ENGINEERING TRIPOS PART IIA
MANUFACTURING ENGINEERING TRIPOS PART IIA

Tuesday 1 May 2012 9 to 10.30

ENGINEERING TRIPOS PART IIA
Module 3C1: MATERIALS PROCESSING AND DESIGN

MANUFACTURING ENGINEERING TRIPOS PART IIA: Paper 1
Module 3P1: MATERIALS INTO PRODUCTS

*Answer not more than **three** questions.*

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

There are no attachments.

STATIONERY REQUIREMENTS
Engineering Tripos:
Single-sided script paper

Manufacturing Engineering Tripos:
20 page answer booklet, rough work pad

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

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

Final version

1 (a) Support rails for seating in a sports arena are made from low carbon steel, with the cross-section shown schematically in Fig. 1. The thickness of the section is 10 mm throughout. The rails are of variable length, between 1 and 5 m, and are manufactured by shaped-section rolling from an initially rectangular ingot. Briefly describe the process of shaped-section rolling, using a sketch to illustrate an arrangement of rolls suitable for the production of this shape. [15%]

For each of the following processes and materials, briefly state two reasons why they would not be suitable alternatives to shaped-section rolling of a low carbon steel for this application:

(i) sand cast bronze;

(ii) three low alloy steel strips, joined by arc welds to form the shape. [30%]

(b) Fig. 2 shows a plane strain deep-drawing operation. Details of the deformation region within the die of length $2t$ are shown in the enlarged inset figure, with a proposed pattern of deformation for analysis by the upper bound method. Sticking friction occurs between the die and the workpiece. No friction acts on the interface between the punch and the workpiece. The shear yield stress of the workpiece material is k and the punch moves at a velocity v.

(i) Use the upper bound method to find the punch force, F, per unit depth normal to the figure, in terms of t and k.

(ii) Calculate the resulting tensile stress in the material leaving the die, and comment on your result. [55%]

