Version HRS/5

EGT1
ENGINEERING TRIPOS PART IB

Tuesday 3 June 2014 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.

*Write your candidate number **not** your name on each cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Engineering Data Book

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

SECTION A

1 Figure 1 shows the phase diagram for the magnesium-lead (Mg-Pb) system.

(a) Find the chemical formula for the intermetallic compound in this system, and write down its melting point. [5]

(b) Identify the phases present in the fields labelled A-D in Fig. 1. Write down the temperature and composition of the eutectic points. [4]

(c) Describe the evolution of the microstructure as temperature is slowly decreased from 700 ^{o}C to room temperature, for Mg-Pb alloys containing:

(i) 10 wt % Pb; [8]

(ii) 90 wt % Pb. [8]

In each case, identify key temperatures at which phase reactions start and finish, noting the phases involved. For both alloys, sketch the final microstructure and find the proportions and compositions of the phases.

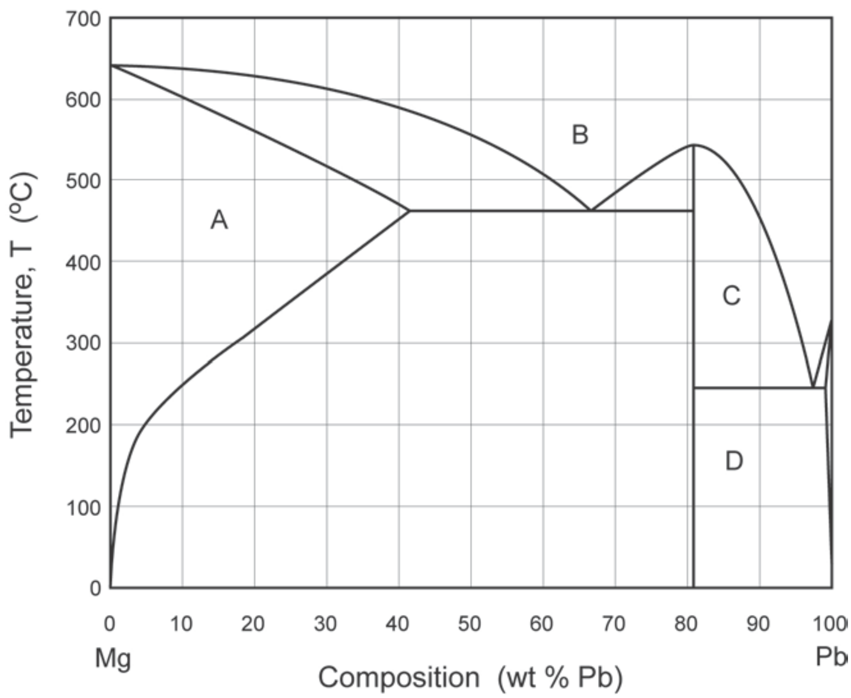

Fig. 1

2 (a) The steady-state creep strain-rate at constant temperature $\dot{\varepsilon}_{ss}$ depends on the applied stress σ according to:

$$\dot{\varepsilon}_{ss} = B\,\sigma^n$$

where B and n are constants. Figure 2 shows the steady-state creep response of an alloy steel at 500 ^{o}C. Show that the creep exponent n is equal to 6 for this alloy, and find the value of the constant B at this temperature. [6]

(b) A component of mass M hangs from the end of a cylindrical rod in a power system at 500 ^{o}C. The rod has a length L and a radius R and is made from the alloy steel in Part (a).

(i) Ignoring the mass of the rod, derive an expression for the rate of extension of the rod, dL/dt. [4]

(ii) Now derive an expression for dL/dt also taking into account the mass of the rod. Comment on the accuracy of the equation in Part (i) above for the case where the rod has a mass of $M/100$. [11]

(iii) A mass M = 200 kg is suspended vertically from a rod at 500 ^{o}C for 10,000 hours. The rod has a length L = 0.5 m and a radius R = 3 mm. Find the mass of the rod, and calculate the extension of the rod in this time, stating any assumptions made. [4]

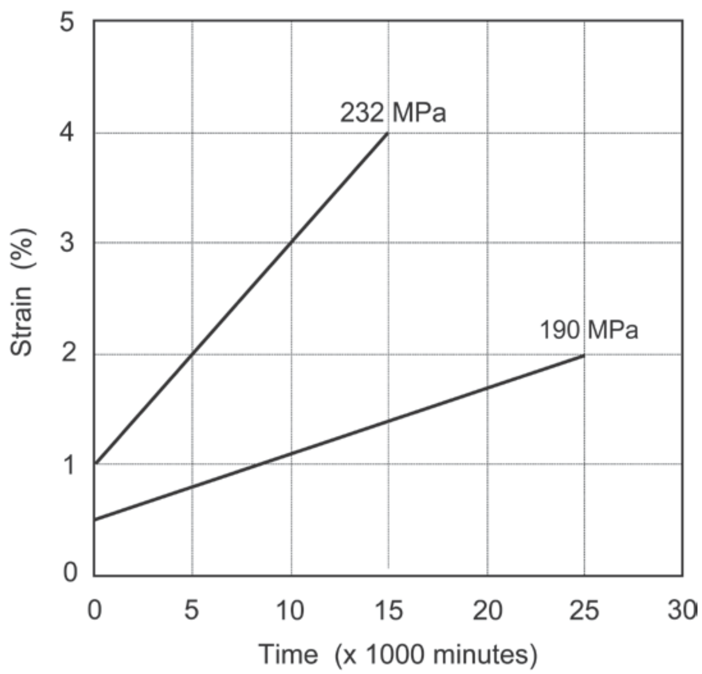

Fig. 2

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3 (a) State the form of the temperature-dependence of diffusion. Briefly explain the physical basis of this dependence on temperature. [5]

(b) A laminated metal sheet is manufactured by stacking and bonding alternating dissimilar foils of thickness 2 μm. The foils are made of a metal M containing two different concentrations of an element X in solid solution. Bonding between the layers may be assumed to be perfect, such that the initial concentration of element X through the thickness of the laminate is as shown in Fig. 3. In service the laminated sheet is held at an elevated temperature, leading to re-distribution of the solute by diffusion.

