Drexel University, Department of Materials Science and Engineering

Materials Science and Engineering II – Winter 2008

MATE 221: Introduction to Mechanical Properties of Materials

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Homework 6

Chapter 8 (Ashby, Shercliff, Cebon)

E8.1 H6.Q1 (8pts): What is meant by toughness? How does it differ from strength?

Strength is resistance to plastic flow (1pt) and thus is related to the stress required to move dislocations through the solid (1pt). The initial strength is called the yield strength (1pt). Strength generally increases with plastic strain because of work hardening (1pt), reaching a maximum at the tensile strength (1pt).

Toughness is the resistance of a material to the propagation of a crack (1pt). A material with low fracture toughness, if it contains a crack, may fail before it yields (1pt). A tough material will yield, work harden even when cracked – the crack makes no significant difference (1pt).

E8.2 H6.Q2 (8pts): Why does a plastic zone form at the tip of crack when the cracked body is loaded in tension?

The intense stress field at the tip of a crack in a ductile material generates a process-zone: a region in which plastic flow takes place (1pt). The stress σ_{local} rises as the crack tip is approached

$$\sigma_{\text{local}} = Y \frac{\sigma\sqrt{\pi c}}{\sqrt{2\pi r}} \text{ (2pt)}$$

as the crack tip is approached (r is the radial distance from the crack tip, c the crack length and σ the remote stress). At the point where it reaches the yield strength σ_y the material yields (1pt) and – except for some work hardening – the stress cannot climb higher than this (1pt). The size of the plastic zone is found by setting $\sigma_{local} = \sigma_y$ and solving for r giving

$$r_y = \left(\frac{\sigma^2 c}{2\pi\sigma_y^2}\right) = \frac{K_1^2}{\pi\sigma_y^2} \text{ (2pt)}$$

(taking Y = 1). In reality the truncated part of the elastic stress field is re-distributed, making the plastic zone larger by a factor of 2 (1pt).

E8.3 H6.Q3 (5pts): Why is there a transition from ductile to brittle behavior at a transition crack length, c_{crit} ?

When cracks are small, materials yield before they fracture (1pt); when they are large, the opposite is true (1pt). When the crack is small, this stress is equal to the yield stress(1pt); when large, it falls off according to equation (taking Y = 1 again)

$$\sigma_f = \frac{K_{1c}}{\sqrt{\pi c}} \text{ (1pt)}$$

The transition from yield to fracture occurs when $\sigma_f = \sigma_y$, giving the transition crack length

$$c_{crit} = \frac{K_{1c}^2}{\pi \sigma_y^2} \text{ (1pt).}$$

Chapter 8 (Ashby, Shercliff, Cebon)

H6.Q4 (6pts): What is meant by the mechanical loss coefficient, η, of a material? Give examples of designs in which it would play a role as a design-limiting property.

The mechanical loss-coefficient or damping coefficient, η (a dimensionless quantity), measures the degree to which a material dissipates vibrational energy (1pt). If an elastic material is loaded, energy is stored (1pt). When it is unloaded some energy is returned, but not all. The difference is called the loss coefficient, η (1pt). It is the fraction of the stored elastic energy that is not recovered on unloading; instead it appears as heat (1pt). Applications in which resonance or fast elastic response is required (bells, high-speed relays and springs) require materials with low η (1pt). Applications in which it is desirable to damp vibration (sound isolation of buildings, supression of vibration in machine tools) use material with high η (1pt).

H6.Q5 (5pts): What is meant by the endurance limit, σ_e, of a material?

For many materials there exists a fatigue or endurance limit, σ_e (units: MPa) (1pt). It is the stress amplitude σ_a, about zero mean stress (1pt), below which fracture does not occur, or occurs only after a very large number ($N_f > 10^7$) cycles (1pt). Design against high-cycle fatigue is therefore very similar to strength-limited design (1pt), but with the maximum stresses limited by the endurance limit σ_e rather than the yield stress σ_y (1pt).

H6.Q6 (4pts): What is the Fatigue ratio? If the tensile strength σ_{ts} of an alloy is 900 MPa, what, roughly, would you expect its endurance limit σ_e to be?

The fatigue ratio R_f is the ratio of the endurance limit to the tensile stress: $R_f = \frac{\sigma_e}{\sigma_{ts}}$ (2pt).

Form metals and polymers $R_f \approx 0.33$ (1pt). Thus the expected value of the endurance limit for the alloy is about 300 MPa (1pt).

H6.Q7 (4pts): The figure shows an S−N curve for AISI 4340 steel, hardened to a tensile stress of 1800 MPa.

What is the endurance limit? The endurance limit is about 630 MPa (1pt).

If cycled for 100 cycles at an amplitude of 1200MPa and a zero mean stress, will it fail? No. (1pt).

If cycled for 100,000 cycles at an amplitude of 900MPa and zero mean stress, will it fail? Yes. (1pt).

If cycled for 100,000 cycles at an amplitude of 800MPa and a mean stress of 300 MPa, will it fail?

$$\Delta\sigma_{\sigma_m} = \Delta\sigma_{\sigma_0}\left(1 - \frac{\sigma_m}{\sigma_{ts}}\right) \Rightarrow \Delta\sigma_{\sigma_0} = \frac{\Delta\sigma_{\sigma_m}}{(1-\sigma_m/\sigma_{ts})} = \frac{800 \text{ MPa}}{(1-300/1800)} = \frac{6}{5} 800 \text{ MPa} = 960 \text{ MPa}$$

Yes. (1pt).