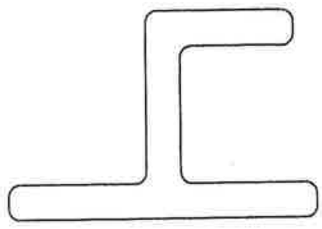

Fig. 1

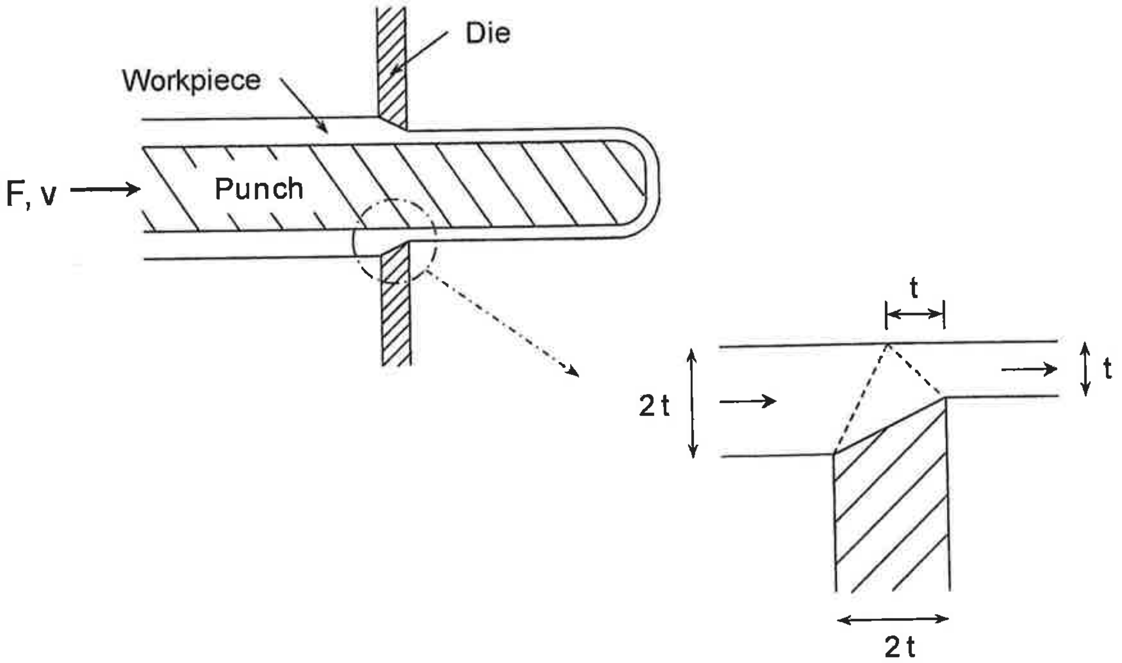

Fig. 2

2 (a) Chvorinov's rule states that the solidification time of a casting with volume V and surface area A is proportional to $(V/A)^2$. For each of the following shapes, find a simple expression for $(V/A)^2$, stating any approximations:

(i) a sphere of radius R;

(ii) a cylinder of radius R, and length $L = 20R$;

(iii) a rectangular plate of dimensions $L \times 10L \times 100L$.

Comment on the results and compare them with the predictions from a simple heat diffusion model. In what respects is Chvorinov's rule analogous to the concept of the *equivalent diameter* in the heat treatment of steel? [40%]

(b) Explain the following observations and identify the underlying physical principles in each case:

(i) the grain size in an Al alloy casting is reduced by adding TiB_2 powder to the melt before casting;

(ii) the grain size in an Al alloy component which has been hot-forged after prolonged homogenization depends on its Mn and Cr content;

(iii) addition of a small amount of Mg to cast iron increases its strength and ductility;

(iv) the insertion of metal blocks in the mould wall at a critical cross-section in a sand casting eliminates macroporosity in that section. [60%]

3 (a) Describe the process of injection moulding for thermoplastic polymers. Briefly discuss the importance of the following variables in this process, for both semi-crystalline and amorphous thermoplastics:

(i) injection pressure;

(ii) hold-on time;

(iii) mould temperature. [30%]

(b) Explain how the following can originate in an injection-moulded thermoplastic product:

(i) molecular chain alignment;

(ii) residual stresses. [20%]

(c) Explain, with one example in each case, why in a thermoplastic product:

(i) molecular chain alignment might be desirable;

(ii) residual stress might be undesirable. [20%]

(d) For each of the following cases, suggest a possible reason for the degradation observed, and indicate how this might be avoided by changes in design, materials selection or materials processing conditions:

(i) a food mixer bowl, injection-moulded from an amorphous thermoplastic, progressively developed many fine cracks on its inner surface after use, one of which eventually grew to cause gross fracture;

(ii) a wind turbine blade, fabricated mainly from a glass-fibre/epoxy composite and exposed to thermal cycles and wet conditions, exhibited a progressive loss of stiffness;

(iii) the housing of a light fitting, mounted on the outside of a building, was made from a translucent thermoplastic polymer, and after several years exposure showed surface discoloration and cracking. [30%]

4 (a) Briefly describe the process steps involved in the production of a small steel component, with a tempered martensitic structure, by a conventional powder metallurgy (PM) process involving a uniaxial pressing operation. Explain the role of each of the raw materials used in the process. What are the disadvantages of the PM route in comparison with machining from bar stock? [40%]

(b) What steps could be taken to achieve uniform properties throughout a complex-shaped component made by PM in a uniaxial press? [20%]

(c) For each of the following components, describe the particular features of the PM manufacturing route which would be needed to achieve the required properties:

(i) a high-strength gear made from medium-carbon steel (0.5 wt% C);

(ii) a high-porosity gas filter, with 40% interconnnected porosity by volume, with a narrow range of pore sizes, made from bronze (copper – 10 wt% tin).

For component (i), how might the manufacturing route be modified to achieve higher strength in the gear teeth? [40%]

END OF PAPER

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Numerical answers

Question 1. (b) (i) $F = 6.33\ kt$ (ii) tensile stress = $3.17\ k$