MET2
MANUFACTURING ENGINEERING TRIPOS PART IIA

Thursday 25 April 2024   9.00 to 10.40

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
8 page answer booklet x2

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 A steel component with a stepped profile in its top face is to be forged from a long rectangular billet. The cross-section of the dies and billet at the start of forging are shown in Fig. 1, with an assumed set of slip planes for upper bound analysis. Assume that the upper die descends at a speed $4v$, the forging load per unit depth into the page is F, and the shear yield stress of the steel is k.

(a) Comment briefly on the advantages and disadvantages of undertaking this operation at elevated temperature. [10%]

(b) For the two limiting cases of zero friction and sticking friction between the dies and the billet, find the forging load for two deformation patterns in which, relative to the lower die:

(i) block A remains stationary;

(ii) block B remains stationary.

Hence identify the likely deformation mechanisms for low and high friction. Do you expect the cavity in the die to fill completely in each case? [70%]

(c) A particular forging, with an intermediate level of friction between dies and billet, has reached the point at which the upper die has moved a distance $h/2$, and the cavity in the upper die is half-filled. Find the dimensions of the flash that has formed at this point between the two dies, and sketch an updated set of slip planes for this geometry. Further analysis of the forging load is *not* required. Use your sketch to explain how the formation of the flash helps to ensure that the cavity in the upper die fills completely. [20%]

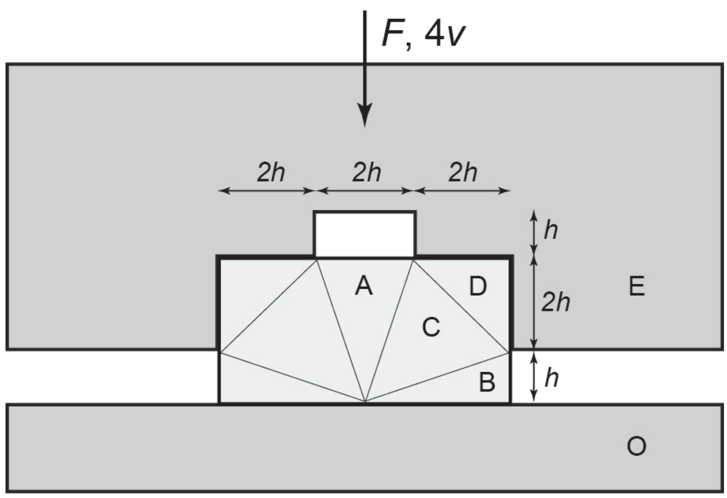

Fig. 1

2 (a) For each of the following examples of a process and material being used in the manufacture of the specified part, discuss why the process physics make this an unrealistic choice, considering technical or economic considerations, as appropriate. In each case, suggest a more suitable process to achieve the desired outcome.

(i) gravity die casting, for polyester-glass fibre canoes;

(ii) investment casting, for stainless steel razor blades;

(iii) hot isostatic pressing, for ceramic teapots;

(iv) induction hardening, for mild steel lawn mower blades;

(v) thermal spraying, for quenched and tempered alloy steel cutting tools. [60%]

(b) Figure 2 shows the cross-section of a prismatic nylon part, 0.5 m in length, that is fitted over an aluminium rail, and held in place with a small number of screws, in the position shown. It is part of an antique manual knitting machine, and the top surface acts as a lightly loaded bearing surface for the main sliding mechanism of the machine. The original part had become discoloured and contained multiple cracks, and needs to be replaced.

(i) What are the likely reasons for failure of the part?

(ii) By discussing the technical, quality and economic factors to consider in making a replacement part, comment on the suitability of injection moulding and additive manufacturing as alternative solutions. [40%]

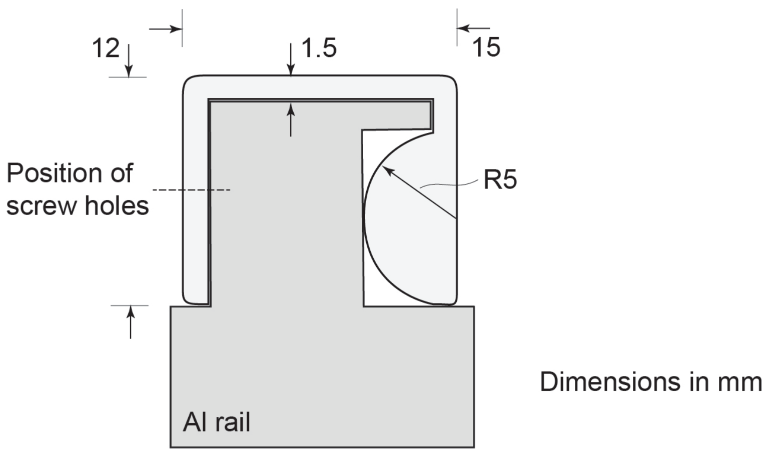

Fig. 2

3 (a) For the following materials and processing outcomes, explain the role of grain size. In each case, briefly describe the process physics that determines the evolution of the grain size during the relevant process, and identify the key process variables that can be manipulated to change the outcome. For (i) and (iii) outline a compositional change or additive that can positively influence the outcome.

(i) segregation and macroporosity in a cast Al-Si ingot;

(ii) strength and formability of a hot rolled and annealed low carbon steel;

(iii) fracture toughness of an arc welded structural carbon steel. [65%]

(b) The drive to increase the recycled fraction in wrought aluminium alloys results in a higher content of impurities, such as iron and silicon. These elements form intermetallic particles and dispersoids during casting and homogenisation. Discuss how the resulting microstructure and properties may differ in a high recycled fraction alloy, compared to the current virgin material, for:

(i) hot rolled and annealed non-heat-treatable Al alloys;

(ii) extruded, quenched and artificially aged heat-treatable Al alloys. [25%]

(c) The growth in production of electric vehicles will lead to a large stockpile of end-of-life Al-Si engine blocks, which are currently recycled into new IC engines. Explain briefly why only a small proportion can be used in recycled wrought Al products. [10%]

4 (a) Joining processes may be categorised into three classes: Mechanical, Welding and Solid-State. Describe briefly how each class may be further sub-divided, identifying the physical distinctions between the sub-classes. [15%]

(b) Apart from compatibility with the material (or materials) in the joint, what are the other two primary criteria to consider in choosing a suitable joining process? Use sketches to illustrate your answer. Give an example of a joint in which these two criteria interact to determine the suitability of a process. [15%]

(c) The choice of joining process must also consider other secondary technical design requirements. For the joining scenarios below, suggest a suitable process, and give examples of primary and secondary technical requirements that will have been critical in the choice of that process:

- (i) MDPE gas pipes, in a trench beside a pavement;
- (ii) gold interconnects in printed circuits;
- (iii) tubular steel climbing frames, with adjustable height and accessories. [30%]

(d) Steel products are susceptible to corrosive failure by a number of mechanisms. Identify the likely cause of failure in the following scenarios:

- (i) collapse of a mild steel lamp-post embedded in concrete;
- (ii) fracture of a heavy duty Zn-plated wheel bolt made of carburised steel;
- (iii) surface pitting and cracking close to a weld in stainless steel;
- (iv) pitting and leakage of a storage tank containing sewage sludge. [40%]

END OF PAPER

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