ENGINEERING TRIPOS PART IB

Tuesday 6 June 2006 9 to 11

Paper 3

MATERIALS

Answer not more than ***four*** *questions, which may be taken from either section.*

All questions carry the same number of marks.

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

Answers to questions in each section should be tied together and handed in separately.

There are no attachments to this paper.

STATIONERY REQUIREMENTS
Single-sided script paper

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

SECTION A

1 (a) Explain what is meant by a binary alloy. Define the following features of the phase diagram of a binary alloy: (i) solidus line; (ii) liquidus line; (iii) eutectoid point; (iv) eutectic point. Give examples of each feature, using sketches to support your answers where appropriate. [6]

(b) Describe the lever rule for a two-phase region, $\alpha + \beta$, in the phase diagram of a binary alloy. Using the lever rule, derive equations for the mass fractions, W_α and W_β, of each phase in a two phase region for a binary alloy at a given constitution point, in terms of the concentrations of the alloy and of the two phases involved. [6]

(c) Identify the phases present at a constitution point of 30 wt. % Sn, 70 wt. % Pb and 200 °C for a lead-tin binary alloy using the phase diagram in Fig. 6.2 of the Materials Data Book. Determine the compositions of these phases and calculate the relative amount of each phase present in terms of its mass fraction. Explain briefly the significance of using a *% weight* scale, rather than a *% atom* scale, on a binary phase diagram. [6]

(d) Describe the main properties of a 60 wt. % Sn, 40 wt. % Pb binary alloy and identify the main practical application of this material. [2]

2 (a) Define the term *ceramic* and outline the physical and mechanical properties of a typical crystalline ceramic material. Describe carefully how crystalline ceramics are processed into solid bodies from powders. Your answer should include details of the various options for the preparation and densification of green bodies. [5]

(b) Explain the mechanism of densification that takes place in polycrystalline ceramics during sintering. Identify the process parameters that determine the rate of densification of ceramics and comment on their optimisation for the best mechanical properties for the shortest processing time. [6]

(c) Discuss two ways of improving the strength of ceramics, giving examples to support your answer. [4]

(d) The ceramic $YBa_2Cu_3O_7$ (YBCO) is a high temperature superconductor and may be obtained by annealing the as-sintered material ($YBa_2Cu_3O_{6.5}$) in a pure oxygen atmosphere. Full superconductivity is obtained when oxygen diffuses to all parts of the ceramic. A disc-shaped sample of $YBa_2Cu_3O_{6.5}$ of dimensions shown in Fig. 1 is to be annealed under pure oxygen to produce a fully-superconducting ceramic. Estimate how many times longer this process would take if the annealing was performed at 450 °C rather than 500 °C. The activation energy Q for oxygen diffusion in YBCO is 108 kJ mol^{-1}. [5]

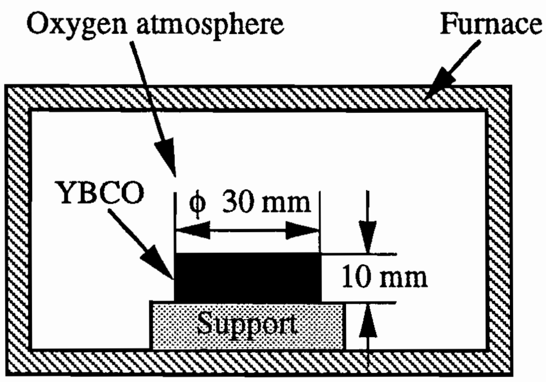

Fig. 1

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3 (a) What composition of aluminium alloys and what process histories lead to their classification as:

(i) suitable for casting;

(ii) wrought, heat-treatable;

(iii) wrought, non heat-treatable?

