ENGINEERING TRIPOS PART IB

Tuesday 2 June 1998 9 to 11

Paper 3

MATERIALS

Answer not more than **four** *questions.*

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

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1 (a) Each leg of the front forks of a bicycle can be modelled as a solid cantilever beam of cylindrical cross-section subjected to a lateral force F as shown in Fig. 1. During use it is anticipated that the front forks of the bicycle, which are 40 cm long, will be subject to a maximum force of 2 kN and that a deflection of up to 5 mm is tolerable. Derive a performance index $M1$ for the selection of a minimum-mass material if the forks are to provide the required stiffness. [5]

(b) Another criterion is that the forks should not fail under the given applied load. Derive a second performance index $M2$ for the selection of minimum-mass material which avoids failure. [5]

(c) Use your performance indices to identify the most suitable material for the fabrication of bicycle forks from those listed in Table 1. Hence determine the minimum mass of forks made from this material, explaining carefully the reasons behind your choice. [5]

(d) Discuss briefly two other factors that influence the choice of material for the fabrication of bicycle forks. [5]

You may assume that the following relationships are valid for the arrangement shown in Fig. 1:

$$\sigma = \frac{F\,L\,r}{I}; \qquad I = \frac{\pi\, r^4}{4}; \qquad \delta = \frac{F\,L^3}{3\,E\,I};$$

where σ is the maximum bending stress in the beam, δ is the deflection at the beam tip, L is the length, r is the radius, I is the second moment of area and E is Young's modulus of elasticity of the material.

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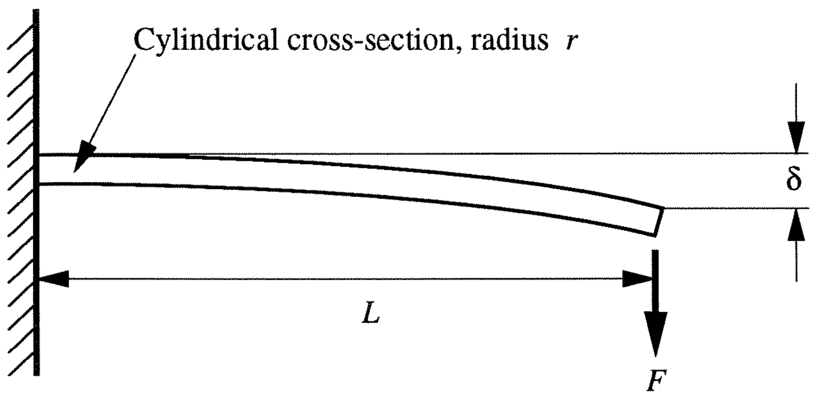

Fig. 1

Material	**Density,** ρ **(kg m^{-3})**	σ_f **(MPa)**	***E*** **(GPa)**
Nylon	1100	80	4
CFRP	1600	1000	100
Aluminium Alloy	2700	600	70

Table 1

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2 (a) Describe briefly the factors which determine the hardness of plain-carbon steels. Give examples to support your observations. [5]

(b) Figure 2 shows schematic diagrams of the microstructure of four iron-carbon alloys at room temperature. Alloys (ii) and (iii) have identical composition which differs from alloys (i) and (iv). Suggest the approximate carbon content of these steels and rank the microstructures in order of decreasing hardness, briefly explaining your reasons. State the names of the phases and microstructures in each case. [5]

(c) Describe briefly how TTT diagrams are used to map the microstructure formation in plain-carbon steels. Hence explain the formation of the microstructures (ii) and (iii) shown in Fig. 2. In each case discuss the effect of changing the hold temperature on the structure and properties of the steel. [6]

(d) Identify a type of steel suitable for the manufacture of railway track. By referring to the microstructure and properties of this steel, describe briefly why it is well suited to this application. [4]

