocation whose Burger's vector makes an angle θ with the dislocation line. At what value of θ is the dislocation energy minimised? What is the significance of this result on the shape of a dislocation loop? [25%]

2 (a) Illustrating your answer with suitable examples, describe how failure can be expressed in terms of mean stress, Mises equivalent stress, maximum principal stress, maximum shear stress, and maximum principal strain. [25%]

(b) Consider a thin-walled tube with closed ends that is subjected to an internal pressure p and a torque of 100 kNm. The tube has radius 200 mm and wall thickness 10 mm. The pressure p is gradually increased until the tube fails. It is subsequently found that the tube material fails by the cleavage 2 mechanism, with a critical failure stress of 200 MPa in uniaxial tension.

(i) If the tube failure is controlled by crack initiation and the tube material yields according to the Tresca criterion, calculate the magnitude of p at failure. [30%]

(ii) If failure is controlled by crack propagation, write down the corresponding failure criterion and calculate the magnitude of p at failure. Along which orientation would the crack most likely propagate? [30%]

(iii) Discuss in detail how changes in grain size may affect cleavage 2 failure. [15%]

3 (a) Define the energy release rate G and the stress intensity factor K, and briefly explain how these quantities can be used to characterise fracture in materials. [20%]

(b) Describe briefly a method for the experimental measurement of G. [20%]

(c) Two strips of steel each of length L, thickness $t/2$ and unit width into the plane of the paper, are glued together using an epoxy adhesive. The gluing process left a central crack of length $2a$ as shown in Fig. 1. The entire assembly then is subjected to a bending moment M.

(i) Show that the energy release rate G is

$$G = \frac{18M^2}{Et^3}$$

where E is Young's modulus of steel. Assume that $L >> a >> t$. [40%]

(ii) Given that the epoxy has a linear stress versus displacement response with a rupture stress σ_U at a displacement δ_U, determine the moment at which the crack starts to propagate. [20%]

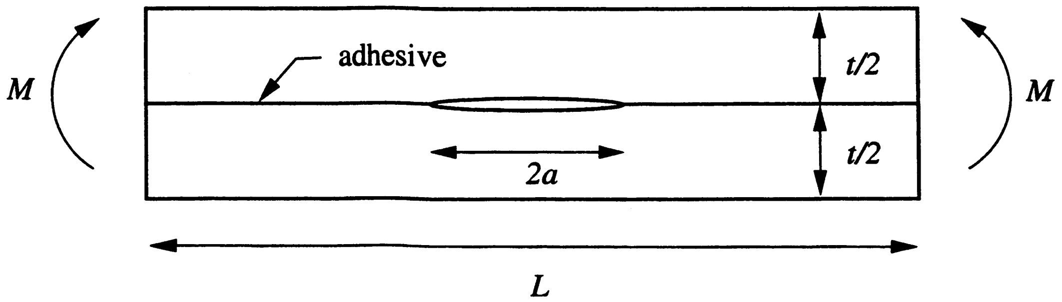

Fig. 1

4 (a) Sketch how a measurement of fracture toughness K_C of a metal depends on the thickness of the test specimen. Use this sketch to define the plane strain fracture toughness K_{IC} . [20%]

(b) Describe the conditions that must be satisfied for a valid measurement of the plane strain fracture toughness of a material. [20%]

(c) A ceramic is reinforced by a volume fraction V_f (where $V_f < 1$) of cylindrical fibres made from a rigid ideally plastic material with yield strength σ_Y .

(i) Explain why the fracture toughness of the reinforced ceramic would be observed to increase as a crack propagates through the material. [20%]

(ii) A bridging zone of length l is observed behind the tip of a long crack in the ceramic. Given that the fracture toughness of the ceramic in the absence of the reinforcement is K_{IC}^C , calculate the expected mode I fracture toughness of the reinforced ceramic. [40%]

END OF PAPER