

ENGINEERING TRIPOS PART IB

---

Tuesday 3 June 2003 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.*

**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 If the equilibrium temperature of a phase transformation is  $T_E$ , sketch a graph showing the rate of transformation to the new phase as a function of temperature  $\Delta T$  below  $T_E$  and explain its shape. How does this graph lead to the TTT diagram in Fig. 5.3 in the Materials Data Book (En12 steel), and in particular the 'nose' of these curves? Describe briefly the experiments used to construct such a diagram. [5]

What is the function of the alloying elements which cause the differences between En12 and En24, Figs.5.3 and 5.5 respectively in the Materials Data Book? What determines which of these steels you would use in a particular application?

Explain the meaning of *hardenability* and *weldability* and the relation between them. What is the Jominy end quench test and why is it useful? [4]

The surface of a thick slab at a temperature  $T_s$  is suddenly reduced to a lower temperature  $T_o$ . The temperature, as a function of time  $t$  and distance  $x$  into the slab, is given by:

$$T = T_o + (T_s - T_o) \operatorname{erf} \left( x / 2\sqrt{at} \right)$$

Here  $a$  is the thermal diffusivity. In steel it has a value  $9 \times 10^{-6} \text{ m}^2 \text{ s}^{-1}$ . Table I on the next page gives numerical values for  $\operatorname{erf}(y)$ .

Use the TTT diagram of Fig. 5.5 in the data book to find the temperature at which the time to start diffusive transformations is a minimum. Use this time and temperature to estimate the distance in a Jominy test at which the material ceases to be 100% martensite. Assume the starting temperature is 900 °C and the quenching bath is at 20 °C. Say if this is an overestimate or underestimate of the cooling rate required giving reasons for your answer.

Does your result agree with what you would expect from Fig 5.6 in the data book (En24) which shows the hardness as a function of distance? [6]

Sketch how the elastic modulus and fracture toughness might be expected to vary along the length in the bar of fig. 5.4 (En12):

- (a) for samples as quenched;
- (b) for samples tempered at 575 °C. [5]

(cont.)

Table I

$y$	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	
$erf(y)$	0	0.11	0.22	0.33	0.43	0.52	0.60	0.68	
$y$	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	$\infty$
$erf(y)$	0.74	0.80	0.84	0.88	0.91	0.93	0.95	0.97	1.0

2 What is meant by the surface energy between phases? What is the atomic basis of surface energy and why does it lead to supercooling in phase transformations? There are many precipitates which form as lamellar structures. Is this as a result of the surface energy or is it a kinetic effect? Give an example of such a structure. [7]

The surface energy between two phases is  $\gamma$  and the free energy difference per unit volume between them is  $\Delta G$ . If the new phase is to nucleate in the form of spheres obtain an expression in terms of  $\gamma$  and  $\Delta G$  for the critical radius which must be reached before the phase change can take place. [5]

Give two examples of common materials in which a phase which is not stable at room temperature is used and explain how this is achieved. [2]

The grain structure of metals such as aluminium can be controlled by suitable plastic deformation and subsequent heat treatment. How would you make a material with:

- (a) a very small grain size;
- (b) a very large grain size?

Explain the physical processes involved. [6]

(TURN OVER

3 Figure 4.2 in the Materials Data Book shows the lead-tin phase diagram. What phases are present at compositions of 0.1, 10, 61.9 and 90 wt% tin at room temperature? [3]

The 'lever rule' is often used to calculate the proportions of phases in a material of a given composition. What is its physical basis? Explain how it is used and prove why it works. Does it work for weight percent, atomic percent, or both? Justify your answer. [6]

Sketch the microstructures at 61.9 and 90 wt% tin assuming slow cooling from the melt to room temperature. What is likely to be the effect on the microstructure of fast cooling? [5]

Sketch the slow-cooling curves of a material of 10 and 61.9 wt% tin from 330°C to room temperature, explaining the shape of each. [4]

What composition would you use for:

- (a) soldering fine copper wires;
- (b) mending a leak in a water pipe?

Give reasons for your choice. [2]

## SECTION B

4 (a) What are the two main mechanisms by which metallic alloys creep? Explain briefly how each mechanism and the resulting creep rate are affected by :

- (i) temperature;
- (ii) grain size;
- (iii) alloying;
- (iv) melting point;
- (v) elastic modulus;
- (vi) dislocation density?

Give an example of a creep resistant alloy and explain how the resistance is achieved. [10]

(b) A tubular pressure vessel is made of an alloy where power law creep occurs according to the relation :

$$d\varepsilon/dt = \alpha\sigma^n$$

where  $\sigma$  and  $\varepsilon$  are the tensile stress and strain respectively and  $\alpha$  is a constant. It can be assumed that the density remains constant.

The cylinder consists of a volume  $V$  of material per unit length and the initial wall thickness is  $d_o$ . The vessel is pressurised to a constant pressure  $P$ . Obtain a differential equation for the wall thickness  $d$  as a function of time in terms of  $P$ ,  $\alpha$ ,  $n$  and  $V$ . Hence show that the wall will reach zero thickness after a time  $t$  where:

$$t = \frac{1}{2n\alpha} \left( \frac{2\pi d_o^2}{PV} \right)^n$$

Ignore the effect of longitudinal stresses and assume the wall thins uniformly. [6]

Given the simplifying assumptions is this a lower or upper limit to the lifetime? What are the causes of inaccuracy in the result? [4]

(TURN OVER

5 (a) Discuss the properties required in a silicon wafer to be used in microcircuit fabrication, and outline the processes by which raw silicon wafers (before further processing) are made. [3]

Define the term *doping* in the context of semiconductor processing. What determines whether a doped semiconductor is *p*-type or *n*-type? [2]

Boron can be diffused into silicon in two stages, a pre-deposition stage and a drive-in stage. Sketch the concentration of boron as a function of depth produced by each process, and explain the advantage of two-stage diffusion. [3]

Write down a simple expression for the average depth to which a dopant will diffuse in terms of the diffusivity  $D$  and time  $t$ . Hence estimate the ratio between the diffusion times needed to achieve the same penetration of boron into silicon at  $1000^\circ\text{C}$  and  $1200^\circ\text{C}$ .  
(The activation energy for diffusion of boron in silicon is  $334\text{ kJ/mol}$ ). [3]

(b) Describe the techniques used for the processing of ceramics. Discuss the effects of temperature and sintering time on the mechanical properties. What methods are used to obtain the maximum fracture toughness? [5]

The fracture toughness of silicon carbide is  $3.4\text{ MN/m}^{3/2}$ . A beam  $2\text{ mm}$  deep is simply supported in a four point bending test with supports  $30\text{ mm}$  apart and loaded with equal forces as shown in Fig. 1. Where is fracture most likely to occur? If the inherent flaw size is  $5\text{ microns}$  approximately how far will the centre have deflected when the strip breaks?  
(For silicon carbide Young's Modulus  $E = 450\text{ GN/m}^2$ ). [4]

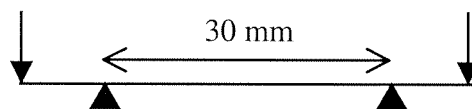


Fig. 1

6 (a) What attributes of shaping processes can be used to guide process selection? Discuss the effect on the choice of the number of articles to be made. [10]

(b) Suggest materials and processes which would be suitable for manufacturing the following items:

(i) a metallic container for liquid nitrogen;

(ii) a plastic garden chair;

(iii) a gas turbine blade;

(iv) a toughened drinking glass.

In each case give reasons for the choice of material and processing route. [10]

**END OF PAPER**