MET2
MANUFACTURING ENGINEERING TRIPOS PART IIA

Tuesday 28 April 2015 9 to 10.30

Paper 1

Module 3P1: MATERIALS INTO PRODUCTS

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
20 page answer booklet
Rough work pad

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
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) The Levy-Mises flow rule states that the relationship between the increments of strain ($d\varepsilon_1, d\varepsilon_2, d\varepsilon_3$) in 3-dimensional plastic deformation, and the principal stresses (σ_1 , σ_2 , σ_3), is given by

$$\frac{d\varepsilon_1}{(\sigma_1 - \sigma_m)} = \frac{d\varepsilon_2}{(\sigma_2 - \sigma_m)} = \frac{d\varepsilon_3}{(\sigma_3 - \sigma_m)} = \text{constant}$$

where σ_m is the mean hydrostatic stress: $\sigma_m = (\sigma_1 + \sigma_2 + \sigma_3)/3$.

For the case of plane strain, and assuming $\sigma_1 > \sigma_2 > \sigma_3$, find the relationship between the intermediate principal stress σ_2 and the other principal stresses. Hence express the von Mises yield criterion for plane strain conditions in terms of σ_1 and σ_3 and the uniaxial yield stress, Y. Compare this with the corresponding expression using the Tresca yield criterion, and hence define what is meant by the *plane strain yield stress*. [30%]

(b) Figure 1 shows a schematic of the geometry of an experimental equal channel angular extrusion (ECAE) process, which deforms a sample of metal at a constant speed, v, without changing its thickness, t. The extrusion dies and sample may be pre-heated and a range of extrusion speeds may be applied.

(i) For what metallurgical purpose might the ECAE process be used? [15%]

(ii) Assuming plane strain conditions apply, use the upper bound method to find an expression for the extrusion pressure p in terms of the material shear yield stress k and ECAE semi-angle, θ. Friction may be neglected. Sketch how the pressure varies for $\pi/4 < \theta < \pi/2$, and comment on the magnitude of the pressure compared to the uniaxial yield stress. [30%]

(iii) Without further calculation, state how you would estimate the temperature rise in the metal caused by ECAE. [10%]

(iv) In practice, friction on the channel walls will be significant. Comment on the effect of friction on the extrusion pressure and the temperature rise, and how these will be influenced by the length of the channel. [15%]

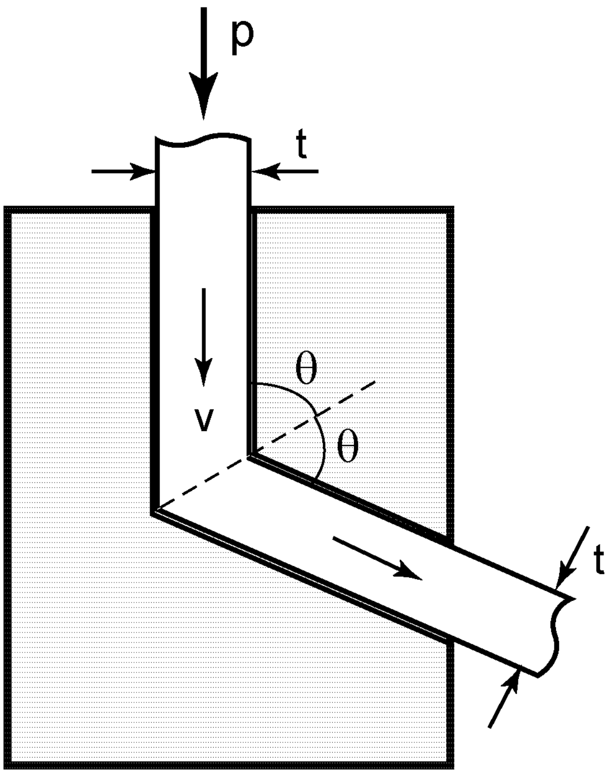


Fig. 1

2 (a) Explain how residual stresses result from the following processes:

(i) intense heating of one surface of a steel slab in a welding process, followed by cooling;

(ii) injection moulding of a thin-sectioned component from a thermoplastic polymer.

