ENGINEERING TRIPOS PART IB

Tuesday 4 June 2002 9 to 11

Paper 3

MATERIALS

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

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 the two sections should be tied together and handed in separately

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.

(TURN OVER

SECTION A

1 (a) How do the mechanical properties (Young's Modulus, Yield Stress and Fracture Toughness) differ between ceramics and metals? How can the differences be explained by the different types of atomic bonding in the two classes of material? What processing techniques are used to make ceramic articles? How does the processing influence the fracture stress of the product? [6]

(b) In a test of 100 ceramic bars under uniform tensile loading the number surviving at each stress was as follows:-

Load (MPa)	80	102	123	148
Number	90	70	40	10

The volume of each sample was 8 cm^3.
Use these data to find the constants in the Weibull expression for the probability of survival of a sample. [6]

(c) A waisted cylindrical specimen of this ceramic with the dimensions shown in Fig. 1 is subjected to a tension of 8 kN. Find the probability that it will survive this force. [6]

(d) Can you suggest precautions (including minor shape changes) that might be taken to ensure a better survival rate? [2]

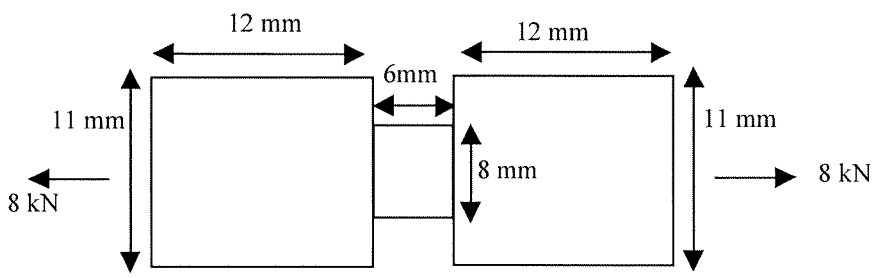

Fig. 1

2 Fig. 2 shows the phase diagram for Ti Al alloys.

(a) How would you describe a solid of composition A? State the temperature, composition and type of any eutectic, eutectoid, peritectic or peritectoid reactions in this diagram. Label the unlabelled areas with the phases present, including the phase labeled 'A'. Hand in the diagram with your answer (a separate copy of the diagram is supplied). [7]

(b) A Ti 30 At% Al alloy is cooled slowly from the melt. Describe the changes that occur and the microstructure we might expect. What will be the phases at room temperature and in what proportion by weight?
Repeat the process for an alloy of composition 75 At% Al. [7]

(c) Give three examples of the effects of cooling an alloy too rapidly for equilibrium to be achieved. Sketch the curve of temperature against time for a sample of 40At% Al if it is heated to 1800°C and allowed to cool in an environment at 25°C. Explain the general shape of the curve and any discontinuities. [6]