Use sketches of appropriate regions of relevant phase diagrams to support your answers and give examples of applications in each case. [6]

(b) Sketch the variation of hardness with logarithm of ageing time for a heat-treatable aluminium alloy at constant temperature. The contribution of the hardening mechanisms to the net ageing curve should be included in your sketch. Describe carefully the evolution of the microstructure with time, making specific reference to the formation of phases and their contribution to the mechanical properties of the alloy as the material ages. [6]

(c) Figure 2 shows a transmission electron micrograph of the microstructure of a heat-treatable aluminium alloy. Identify the salient features of this microstructure in relation to your answer to (b) and suggest its likely position on the ageing curve. Estimate the yield stress of this alloy if, in its over-aged state, the precipitates have an average separation of 0.1 μm. You may assume that the Burgers vector and Young's modulus of this alloy are 0.3 nm and 75 GPa, respectively, and that the particles form 'strong obstacles' to dislocation movement. [6]

(d) Outline briefly the precautions that must be taken when:

(i) using rivets of an aluminium alloy that precipitate hardens, such as a 2000-series;

(ii) welding structures of a work-hardened aluminium alloy, such as a 5000-series. [2]

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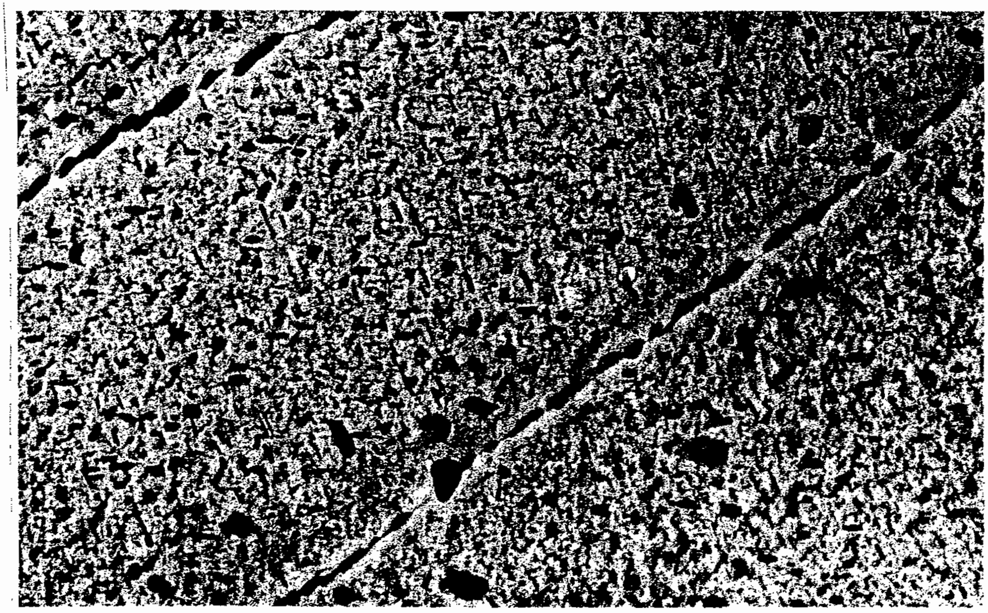

0.1 μm

Fig. 2

(This figure is used by permission of John Wiley & Sons Inc.)

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SECTION B

4 (a) Explain carefully the role of diffusion in the creep of metal alloys under conditions of low stress. [4]

(b) The strain rate for steady-state power law creep is given by $\dot{\varepsilon} = \dot{\varepsilon}_0 (\sigma / \sigma_0)^n$, where n is a constant, σ is the applied stress, $\dot{\varepsilon}_0$ is a constant with the dimensions of strain rate and σ_0 is a temperature-dependent parameter. Derive an expression for the variation of σ_0 with temperature and give the typical range of values of n for a metal undergoing power law creep. [4]

(c) Creep deformation under self-weight is a design consideration for tungsten light-bulb filaments. A bulb operates typically at 2773 K, at which temperature creep of the tungsten is governed by the power law described in Part (b), with $n = 2$.

