Version YYSH/9

EGT1
ENGINEERING TRIPOS PART IB

Monday 4 June 2018 9 to 11.10

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.*

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

STATIONERY REQUIREMENTS
Single-sided script paper

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.

SECTION A

1 (a) Write down the temperature-dependence of the rate of diffusion in solids, as described by the Arrhenius law. Explain the physical basis of this dependence. [4]

(b) Using your knowledge of diffusion, briefly account qualitatively for the following observations.

(i) Diffusion of impurities is faster in a polycrystalline nickel alloy than in a single-crystal nickel alloy. [3]

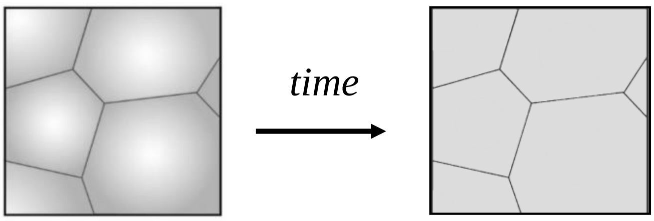
(ii) Carbon diffuses more rapidly than nickel in iron. [3]

(iii) At longer times, the oxide thickness of a surface oxidised silicon depends on the square root of time. [4]

(iv) Lamellar pearlite microstructures form during the transformation of austenite in slow cooling. [4]

(c) For the following scenarios, briefly outline how you would set up a one-dimensional model for the associated atomic diffusion, identifying appropriate assumptions, initial conditions and boundary conditions. There is no need to derive relevant equations. On axes of concentration versus distance, sketch how the concentration distribution is expected to vary with increasing time.

(i) Homogenisation of a crystalline cast metal, as illustrated below, from an initially-segregated microstructure. [3]



(ii) Doping of silicon with boron through a two-step process: pre-deposition and drive-in. Sketch the two steps on separate graphs. [4]

2 (a) Sketch the temperature dependence of the Gibbs free energy for the solid, liquid and gas phases of a pure material. Comment on the key features of the plot. [5]

(b) Figure 1 shows the phase diagram for the aluminium - copper system.

(i) An alloy containing 15 wt% Cu is cooled slowly to 500 °C from the melt. Describe the phase changes that occur during cooling, using sketches of the microstructure at key temperatures to illustrate your answer. [6]

(ii) Estimate the mass fraction of the phases present in the 15 wt% Cu alloy at 250 °C. How does the microstructure change between 500 °C and 250 °C? [4]

(iii) Sketch a temperature-time curve for the cooling of a 15 wt% Cu alloy over the range 650°C to 450 °C. Account for the shape of the curve. [5]

(c) Qualitatively compare and contrast homogenous nucleation and heterogeneous nucleation. Explain how nucleation and growth mechanisms can account for the final spatial distribution of phases for the alloy of part (b) (i). [5]

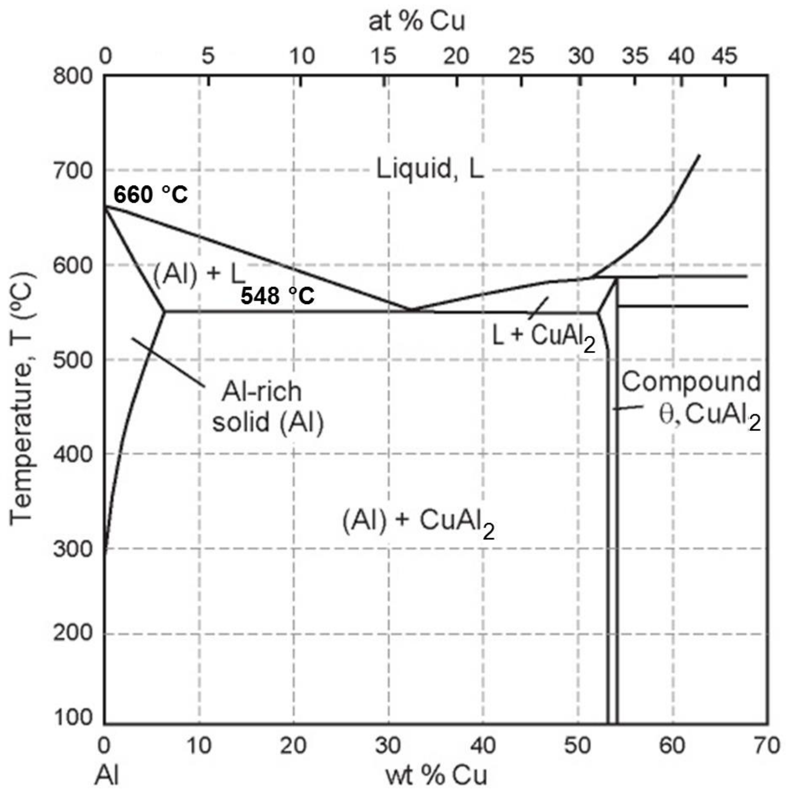


Fig. 1

3 (a) (i) Sketch typical molecular structures of a linear amorphous thermoplastic and an elastomer; label any key features. [2]