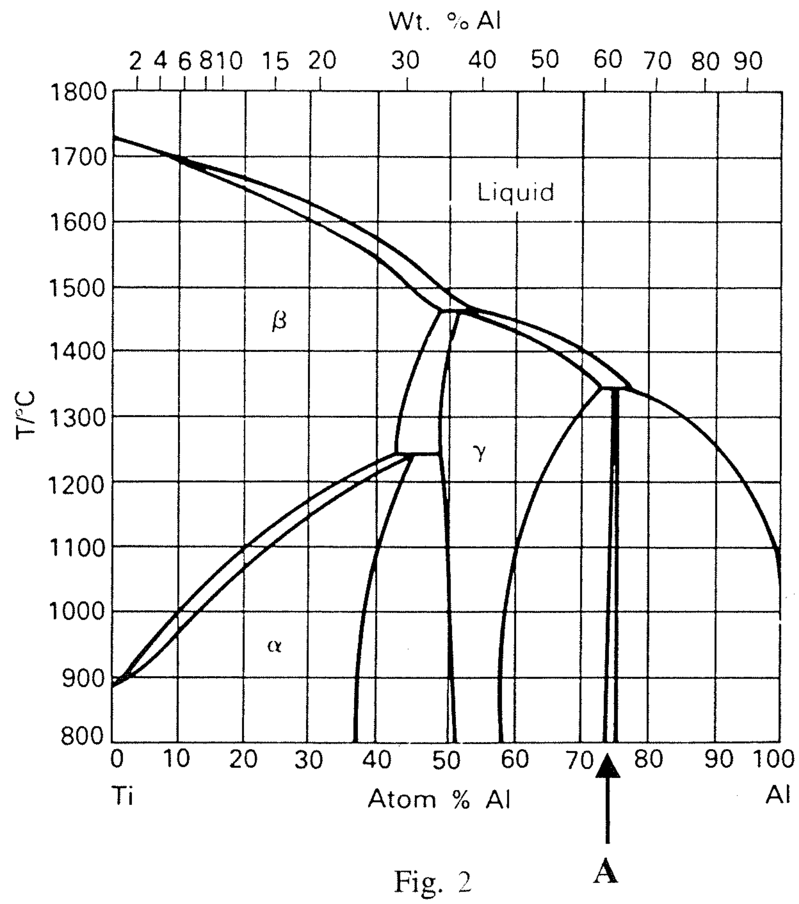

Fig. 2

3 (a) How do the following parameters affect the macroscopic properties of a polymer?

(i) Degree of Cross Linking.
(ii) Nature and complexity of side groups.
(iii) Degree of crystallinity.
(iv) Chain alignment

What processing methods are used to make polymers and artifacts out of them? Which of the above properties can be controlled by processing the polymer during manufacture? [6]

(b) Fig. 3 Shows a spring and dashpot model of a typical polymer. It consists of a spring of elastic constant E and a viscous damper which produces a stress $\eta dy/dt$. The macroscopic stress and strain are σ and ε respectively.
How would you expect E and η to depend on the nature of the polymer and the temperature?
Obtain a differential equation relating stress to strain in terms of the material parameters and the intermediate strain y. If a harmonic stress $\sigma_o \, exp(j\omega t)$ is applied with a corresponding strain $\varepsilon_o \, exp(j\omega t)$ find the resulting strain amplitude ε_o. Sketch the variation of the amplitude of the strain as a function of frequency at several temperatures. [6]

(c) Estimate the frequency at which the viscosity has a significant effect. If the viscosity is a thermally activated process which varies as $exp(-U/kT)$ where U is a measured activation energy suggest how a scaling of the axes would map all the curves onto a single graph [4]

(d) Obtain an expression for the loss per unit volume as a function of E, σ_o, η and ω. [4]

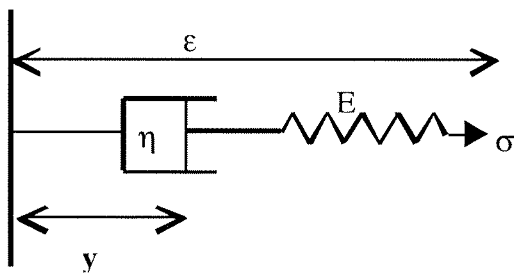

Fig.3

SECTION B

4 (a) A beam of width w length L thickness b and Young's modulus E is bent with a uniform bending moment. Obtain an expression for the maximum elastic energy which can be stored in the beam in terms of these parameters and the yield stress σ_y. [8]

(b) Discuss the materials which give the optimum energy per unit mass, and energy per unit volume, which might be used in a watch spring. In what applications is energy per unit mass more important than energy per unit volume? What other considerations are needed when choosing a material? Pick the most suitable material for each criterion. [6]

(c) Discuss the advantages and disadvantages of using a more complex shape such as a hollow tube or an 'I' beam. For a given stored energy how would you decide on the best values of w, L and b ? [6]

5 (a) Compare the advantages and disadvantages of hot and cold forging. Find the yield stress of a material in pure shear, k, in terms of the tensile yield stress σ_y Explain how the Tresca yield criterion is used to predict yield in more complex stress states. [4]

(b) A slab of material of yield stress σ_y is pressed between two platens. The material is of thickness h (the z direction) and width w (the x direction). Deformation in the directions perpendicular to h and w can be ignored. The coefficient of friction is large, so that a thin layer next to the faces of the platens yields in shear. Obtain an expression for the variation in pressure on the platens with x. Hence find P/σ_y, the ratio of the pressure required to deform the sample to σ_y. [8]

(c) Assuming that the rolling of a sheet of metal can be modelled by a compression process of this type, sketch the variation of frictional force and pressure as a function of position in the region where the material is in contact with the rollers. Show how the balance of forces leads to a torque on the rollers. What is the role of friction in the rolling process? [4

(d) A sheet of metal 40 cm wide is to be rolled from a thickness of 10mm to a thickness of 7mm at a speed of 4 m/s. The yield stress is 60 MPa. Ignoring the effect of friction (so that the compressive stress is σ_y) estimate the work done per metre of rolled sheet. Hence estimate the torque needed on 12 cm diameter rolls. [4]

