Version NAF/2

EGT2
ENGINEERING TRIPOS PART IIA

Monday 2 May 2016 2 to 3.30

Module 3C9

FRACTURE MECHANICS OF MATERIALS AND STRUCTURES

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.*

Write your candidate number ***not*** *your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Attachment: 3C9 datasheet (8 pages).
Engineering Data Book

10 minutes reading time is allowed for this paper.

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

1 (a) Explain why the energy release rate G and the stress intensity factor K are equivalent loading parameters in linear elastic fracture mechanics. [20%]

(b) Figure 1 shows an asymmetric double cantilever beam, of thickness B, made from an elastic-brittle solid of Young's modulus E and toughness G_C. The beam is subjected to an end load P, to produce a crack mouth opening displacement u.

(i) Show that the energy release rate is given by

$$G = \frac{P^2}{2B}\frac{\partial C}{\partial a},$$

where $C = u / P$ is the compliance of the specimen and a is the crack length. [25%]

(ii) Thereby obtain an expression for the failure load P_c in terms of G_C, a, h_1, h_2 and B. [40%]

(iii) Comment on the expected crack path in the context of mode mixity. [15%]

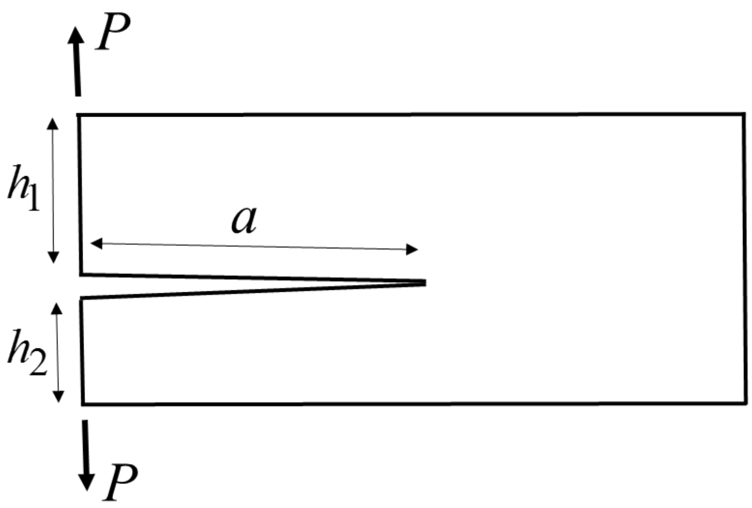

Fig. 1

2 (a) It is commonly observed that the stress intensity factor K_R for continued crack growth increases with crack extension Δa for a metallic alloy. Explain the physical basis for this observation. Show on a sketch of K_R versus Δa how this behaviour can lead to stable crack growth before fast fracture, and state the conditions for instability. [30%]

(b) A welding operation on a large steel plate imparts a longitudinal residual stress distribution, through the thickness of the plate, as sketched in Fig. 2. Poor welding practice leads to the existence of a through-thickness crack, of semi-length a = 10 mm, at the centre of the plate as shown. The plane of the crack is normal to the stress field.

(i) Calculate the magnitude of the stress intensity factor K at each crack tip due to the residual stress field. [20%]

(ii) In service, the crack extends by stress corrosion. Obtain expressions for K as a function of crack semi-length a, for a in the range 10 mm to 100 mm, and state the values of K for a = 30 mm, 90 mm and 100 mm. [35%]

(iii) An additional longitudinal stress state is now applied to the plate by external loading, and the total value of K is obtained by superposition of the residual and applied stress states. Explain the limitations of the assumption of linear superposition. [15%]

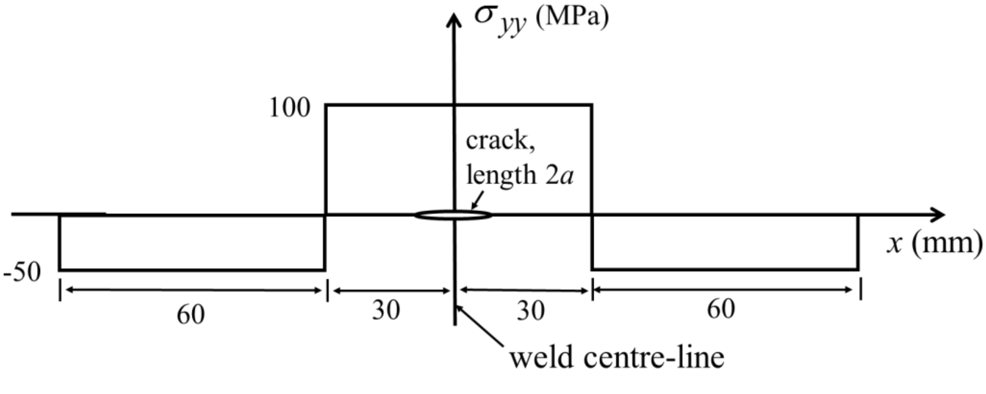

Fig. 2

3 Account for the following observations:

(a) It is necessary to qualify the safety of a nuclear reactor pressure vessel made from welded steel using the J-integral approach rather than linear elastic fracture mechanics. [25%]

(b) Metallic alloys are tougher but weaker than freshly drawn silica glass. [25%]

(c) Non-propagating fatigue cracks can exist at the root of a small notch but not at the root of a large notch. [25%]

(d) Severe turbulence on a metallic aircraft wing can extend its fatigue life. [25%]

4 (a) Specimens of 7075-T6 aluminium alloy were subjected to fully reversed cyclic loading. Failure occurred after 545 cycles when tested at a cyclic plastic strain range $\Delta\varepsilon^{\mathrm{p}} = 0.01$, and after 2000 cycles at $\Delta\varepsilon^{\mathrm{p}} = 0.005$. Calculate the constants in the Coffin-Manson fatigue law for this material. [25%]

(b) The amplitude of cyclic stress-stress strain response of the 7075-T6 aluminium alloy is idealised by the bi-linear relation

$$\frac{\Delta\varepsilon}{2} = \frac{1}{E}\frac{\Delta\sigma}{2} , \qquad \text{for} \quad \frac{\Delta\sigma}{2} \leq \sigma_{\mathrm{Y}}$$

$$\frac{\Delta\varepsilon}{2} = \frac{\sigma_{\mathrm{Y}}}{E} + \frac{1}{E_{\mathrm{T}}}\left(\frac{\Delta\sigma}{2} - \sigma_{\mathrm{Y}}\right) , \qquad \text{for} \quad \frac{\Delta\sigma}{2} > \sigma_{\mathrm{Y}}$$

in terms of the Young's modulus E = 70 GPa, post-yield tangent modulus E_{T} =7 GPa, and yield strength σ_{Y} = 280 MPa. A large sheet of the 7075-T6 aluminium alloy contains a circular hole (with elastic stress concentration factor $k_T = 3$) and the plate is subjected to a fully reversed uniaxial cyclic stress of amplitude $\Delta\sigma / 2$ = 250 MPa. Estimate the number of cycles for crack initiation by making use of Neuber's rule, $k_{\sigma}k_{\varepsilon} = k_{\mathrm{T}}^2$. [50%]

(c) Explain mean stress relaxation at a notch root and whether Neuber's rule takes it into account. [25%]

END OF PAPER