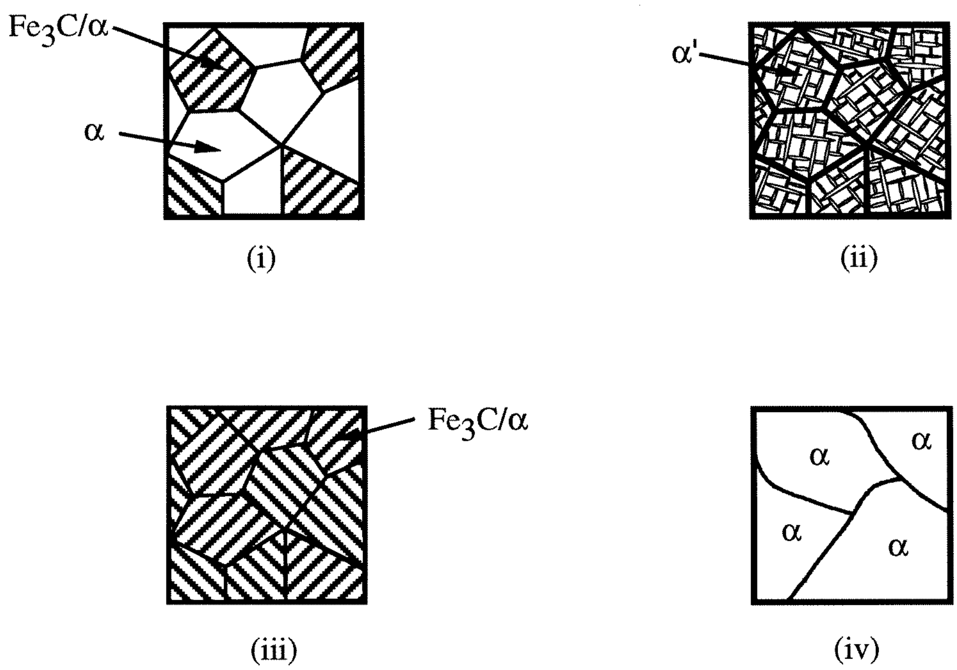

Fig. 2

3 (a) Figure 3 shows the phase diagram for the lead-tin system. Identify the following features on a sketch of this diagram: (i) single-phase regions; (ii) solidus lines; (iii) liquidus lines; (iv) solvus lines and (v) the eutectic point. Explain carefully the meaning of each of these terms. [6]

(b) Define the parameters C_α and C_β at either end of the tie line indicated on the figure. Hence derive the lever rule for a two-phase alloy and explain how it is used to determine the weight fraction of one particular phase in an alloy of known net composition at a given temperature. [6]

(c) Using Fig. 3, identify the phases present for a 40 wt % Sn and 60 wt % Pb alloy at 150°C and determine their compositions. Calculate the relative amount of each phase present in this alloy in terms of its mass fraction. [6]

(d) Pb-Sn alloy is used for soldering electronic components. Identify the composition of this alloy and explain why it is particularly suitable for this application. [2]

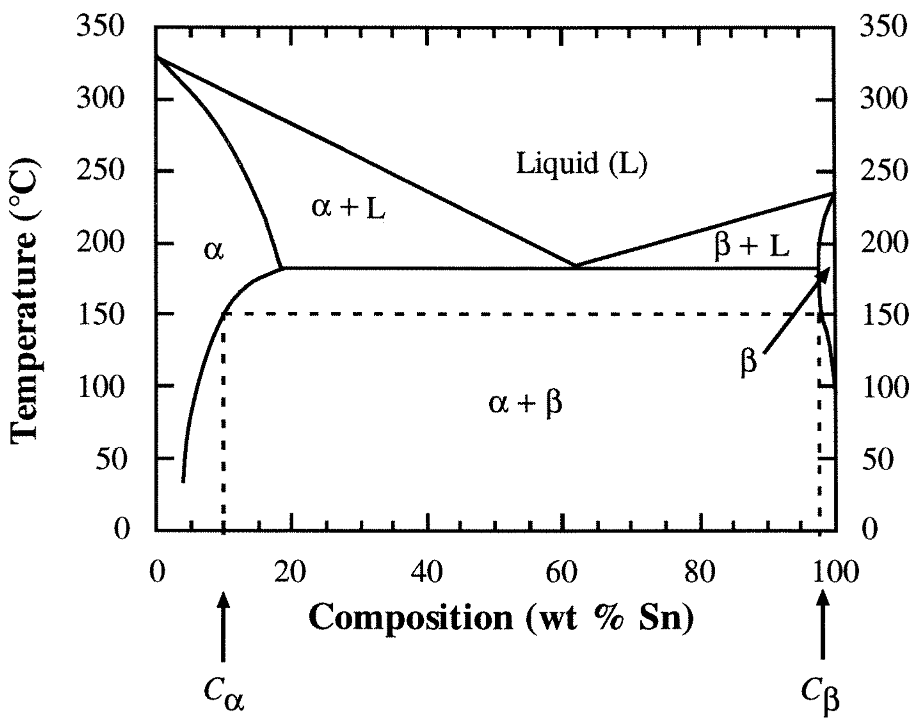

Fig. 3

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4 (a) Aluminium alloys can be divided into two groups, *wrought* and *cast*. Outline the essential differences between these types of material. [4]

(b) Describe carefully how some aluminium alloys can be hardened by heat treatment. Your answer should include a sketch of the variation of yield stress or hardness with logarithm of ageing time for a hardenable aluminium alloy at constant temperature. [6]

(c) Discuss the relative potential of wrought and cast aluminium alloys for hardening by heat treatment. Illustrate your discussion with examples. [6]

(d) Account briefly for the following: [4]

(i) 2000 series aluminium alloy rivets must be refrigerated before use;

(ii) the strength of structures fabricated from 5000 series aluminium alloy can decrease significantly when welded.