6 (a) What are meant by the terms 'hardenability' and 'weldability' as applied to Carbon Steels? Why is it difficult to maximise both in the same material? What hardening mechanisms can be used for alloys that will have to be welded? [5]

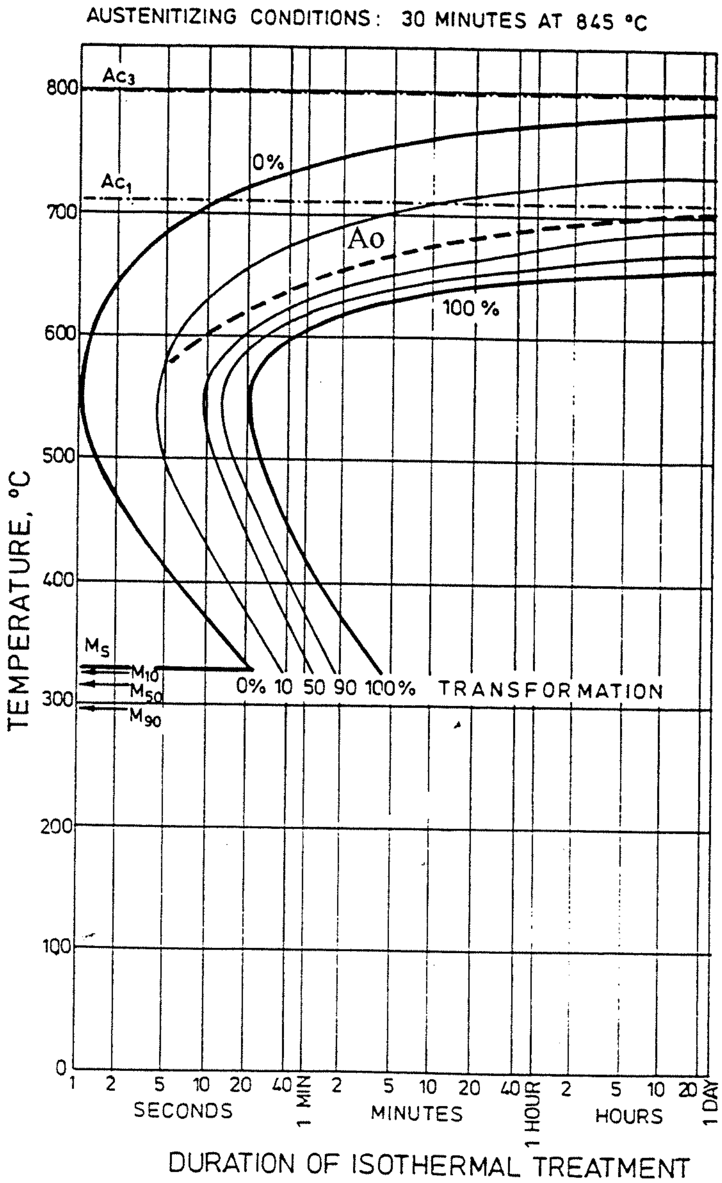

Fig. 4

(b) Fig. 4 shows the TTT diagram for a 1% Nickel Steel.
Is the hardenability low or high? Say why you come to your conclusion. What are the meanings of the lines Ac1 Ac3 and Ao Explain briefly the shape of the contours

(Cont.

of constant fraction transformed in terms of the thermodynamics and kinetics of phase transformations. [5]

(c) Which of the lines in Fig.4 can be deduced from the equilibrium phase diagram, Fig. 4.7 in the data book, (the presence of Ni can be neglected for this purpose)? What is the percentage of carbon in this steel? Why does the Ao line (dashed) tend to the Ac1 line at long times? Explain what is meant by 'Austenitising Conditions' and why a temperature of 845C is suitable. What would be the effect of changing this temperature?
Point out the differences between the Ms and Ac3 lines. In particular why do we need undercooling below Ms to form martensite, but the duration is irrelevant? [5]

(d) Three samples of this steel are given the following heat treatments:-

(i) Cooled to room temperature in 2 seconds.

(ii) Cooled to 400°C in 1 sec, held for 40 secs, quenched to room temperature.

(iii) Cooled to 650°C in 2 secs, held for ten minutes, quenched to room temperature.

Describe the microstructure in each case .
Rank qualitatively the elastic modulus, yield stress and fracture toughness of the three samples. What further heat treatment might be used to improve the properties? [5]

END OF PAPER

EXTRA SHEET

DO NOT PRINT.

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MATERIALS

Question 2.

Candidate Number