Use sketches to indicate how the stresses are developed, their locations and their nature (compressive or tensile). Explain in each case why the presence of residual stresses may be undesirable, and indicate how the levels of stress can be reduced. [50%]

(b) A rolled steel I-section beam forms part of a road bridge. In use, the maximum tensile stress in the beam (with equal contributions from residual stress and the applied load) approaches the yield stress of the steel. Pitting corrosion has generated surface-breaking defects which can be treated as edge-cracks 5 mm in length. The steel has a yield stress of 300 MPa which can be assumed to be independent of temperature, and a fracture toughness K_{IC} which falls linearly with temperature from 50 MPa $m^{1/2}$ at 20 °C to 30 MPa $m^{1/2}$ at −20 °C. As the temperature of the bridge falls overnight, estimate the temperature at which the beam will fail by fast fracture.

What measures could be taken in the design, construction and maintenance of the bridge, using the same grade of steel, to avoid failure from this cause? [50%]

3 500 mm square plates are required for a range of applications. The specified thickness is different for the different applications, and in all cases out-of-plane distortion must be kept small. The plates are to be made from aluminium-silicon casting alloy, glass fibre reinforced plastic (GFRP) or high density polyethylene (HDPE), for different applications.

(a) The aluminium-silicon casting alloy is to be used for two different applications. In one case, the plate is 3 mm thick and the mechanical properties are considered unimportant. In the second case, the plate is 10 mm thick and strength should be optimised. In both cases cost should be minimised. Specify and justify appropriate compositions for the alloy to be used in the two different cases. Discuss what casting processes you would choose to manufacture 10,000 plates for each of the two applications, and briefly describe your chosen processes. [30%]

(b) GFRP plates are to be made in two forms. In the first, the cost must be minimised. In the second, the bending stiffness parallel to the edges is to be maximised, and the weight of the plate is to be minimised. Identify and justify materials and manufacturing processes for making 50 plates of each of these two forms. [20%]

(c) 1000 GFRP plates are to be manufactured for use in a high humidity area where the temperature fluctuates between -20° C and 100° C. Cost must be minimised, and there are no special mechanical property requirements. Discuss which materials and manufacturing processes could be used to make these plates. How might the plates degrade in this environment? [25%]

(d) The HDPE plates are 3 mm thick and are strengthened on the underside by HDPE reinforcing bars 5 mm thick and 10 mm in height. Briefly describe the manufacturing process you would choose. The application requires the top surface of the plate to be smooth and flat. What steps would you take to optimise the surface flatness, while still using HDPE? [25%]

4 (a) Define what is meant by the *equivalent diameter* in the heat treatment of steels. [10%]

(b) Figure 2 shows a stepped cylindrical steel component, composed of three parts. The two end pieces A and C each contain a cylindrical recess, and are joined by a solid shaft B. The design specifies that the minimum Vickers hardness of the component must lie between 340 and 420, with a minimum surface hardness of 500. The component is to be oil quenched and tempered to achieve the target properties.

(i) Three locations 1-3 are marked on the cross-sectional view in Fig. 2. Use the equivalent diameter correlations in Fig. 3 to determine which of these locations will govern the minimum hardness in the target specification. [30%]

(ii) Figure 4 shows the tempered hardness as a function of bar diameter for a steel, after oil quenching followed by a range of tempering treatments, all of duration one hour. Determine which tempering treatments are suitable for the component. [20%]

(c) The yield strength of heat-treatable aluminium alloys after extrusion and ageing depends on the shape of the component, the processing, and the alloy. Summarise the key parameters and characteristics of the geometry, the process history and the alloy composition and microstructure, and explain briefly how they influence the outcome. [40%]

