ENGINEERING TRIPOS PART IIA
MANUFACTURING ENGINEERING TRIPOS PART I

Wednesday 30 April 2008 9 to 10.30

ENGINEERING TRIPOS PART IIA: Module 3C2
MANUFACTURING ENGINEERING TRIPOS PART I: Paper P4B

MATERIALS PROCESS MODELLING AND FAILURE ANALYSIS

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.*

There are no attachments.

STATIONERY REQUIREMENTS	SPECIAL REQUIREMENTS
Engineering Tripos:	Engineering Data Book
Single-sided script paper	CUED approved calculator allowed

Manufacturing Engineering Tripos:
20 page booklet, rough work pad

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

Version 4

1 Figure 1 shows a section through a lateral extrusion process, in which two opposed rams move towards each other at speed v. The process has depth (into the page) D, and is assumed to operate in plane strain. The workpiece material is assumed to obey the rigid-plastic assumption, with yield stress in shear of k. Friction between the workpiece and the stationary die is assumed to be of the sticking type and applies at all sliding contacts between die and workpiece.

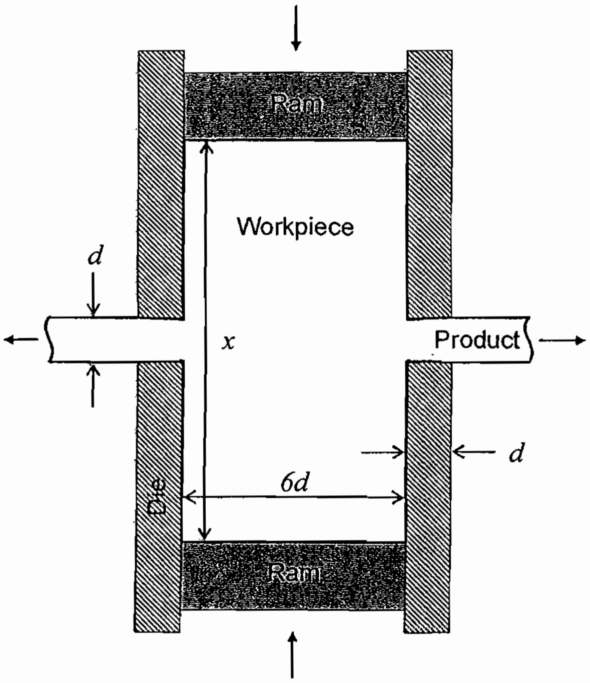

Fig. 1

(a) Identify any symmetric features of this design, and describe the implications of this for the flow of material. [15%]

(b) By postulating a suitable compatible mechanism, derive an upper bound estimate of the ram forces P when the separation of the two rams is x. [35%]

(c) Derive a formula for the time history of the workpiece temperature as the rams both move at constant speed v from initial separation $10d$ to final separation d.

Make the following assumptions: all work done by the two rams is converted into heat energy; the workpiece conducts heat instantaneously so is always at a uniform temperature; the workpiece is initially at temperature T_0 ; the workpiece has a volumetric heat capacity of $\rho\, c_p$; the product is just emerging from the outer surface of the die as the process begins. [35%]

(d) Briefly discuss any practical difficulties in designing the equipment for this process. [15%]

2 (a) What are the potential benefits and limitations of using mathematical models to analyse industrial thermal and mechanical processes? [40%]

(b) The following methods can be used to protect mild steel against corrosion from water: cathodic inhibition; anodic inhibition; galvanising; coating with polythene.

For each method, explain how the protection works, and discuss the advantages and disadvantages of the method. [40%]

(c) Explain which corrosion protection methods would be suitable for protecting:

(i) a tank used for supplying drinking water;

(ii) a domestic central heating system. [20%]

3 (a) The cooling rate in thermal processing of steels may be characterised by the time taken for cooling between 800°C and 500°C, $\Delta t_{8\text{-}5}$. Explain briefly the physical basis for this choice, and distinguish between its relevance in heat treatment and welding of steels. [10%]

(b) A large steel plate of thickness $2l$ at uniform temperature T_1 is quenched into water at a temperature T_0. If perfect heat transfer is assumed, the temperature transient at mid-thickness in the plate at time t is given by

$$T(t) = T_0 - (T_1 - T_0) \sum_{\substack{n=1 \\ n\,odd}}^{\infty} \frac{4}{n\pi}(-1)^{(n+1)/2} \exp\left(-n^2 \pi^2 at/4l^2\right)$$

where a is the thermal diffusivity of the material.

(i) The solution is well-approximated by the first term in the series, provided $t \geq C(l^2/a)$, where C is a numerical constant. Find the value of C such that the error produced by ignoring all terms after the first is less than 1%. Hence find the corresponding dimensionless temperature when t reaches the value of $t \geq C(l^2/a)$.

(ii) Assuming that this approximation holds, derive an expression for the time to cool from 800°C to 500°C at the centre of the plate. [35%]

(c) For quenching of heat-treatable aluminium alloys extrusions, the time for cooling between 400°C and 300°C, $\Delta t_{4\text{-}3}$, would be the equivalent cooling parameter.

(i) Does the same criterion still apply for the first term of the solution for perfect heat transfer to give an error of less than 1% compared to the full solution?

(ii) An extrusion is quenched to an ambient temperature of 20°C. Calculate the minimum initial temperature prior to quenching in order for the approximate solution to be valid from a temperature of 400°C onwards.

(iii) Assuming the initial temperature exceeds this value, write down an expression for $\Delta t_{4\text{-}3}$. [30%]

(d) The components listed below are quenched from a uniform initial temperature T_l into a medium at ambient temperature T_o. Using suitable axes of dimensionless temperature against dimensionless time, sketch on a single graph the shape of the cooling curves at the centre of the components, for the following:

(i) a large plate of thickness $2l$ with perfect heat transfer;
(ii) a sphere of diameter $2l$ with perfect heat transfer;
(iii) a large plate of thickness $2l$, air-cooled.

Comment on the relative importance of component shape and surface heat transfer in determining the cooling rate at the centre of the component. Explain why the surface cooling history in case (iii) is essentially the same as that at the centre. [25%]

4 Explain the following observations.

(a) A seat for a rowing boat was made from a plate of age-hardened Al-4%Cu alloy which was bent to shape. It failed rapidly after the boat was used in the sea. [25%]

(b) Aluminum cooking foil is easily torn, whereas polythene film of the same thickness is very tough. [25%]

(c) Two samples of low-alloy ferritic steel had identical chemical compositions but different grain sizes, and were subjected to the same heat treatment and service conditions. One sample failed prematurely and suddenly in service at 300°C, producing a fracture surface which sparkled and showed no necking. The other sample was taken out of service at the same time and tested. The material failed by ductile fracture at the design stress. [25%]

(d) A glass shelf under load suddenly failed under damp conditions. [25%]

END OF PAPER

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