(ii) On the same graph, sketch typical stress – strain curves associated with a brittle thermoplastic polymer, and a natural rubber respectively, given that the tests are performed under uniaxial extensional configurations at room temperatures. [2]

(iii) On two separate graphs, sketch the variation of Young's modulus with temperature, around the glass transition temperature (T_g), for a linear amorphous thermoplastic with T_g = 150 °C and for an elastomer with T_g = −20 °C. Briefly explain the shapes of the graphs. [4]

(iv) A mass is hung from a strip of polymer with rest length L_0 at 35 °C. The temperature is decreased from 35 °C to 10 °C. For either choice of the polymer in part (iii), describe qualitatively the subsequent displacement of the mass. [3]

(b) The following items all involve the use of thermoplastic polymers. Outline how material selection and the choice of shaping/manufacturing process can lead to materials properties meeting the key performance requirements.

(i) Plastic bottles for carbonated soft drinks. [3]

(ii) Thin film packaging materials. [3]

(iii) Fabric for boat sails. [4]

(c) Thin gloves for chemical handling are typically made of a cross-linked latex rubber. Discuss why such gloves will require a very different manufacturing process from the product described in part (b) (ii). [4]

SECTION B

4 (a) (i) State the conditions required for aqueous corrosion. [3]

(ii) Iron can corrode into Fe^{2+} in both acidic and neutral aqueous environments. State the corresponding half-cell and overall equations for both conditions. [3]

(b) Describe the working principle of galvanic corrosion. Explain how this principle can be used to protect steel structures from corrosion in an aqueous environment. [5]

(c) The kinetics of oxidation of a mild steel plate at 400 °C can be described by the relation $\Delta m = 10^{-4} \sqrt{t}$, where Δm is the mass change in kg per square metre of plate as a function of time t (in seconds). The steel plate is made into a cylindrical pressure vessel with a diameter of 500 mm and an initial wall thickness of 5 mm. The vessel is subjected to an internal pressure of 10^6 Pa above atmospheric pressure.

(i) Assuming that the main oxide formed is FeO and does not bear any load, determine whether oxidation will lead to vessel failure within an operational life-time of 10 years at 400 °C. You can assume that failure occurs when the hoop stress is equal to 150 MPa. The density of Fe is 7,870 kg m^{-3}, the molar mass of Fe is 0.056 kg mol^{-1} and the molar mass of O is 0.016 kg mol^{-1}. [10]

(ii) What additional failure mechanism could be involved if the operational temperature is raised to 650 °C? Briefly state how the material's composition and processing history can be altered to increase the life-time of the vessel for a service temperature of 650 °C. [4]

5 (a) Molten metal is poured into a mould whose temperature is lower than the melting point of the metal. The metal then cools by heat loss through the mould walls.

(i) Draw a typical grain structure through the cross section of the casting, labelling the key microstructure zones. How will an increased cooling rate affect the microstructure obtained? [4]

(ii) Describe how segregation can influence the mechanical properties of a casting. [4]

(b) Based on thermodynamic and kinetic reasoning, and assisted by appropriate sketches, account for the origin of a *C-curve* in a TTT diagram. [6]

(c) For the following applications, discuss how the material composition and thermal history can influence the material properties. Comment on how these properties provide a benefit for the given application.

(i) Aircraft components made of heat treatable aluminium-copper alloy. [6]

(ii) Cutting tools made of high-alloy steel. [5]

6 (a) On appropriate axes, sketch suitable failure surfaces for the following materials subjected to bi-axial in-plane stresses which may be tensile or compressive. Use the given material property information to label key stress values on your sketches. Estimate values for properties not quoted, justifying your choices. Identify the compression and tension quadrants on your sketches.

(i) An aluminium alloy with a tensile yield stress of 200 MPa. [3]

(ii) A concrete block with a compressive strength of 30 MPa and a tensile strength of 5 MPa. [3]

(iii) A composite made of aligned glass fibres and epoxy resin, with a fibre volume fraction of 50%. The tensile strength of the fibres is 1,200 MPa. The in-plane stresses are applied parallel and perpendicular to the fibres. [4]

(iv) Packed dry sand particles, with a critical friction angle of 30°. [3]

(b) A concrete block is loaded in pure shear, and is required to carry a shear stress of 8 MPa. Is the concrete described in part (a) (ii) suitable? Provide a justification for your answer. [5]

(c) During metal annealing, two distinct microstructural changes take place: recovery and recrystallisation. Compare and contrast the recovery and recrystallization processes in relationship to the thermodynamic driving forces, microstructural changes, and the resultant mechanical properties. Include appropriate sketches to support your answer. [7]

END OF PAPER

THIS PAGE IS BLANK