Version HRS/3

EGT2
ENGINEERING TRIPOS PART IIA

Thursday 28 April 2022 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 Books

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.

You may not remove any stationery from the Examination Room.

1 Figure 1 shows a plane strain extrusion process in which two rectangular billets are combined into one. Shear deformation is assumed to be concentrated on the two planes shown by dashed lines. The input billets are of thickness d, which is much less than the billet depth into the page. Both horizontal rams move at a speed v, and apply a force per unit depth F. The output billet emerges vertically at a speed v_o through a die of width $2\alpha d$, where α may be changed from die to die. The shear yield stress of the material is k.

(a) (i) Find an expression relating the input and output speeds, and draw a velocity diagram for a general value of α. [20%]

(ii) Use the upper bound method to find an expression for the force per unit depth, assuming that the dies are frictionless. Find the value of α that minimises the force required. [25%]

(iii) Explain how you would estimate the temperature rise ΔT in the output billet, stating any assumptions, and explain how ΔT will depend on α. In practice, would this estimate be more likely to be accurate for high or low values of α? Briefly describe how friction between the extrusion chamber and the billet would modify the analysis and the uniformity of the temperature in the output billet. [25%]

(iv) The process may also be operated with unequal inlet speeds. Without further analysis, comment on what you would expect to happen to the deformation geometry if the inlet speeds were unequal, with a fixed ratio. What would happen if the ratio was varied continuously? [10%]

(b) In industrial extrusion of heat-treatable aluminium alloys, explain how the temperature rise ΔT is used to positive effect in controlling the microstructure, and what problems may arise if the peak temperature is too low. [20%]

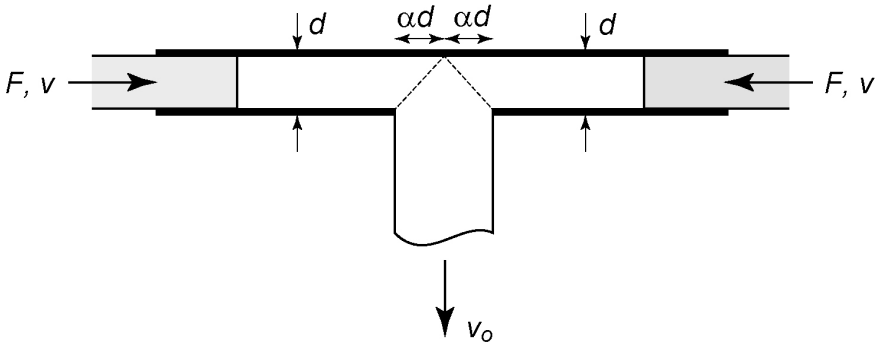

Fig. 1

2 (a) The performance of many manufacturing processes often depends on characteristics of the component geometry. One such characteristic is the aspect ratio, meaning the ratio of the greatest dimension to one or more smaller dimensions.

Consider the processing of a circular plate in the following situations:

(i) casting an Al-4wt% Si alloy;

(ii) cold forging a Cu-Ni alloy;

(iii) quenching a carbon steel prior to tempering.

In each case, identify the key influences of the radius to thickness ratio on the process physics, and explain a possible technical or quality problem, if this aspect ratio is high. Assuming that the component geometry cannot be changed, outline changes in material composition and/or processing conditions that can help to overcome the problems identified. [45%]

(b) The temperature gradient at the solid-liquid interface during casting can lead to one of two distinct regimes in microstructure evolution.

(i) With reference to the phase diagram, explain with appropriate sketches the physical basis for forming each type of microstructure. [25%]

(ii) What consequences may there be in each case for the formation of defects in the casting? [20%]

(iii) Identify two aspects of equipment design or processing conditions that would influence the temperature gradient, briefly explaining their effect. [10%]

3 (a) A cylindrical disc with variable section thickness has been made for a high-strength application. The material used was powdered alloy steel containing a high density of carbide particles. After cold pressing and sintering, the part was found to be distorted.

(i) Briefly explain why a powder method would be suitable for this material.

(ii) What is the likely cause of the distortion?

(iii) How could the problem be solved? [30%]

(b) Cracks are frequently associated with welds in steel structures. Describe four main causes of crack formation, and in each case discuss ways in which the likelihood of crack formation can be reduced. [40%]

(c) The interior of a carbon steel tank containing water may be protected against corrosion by adding chemicals to the water. These affect either the cathode reaction (cathodic inhibition) or the anode reaction (anodic inhibition). Outline how these two methods enable protection against corrosion. For both types of inhibition, explain the consequences if the concentration of the chemical falls below a recommended level. Which type of inhibition is most likely to result in unexpected failure? [30%]

4 (a) Recycling of polymers is being promoted for a range of reasons.

(i) Outline how mechanical recycling can be achieved, explaining the importance of the different steps involved. What are the main barriers to increasing the amount of effective recycling? [25%]

(ii) Looking specifically at the carbon footprint (energy consumption) aspects, explain why recycling of thermoplastics can be beneficial. [15%]

(b) Thermoplastic polymers can be affected by their environment in different ways, such as changing their appearance, shape and properties. For each of the following, briefly describe a practical situation in which each condition might arise, whether the environmental effects are reversible or irreversible, and how the effects might be mitigated:

(i) high temperatures;

(ii) chemicals in the environment;

(iii) ultra-violet light. [30%]

(c) The following articles are to be made from polymer composites:

(i) low-cost shower tray for domestic use;

(ii) large cylindrical vessel for use under pressure in chemical plant.

In each case, outline the manufacturing process and material you would choose, justifying your answers by making comparisons between alternative processes or materials. [30%]

END OF PAPER

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