EGT2
ENGINEERING TRIPOS PART IIA

Friday 26 April 2019 9.30 to 11.10

Module 3C1

MATERIALS PROCESSING AND DESIGN

*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
Engineering Data Book

10 minutes reading time is allowed for this paper at the start of the exam.

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

1 (a) A capstan is a cylindrical device for winding in ropes and lines on a yacht, using friction to reduce the force needed to hold or take in the rope. Figure 1 shows two suggested cross-sections for an aluminium capstan which is to be manufactured by sand casting.

(i) For both geometries, identify and explain where you would need to place the parting plane for this casting, and how the central hole could be made. Identify which of the two designs is preferable, giving reasons for your choice. [25%]

(ii) Both designs are 150 mm in height, with an average outer diameter of 110 mm. Estimate the solidification time t_s for the component using Chvorinov's rule:

$$t_s = C\left(\frac{V}{A}\right)^2$$

where V and A are the volume and surface area respectively, and the constant C for sand casting of aluminium has the value 1.0 s/mm^2. Outline two microstructural features that may be sensitive to the solidification rate. [20%]

(iii) It is suggested that a capstan of identical shape could be manufactured using hot forging. Outline potential advantages and disadvantages of this option, in comparison with sand casting. [25%]

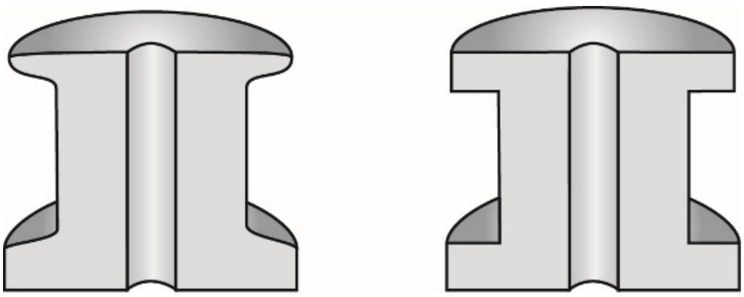

Fig. 1

(b) (i) Briefly summarise four potential advantages of additive manufacturing (AM) methods for producing components, compared to conventional processes. [20%]

(ii) With reference to a specific AM process, explain why in general the mechanical properties of AM components are inferior to those produced by casting or moulding. [10%]

2 (a) Figure 2 shows the plane strain cutting of a mild steel plate of thickness h. The in-plane dimensions of the plate are much larger than the thickness. Cutting occurs by pushing a prismatic, rigid wedge of triangular cross-section and apex half-angle of 45° into the plate at a speed v, as shown in the figure. At a given instant, the cut depth is d. The problem is to be analysed using the upper bound method, with plastic deformation assumed to be concentrated along the dotted lines shown in Fig. 2. The material shear yield stress is k.

(i) Assuming sticking friction between the plate and the rigid wedge, and frictionless conditions between the plate and the rigid support, derive an expression for the cutting force F per unit length of wedge. [40%]

(ii) Discuss the parameters that would influence the temperature rise in the mild steel plate, and its spatial distribution. [15%]

(iii) For the case of sticking friction between the plate and the wedge, *and* between the plate and the support, sketch an alternative pattern of plastic deformation that might be more likely to occur. Explain your reasoning. [15%]

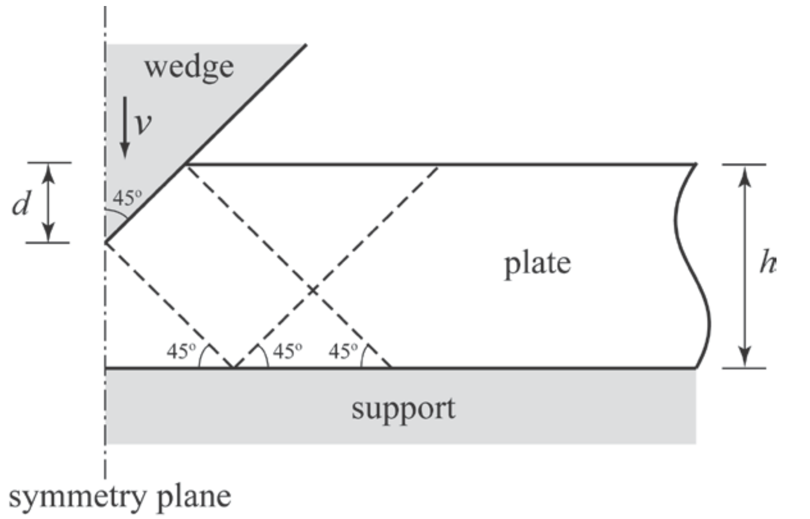

Fig. 2

(b) A container for outdoor use is to be made from mild steel plates of thickness 2 mm, assembled with the joints in a lap configuration.

(i) If the joints are made using mild steel bolts, explain why the joints may be susceptible to corrosion, outlining the expected mechanism. Show with sketches how the bolted joints may be designed to limit this corrosion problem. [20%]

(ii) Comment on possible advantages and disadvantages of assembling the container using fusion welding to make continuous seam welds. [10%]

3 The stepped component shown in side view in Fig. 3 is to be manufactured by uniaxial compaction of a high alloy tool steel powder. In plan view the component is square, with dimensions 40×40 mm. After shaping, the component is also given a heat treatment and a surface treatment.

(a) Explain, with sketches, why a two-part die set is required to achieve uniform compaction. [15%]

(b) After mould filling the powder has a packing density of 50 %. The finished component is considered to be of acceptable quality if it is compacted to a final porosity of 3 %. Find the dimensions of the filled cavity prior to compaction which will produce a uniform density throughout the part, stating any assumptions made. [20%]

(c) Two tool steels of different composition are being considered for the component.

(i) Both compositions include Mn, Cr and W. Explain the roles of these elements in tool steels. [20%]

(ii) Explain what is meant by *critical diameter*. The critical diameters of the first steel are 20 mm and 150 mm for air and oil cooling, respectively; for the second steel, the values are 40 mm and 220 mm. Select the best steel and cooling treatment, giving reasons for your choice. What subsequent heat treatment is required, and what is its purpose? [30%]

(d) The component is then electroplated with nickel. Explain why there is a risk of cracking in the component and identify where it may occur. What precautions could be taken to reduce the risk of cracking? [15%]

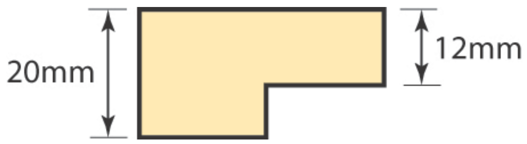

Fig. 3

4 (a) Table 1 lists four products, each of which is to be made from a *different polymer or elastomer*, drawn from the list in Table 2.

(i) Match each product to an appropriate polymer or elastomer and suggest a suitable shaping method, giving reasons for your choices in terms of product shape and key final properties. [60%]

(ii) In each case, explain how the stiffness of the material is influenced by the microstructure, noting any ways in which the outcome is influenced by the way the process is operated. [20%]

Products
Power tool housing
2 litre bottle for carbonated drink
Small gearwheels for child's toy
Food packaging film

Table 1

Polymers / Elastomers
LDPE
Nylon
PMMA
Polyester + 20% short glass fibre
PET
Natural rubber

Table 2

(b) A flat panel for aerospace application is to be manufactured from cross-ply long-fibre reinforced polymer. The panels are to be used for extended periods under variable stress loading in wet environments. Outline the types of damage that may develop, explaining any differences between GFRP and CFRP. [20%]

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