Version HRS/4

MANUFACTURING ENGINEERING TRIPOS PART IIA

Thursday 26 April 2018 9.10 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
20 page answer booklet
Rough work pad

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) Give a brief physical explanation of why the yielding of metals is dependent on the deviatoric stress, but insensitive to the hydrostatic stress. Justify qualitatively the dependence of the Tresca and von Mises yield criteria on the principal stress differences: $\sigma_1 - \sigma_2$, $\sigma_2 - \sigma_3$ and $\sigma_3 - \sigma_1$. [20%]

(b) A plane strain rolling process reduces the thickness of a metal strip from h_1 to h_2 using a pair of rollers of radius R, as shown in Fig. 1. The width of the roll bite is $2w$. A tensile back stress of $\sigma_b$is applied at the inlet, opposing the direction of material motion. The Tresca yield criterion can be assumed.

(i) Sketch the expected variation through the roll bite of the normal pressure p acting between the roller and the strip. Assume Coulomb friction acts between the strip and the rollers, with shear stress τ and coefficient of friction μ. Briefly explain the shape of the curve. [20%]

(ii) What are the rolling pressures required at the inlet and exit of the roll bite to ensure that the material is yielding? State any assumptions. [15%]

(c) A forging analogy for the rolling problem in part (b) is sketched in Fig. 2.The neutral plane is a distance A from the left hand end of the strip. The compressive stress in the horizontal direction is σ_x. Horizontal equilibrium of a small element of width dx at a distance x from the neutral plane requires that:

$$\frac{d\sigma_x}{dx} = -\left(\frac{4\mu}{h_1 + h_2}\right)p \quad (\text{for } x > 0), \qquad \frac{d\sigma_x}{dx} = \left(\frac{4\mu}{h_1 + h_2}\right)p \quad (\text{for } x < 0)$$

(i) Derive equations for the pressure $p(x)$, for both $x > 0$ and $x < 0$. [20%]

(ii) Hence find an expression for the position of the neutral plane, A. [15%]

(iii) What determines the maximum value of the back stress σ_b in this process? [10%]