5 (a) The Weibull equation for the probability of survival $P_s(V_0)$ of a brittle solid specimen under constant applied tensile stress σ is; [6]

$$P_s(V_0) = \exp\left\{-\left(\frac{\sigma}{\sigma_0}\right)^m\right\}$$

where V_0 represents the overall volume of the test specimen. Explain the significance of the reference strength σ_0 and Weibull modulus m in this equation and outline how these parameters can be determined experimentally.

(b) Account briefly for the difference in survival probability of test specimens of a given ceramic for tensile and bending modes of loading. [4]

(c) Laboratory measurements of the strength of ceramics are commonly performed by axial-tension or 4-point bend tests on a beam of length ℓ, breadth b and depth d, as illustrated in Fig. 4. Show that the strength of a test specimen of rectangular cross-section loaded in 4-point bending exceeds that loaded in axial tension by a factor of $[2(m+1)]^{1/m}$. Sketch the variation of this function with m. [Assume that the bending moment is constant between the reinforced end supports.] [6]

(d) 50% of toughened silica glass rods of geometry 5 mm × 5 mm × 20 mm fail in 4-point bend tests at an applied maximum stress of 214 MPa. Determine the probability of survival of 10 mm × 10 mm × 50 mm rods of this material in service if they are required to withstand an axial tensile stress of 30 MPa. Assume $m = 5$ for silica glass. [4]

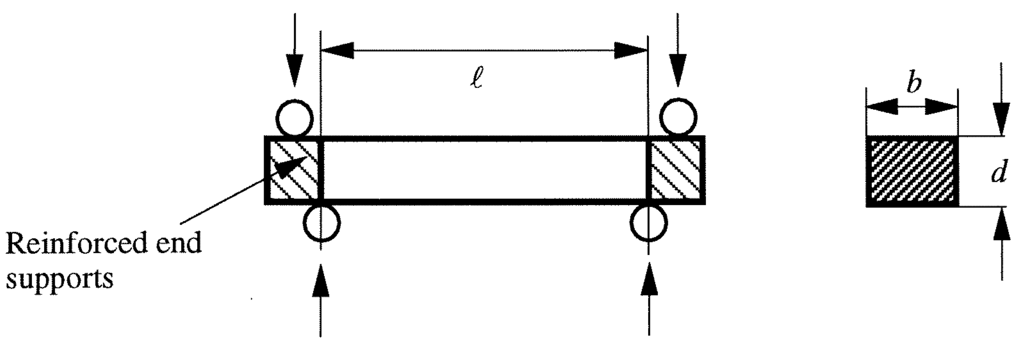

Fig. 4

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6 (a) Explain the origin of the glass transition in thermoplastics. Describe carefully the mechanical properties of thermoplastics above, below and in the vicinity of their glass transition temperature, T_g. [6]

(b) The relaxation of a polymer subjected to an instantaneous step-wise tensile strain can be represented by the mechanical analogy of a spring of modulus E (for which $E = \sigma / \varepsilon$) in series with a linear dashpot of damping constant η (for which $\eta = \sigma / \dot{\varepsilon}$), as shown in Fig. 5. Explain carefully how this arrangement can be used to describe the mechanical properties of a polymer. Describe the sequence of operation when a constant stress σ is applied, maintained for t seconds and then suddenly removed. Illustrate your answer with sketches of stress and total strain ε versus time. [6]

(c) Derive a differential equation for the total strain generated in the spring/dashpot arrangement shown in Fig. 5. [2]

(d) A tensile force of 500 N applied to a 5 mm × 5 mm × 500 mm rod of an unknown polymer under test causes it to extend instantaneously to 508 mm. The force is maintained for two days after which time the rod has elongated further to 570 mm. Determine the parameters E and η of the mechanical analogue of the polymer, assuming it may be modelled by a spring and dashpot in series. Hence identify thermoplastics and thermosets that may form the subject of the test. Explain which of these is the more likely candidate. [6]

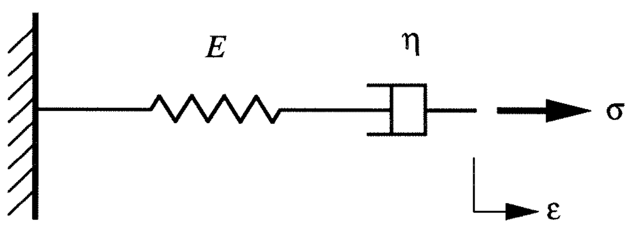

Fig. 5

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