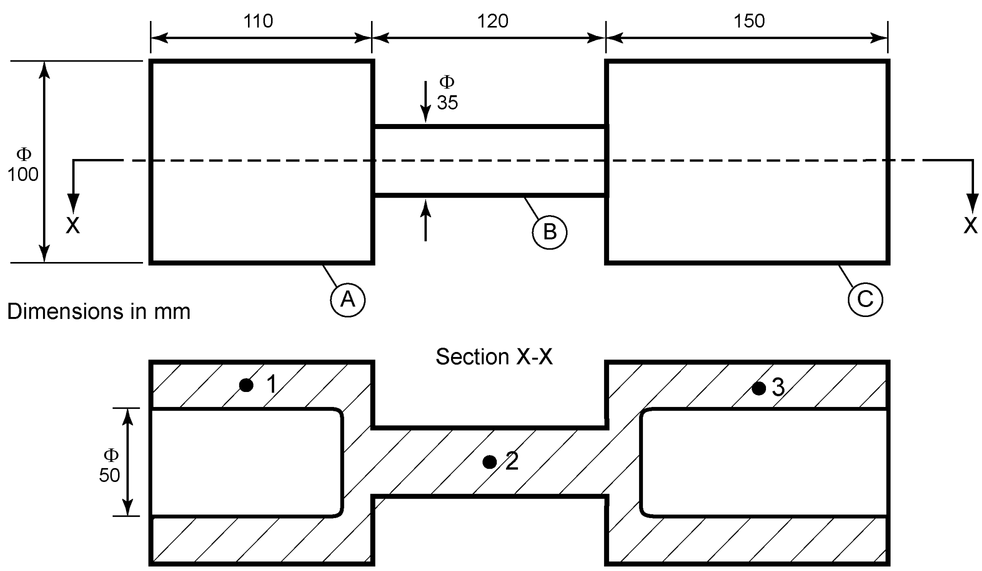
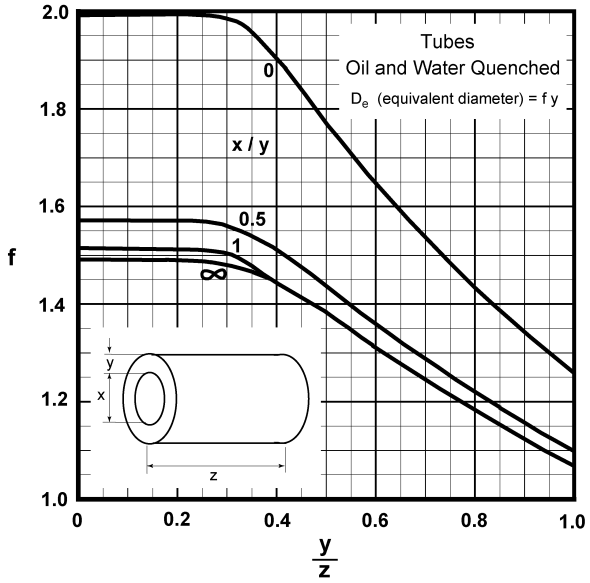


Fig. 2



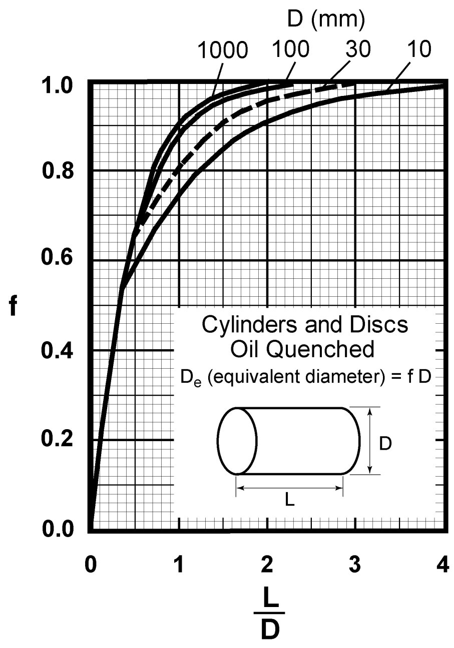


Fig. 3

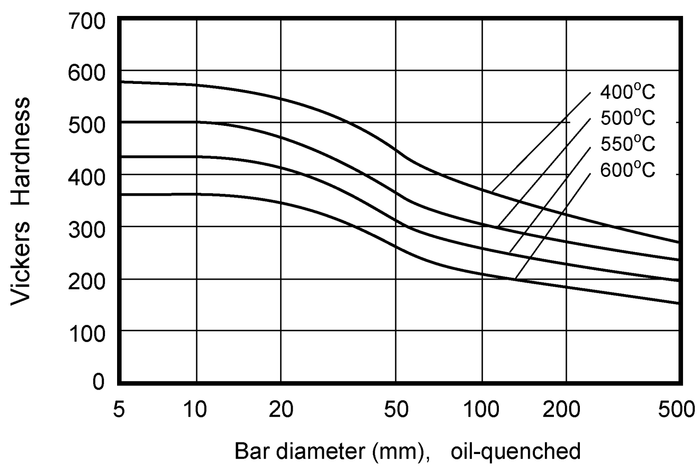


Fig. 4

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Answers:

1 (a) $p=2k \cot \theta$

2 (b) $T= -4.8^{\circ}C$

4. Location 3