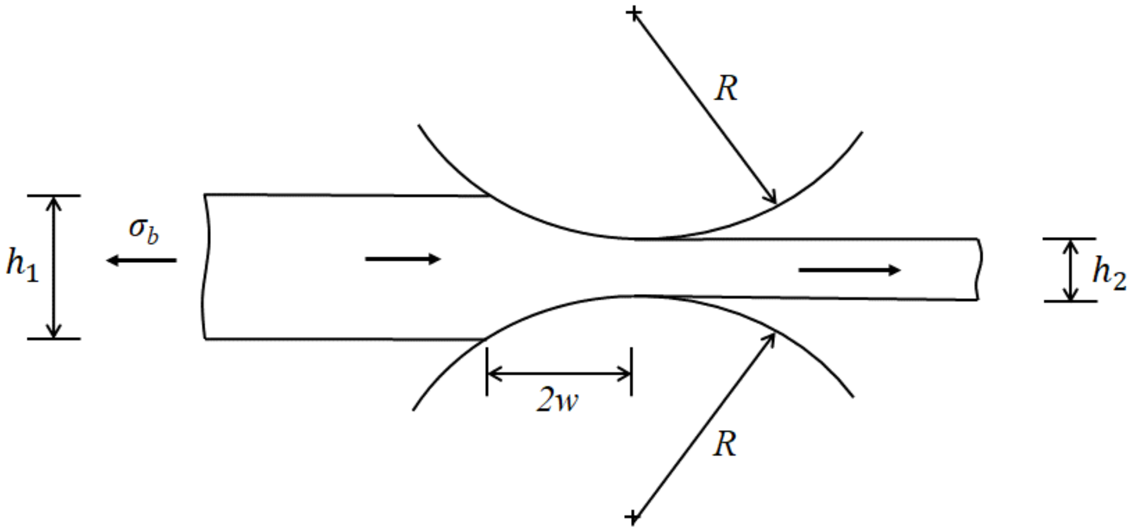
R
σ_b
h_1
h_2
2w
R

Fig. 1

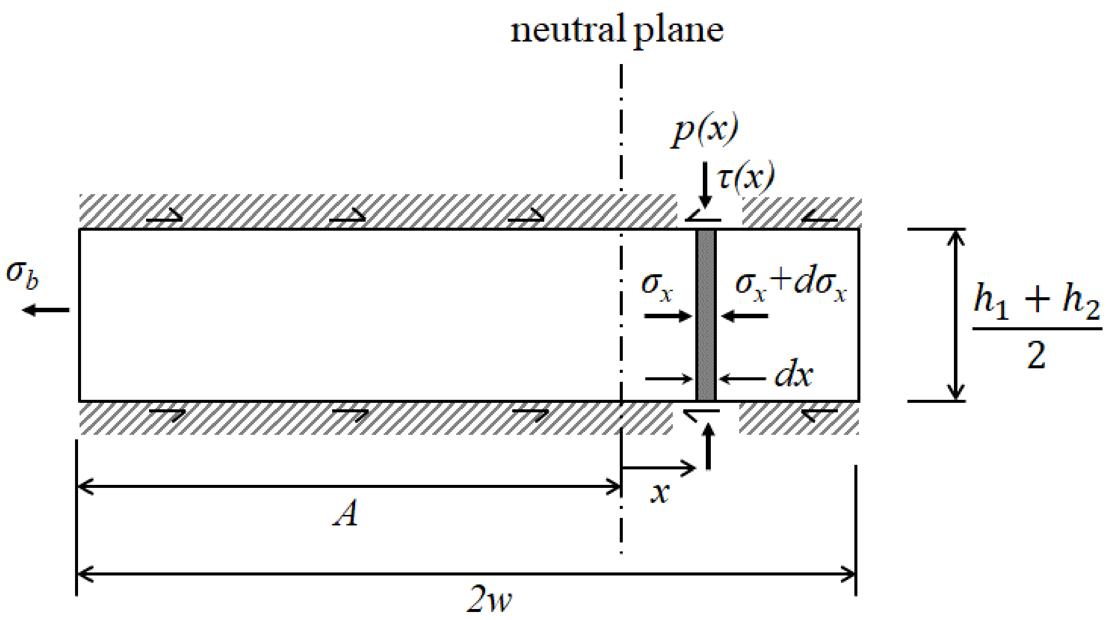
neutral plane
p(x)
τ(x)
σ_b
σ_x
$\sigma_x + d\sigma_x$
dx
$\frac{h_1 + h_2}{2}$
x
A
2w

Fig. 2

2 (a) Outline the difference between *permanent mould* and *permanent pattern* methods for shaped casting. Give one example of each method, and explain briefly which method is more appropriate for large parts, and which for large production runs. [30%]

(b) (i) Sketch and annotate the relevant part of a binary phase diagram to define the meaning of the *partition coefficient*, *k*. Sketch the expected variation of concentration with distance from the mould wall, illustrating the initial transient and the steady state regime, and marking key values of the concentration. [30%]

(ii) Identify two variables of the casting process that influence the temperature gradient in the liquid close to the solid-liquid interface during solidification. Explain why, in the steady state regime, two distinct grain structures may form, depending on the magnitude of this temperature gradient. Explain which of these two microstructures is preferable in terms of minimising macroporosity. [30%]

(iii) Briefly outline two modifications that may be made to alloy compositions prior to casting in order to control macroporosity. [10%]

3 (a) Welds are often associated with loss of performance or failures in metals. For each of the following situations in welding, describe what problem is being addressed, and explain how the suggested material choice or post-welding process counters the problem:

(i) choice of a naturally aged heat-treatable aluminium alloy instead of a cold rolled non-heat-treatable aluminium alloy of comparable strength; [15%]

(ii) choice of an austenitic stainless steel containing Ti or Nb; [15%]

(iii) post-weld heat treatment of medium carbon steel; [15%]

(iv) post-weld grinding of a butt weld; [15%]

(v) post-weld hammer peening of the weld. [15%]

(b) Laser hardening and physical vapour deposition of TiN are being considered as two alternative surface treatments for a low alloy steel component. What is the intended function of both these treatments? With reference to relevant processing temperatures in each case, comment on whether the near-surface microstructure and properties will be sensitive to whether the steel is initially in a normalised condition or a quenched and tempered condition. [25%]

4 (a) Explain the significance of *polymer chain alignment* in products made from thermoplastic polymers, with particular reference to the processes used in the manufacture of bottles, fibres and thin films. How is such alignment achieved in these manufacturing processes? [30%]

(b) Long bars of variable length with a square section of width 10mm are to be made from HDPE. Which manufacturing process would be appropriate, and why? What problems might be encountered with achieving the desired shape and dimensional accuracy, and how might they be addressed? [25%]

(c) A further set of long bars of variable length with a square section of width 10mm are to be made from long fibre GFRP with a thermosetting resin. Which manufacturing process would now be used? How does this process ensure good axial strength and stiffness? To which failure mechanism would the bars be most susceptible? [15%]

(d) An assortment of the HDPE and GFRP bars is available to make a frame to support a fabric sheet as a temporary shelter. The bars need to be joined end-to-end and into T-joints. Comment on the technical suitability of the following joining processes for assembling this frame:

(i) hot plate welding; [10%]

(ii) adhesive bonding; [10%]

(iii) press-fitting into custom-shaped aluminium joint pieces. [10%]

END OF PAPER

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