(i) The initial concentration profile may be described by the Fourier series:

$$C(x, t=0) = C_0 + \sum_{n=1,3,5...} \frac{2C_1}{\pi n} \sin\left(\frac{\pi n x}{h}\right).$$

Use the Maths Databook to find the values of the constants C_0, C_1 and h. [4]

(ii) The solution for the concentration profile after a time t at elevated temperature is given by:

$$C(x, t) = C_0 + \sum_{n=1,3,5...} \frac{2C_1}{\pi n} \sin\left(\frac{\pi n x}{h}\right) \exp\left(-\frac{t}{\tau_n}\right).$$

By substituting this solution into the governing differential equation, Fick's second law, find the form of the terms τ_n in terms of n, defining any other parameters in the expression. [6]

(iii) Explain why, for timescales that are greater than τ_1, Fourier terms with n greater than one can be ignored. Estimate the error in this approximation for a time $t = 0.5\,\tau_1$. [5]

(iv) A laminate with the initial concentration shown in Fig. 3 is held at a temperature of 500°C for 1 hour. Use the solutions above to find the maximum and minimum concentration of element X after this time. The activation energy for diffusion of element X in metal M is Q = 180 kJ mol^{-1}, and the diffusion constant is $D_o = 2.6 \times 10^{-4}$ m^2 s^{-1}. [5]

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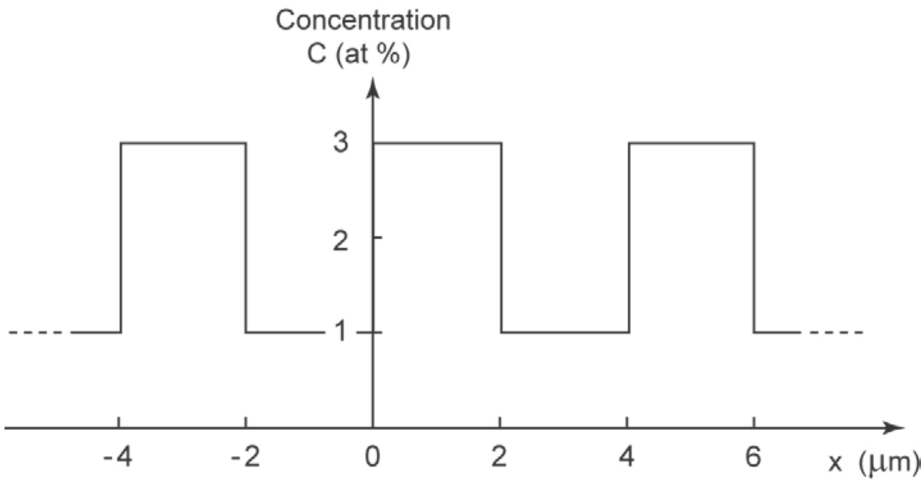

Fig. 3

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SECTION B

4 For each of the following processes, describe the microstructural changes taking place, and the atomic scale mechanisms controlling the change, with sketches as appropriate. In each case, identify the driving force and state whether or not a phase transformation is taking place.

(a) the early stages of artificial ageing of an aluminium-copper alloy after solutionising and quenching; [5]

(b) annealing of an aluminium-magnesium alloy after cold rolling; [5]

(c) slow cooling of a eutectoid steel from 800 ^{o}C to 20 ^{o}C; [5]

(d) water quenching of a eutectoid steel from 800 ^{o}C to 20 ^{o}C; [5]

(e) holding an annealed sample of pure copper for a prolonged period close to its melting point. [5]

5 Explain how the performance of the following components is enhanced by the associated processing step given. In each case, identify key material properties, and explain the role of any alloying or material additions indicated.

(a) immersion of a steel gear in molten carbon-rich salt, followed by surface heating with a traversing laser beam; [6]

(b) quenching and tempering a cutting tool made of a high carbon steel containing tungsten; [5]

(c) casting of nickel superalloy turbine blades, followed by coating with zirconia; [8]

(d) cold drawing of polypropylene for fishing lines; [3]

(e) stretch blow moulding of PET bottles for carbonated drinks. [3]

6 (a) The failure of different classes of engineering materials may be described graphically using failure surfaces for biaxial in-plane principal stresses σ_1 and σ_2. Example cases are:

(1) the Tresca criterion for yielding in metals;

(2) the von Mises criterion for yielding in metals;

(3) the maximum stress criterion in uniaxial fibre composites, where σ_1 is in the fibre direction and σ_2 is in the transverse direction;

(4) failure of concrete.

(i) On axes of principal stresses σ_1 and σ_2, sketch the failure surfaces in all four cases. [6]

(ii) Write down mathematical expressions for the failure criteria, for cases (1) to (3). [4]

(iii) In all four cases, account for the relative magnitudes of the failure stresses in pure tension and pure compression. [5]

(iv) For case (3), explain briefly the limitations of the maximum stress criterion. [3]

(b) Distinguish with sketches between open die and closed die forging. Give typical values for the ratio of the forging pressure to the uniaxial yield stress, explaining qualitatively the roles of friction and multiaxial yielding in determining these values. [7]

END OF PAPER

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