(i) Assume that a tungsten filament may be modelled as a vertical cylinder of length L freely-suspended from one end and creeping under its own weight. Show that the rate of change of length of a filament is given by:

$$\frac{\mathrm{d}L}{\mathrm{d}t} = \frac{\rho^2 g^2 L^3 \dot{\varepsilon}_0}{3\sigma_0^2}$$

where ρ is the density of tungsten and g is the acceleration due to gravity. [7]

(ii) The light bulb is required to operate for at least 1000 hours with a total creep strain of less than 5%. Would you expect a tungsten filament of initial length $L = 0.1$ m to fulfil this creep limitation? $\rho = 19.3 \times 10^3$ kg m^{-3} and $\frac{\dot{\varepsilon}_0}{\sigma_0^2} = 2 \times 10^{-16}$ s^{-1}Pa^{-2} for tungsten in the power law creep regime with $n = 2$ at a working temperature of 2773 K. [5]

5 Figure 3 shows the cold rolling of a wide steel strip of initial thickness h_1 and final thickness h_2 passing between rolls of radius R rotating with angular velocity ω. The input and output velocities of the strip are indicated in the figure as v_1 and v_2, respectively.

(a) What is meant by the neutral plane in a rolling process? Using the principle of continuity of material flow through the rolls, discuss the relationships between the process variables identified in Fig. 3 and use these to explain why a neutral plane exists. [5]

(b) Explain why the following are essential in the plate-rolling process:

(i) friction;

(ii) a roll force P applied between the rolls on the strip;

(iii) a torque Q applied to the rolls. [6]

(c) Sketch the distribution of pressure at the roll-plate interface for a given coefficient of friction, approximating the contact by a flat horizontal surface. [4]

(d) Identify the candidate processing routes for the manufacture of high strength steel railway track. Discuss the advantages and disadvantages of each route and the constraints placed on process selection by material properties and component geometry. Which process route is the preferred option? [5]

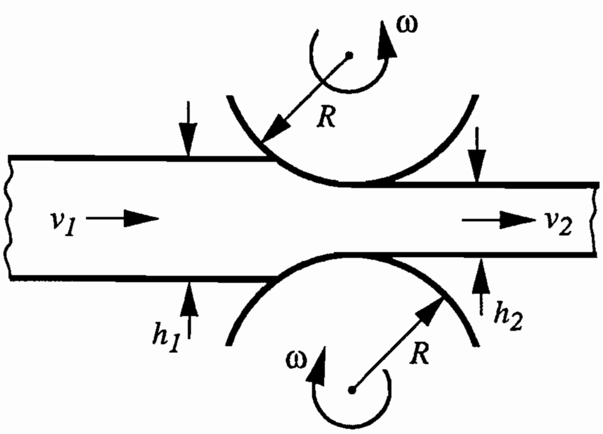

Fig. 3

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6 (a) Describe the factors that determine the yield stress of plain-carbon steels after continuous cooling from the austenite phase. Give examples to support your observations. [5]

(b) A 0.8 wt.% carbon steel is cooled very slowly from 1000 °C to room temperature. Describe the phases involved as the temperature is reduced and sketch the final microstructure, making reference to the iron-carbide equilibrium phase diagram shown in Fig. 6.3 of the Materials Data Book. [5]

(c) A small specimen of a BS503M40 (En12) steel is cooled rapidly to 600 °C from an initial temperature of 810 °C, held at this temperature for 20 s, and then quenched to room temperature. Using Fig. 7.1 of the Materials Data Book, sketch the resulting microstructure and estimate the relative proportions of the microstructures present. [5]

(d) Describe the microstructure of tempered martensite. Using the figures on page 35 of the Materials Data Book, devise a heat treatment schedule to produce a small part of BS817M40 (En24) steel that consists only of tempered martensite of hardness $HV = 400$ kgf mm^{-2}. [5]

END OF PAPER