MAY 2015 NATIONAL EXAMINATIONS

04-BS-11 Properties of Materials

3 Hours Duration

Notes:

(i) If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumption made.

(ii) Candidates may use one of two calculators, the Casio or Sharp approved models. This is a "closed book" examination.

(iii) Any five questions constitute a complete paper. Only the first five questions as they appear in your answer book will be marked.

(iv) All questions are of equal value.

Information:

(1) Atomic Masses ($g.mol^{-1}$)

H	1.01	C	12.01	N	14.01	O	16.00	Na	23.0
Si	28.1	P	31.0	S	32.1	Ge	72.6	Rh	102.9

(2) Constants and Conversions

Avogadro's number, N_A $= 0.602 \times 10^{24}\ mol^{-1}$
Boltzmann's constant, k $= 13.8 \times 10^{-24}\ J.\ mol^{-1}.K^{-1}$
Universal gas constant, R $= 8.314\ J.\ mol^{-1}.K^{-1}$
Angstrom, Å $= 1 \times 10^{-10}\ m$

(3) Prefixes

tera	T	10^{12}	milli	m	10^{-3}
giga	G	10^{9}	micro	μ	10^{-6}
mega	M	10^{6}	nano	n	10^{-9}
kilo	k	10^{3}	pico	p	10^{-12}

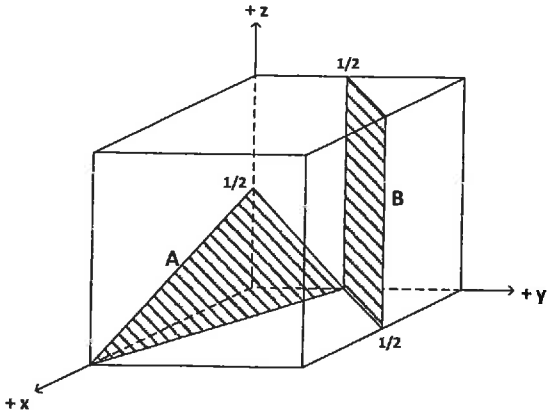
(4) Useful formulae

Diffusion, $J = -D\frac{\Delta c}{\Delta x}$ $D = D_0 \exp\left(\frac{-Q}{RT}\right)$ $\frac{dc}{dt} = D\frac{d^2c}{dx^2}$

Stress relaxation, $\sigma = \sigma_o e^{-t/\lambda}$

Questions:

1. (a) Determine the Miller indices for the planes A and B shown at the right. Starting from the intersection point of the two planes, construct a [012] line.



(b) X-ray studies show the lattice constant of rhodium to be FCC with a lattice constant 3.796 Å. Calculate the density ($g.cm^{-3}$).

2. (a) In a tensile test an extensometer is used to obtain accurate values for the sample gauge length l. Show that the true strain ε_T is given by:

$$\varepsilon_T = \ln\left(\frac{l}{l_o}\right) \quad \ldots\ldots (1) \qquad (l_o = \text{initial length})$$

The true strain can also be determined by monitoring the diameter d. Show that if the specimen volume remains constant the true strain is given by:

$$\varepsilon_T = 2\ln\left(\frac{d_o}{d}\right) \quad \ldots\ldots (2) \qquad (d_o = \text{initial diameter})$$

If, during the test the sample undergoes necking, which type of monitoring should be employed for recording true strain? Give clear reasons for your answer?

(b) Describe the Brinell hardness test. This hardness test gives a closer correlation to tensile strength of structural steels than other hardness tests. Explain. Why does this correlation not exist for heat treated steels? What would be a better hardness test for heat treated steels?

3. (a) A 1.35 kg brick consists of 85% sand (SiO_2) and 15% sodium metasilicate ($Na_2SiO_3.9H_2O$). Sodium metasilicate is known to lose $6H_2O$ at 100°C. What will be the mass of the brick after heating at a temperature slightly above 100°C?

(b) Describe how bricks are made. What factors affect the final mechanical properties of the finished brick?

4. (a) A common copolymer is produced by including both ethylene and propylene monomers in the same chain. Calculate the molecular weight of the polymer using 1 kg of ethylene (C_2H_4) and 3 kg of propylene (C_3H_6), giving a degree of polymerization of 4500.

(b) A stress of 4000 psi is applied to a fastener made of this copolymer. At a constant strain, the stress drops to 3500 psi after 100 hours. If the stress on the fastener must remain above 2500 psi in order for the part to function properly, determine the life of the fastener.

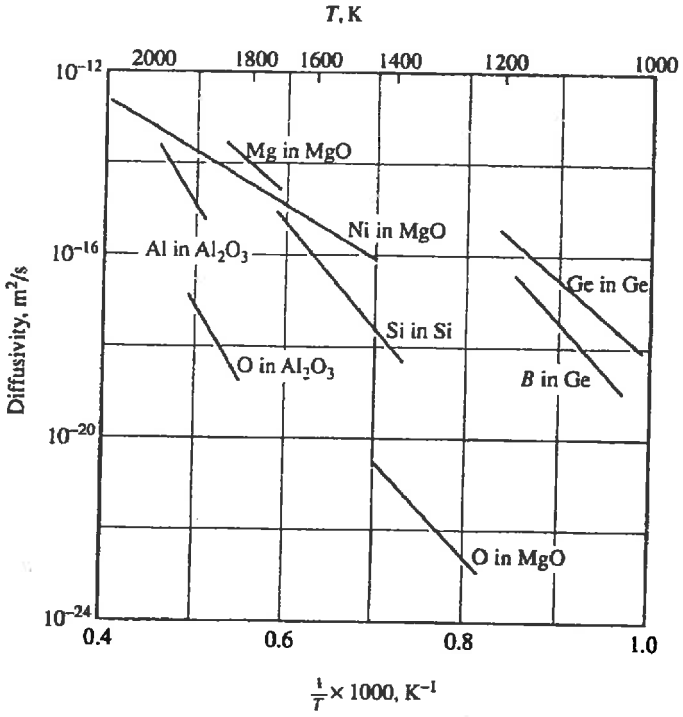


Fig 1 Diffusivity data for some non-metallic systems

5. (a) Refer to Fig 1 above.

(i) Show that the units of diffusivity (diffusion constant) are m^2/s

(ii) Explain the general nature of the data i.e. straight lines with negative slopes.

(iii) At a given temperature, why would you expect the diffusivity of oxygen in MgO to be less than that of Mg in MgO? Explain.

(iv) Similarly, at a given temperature, why does the diffusivity of Mg in MgO lie close to, but higher than that of Ni in MgO?

(v) Si and Ge are both semiconductors. Compare the diffusion data for both materials. What, if any, is the significance of this?

(b) In order to make n-type extrinsic semiconductor material for a transistor, phosphorus is to be diffused into pure silicon. The silicon is in the form of a 1mm thick wafer. The original concentration of phosphorus is one atom per for every 10 million Si atoms. The concentration is to be increased by a factor of 500. Calculate the diffusion flux for phosphorus in silicon, expressing your answer as the number of phosphorus atoms passing through a unit cell of silicon per minute. For the conditions employed, the diffusivity of P in Si is 10.5×10^{-10} m^2/s.

Note: silicon is diamond cubic (8 atoms/unit cell), lattice constant 5.431 Å

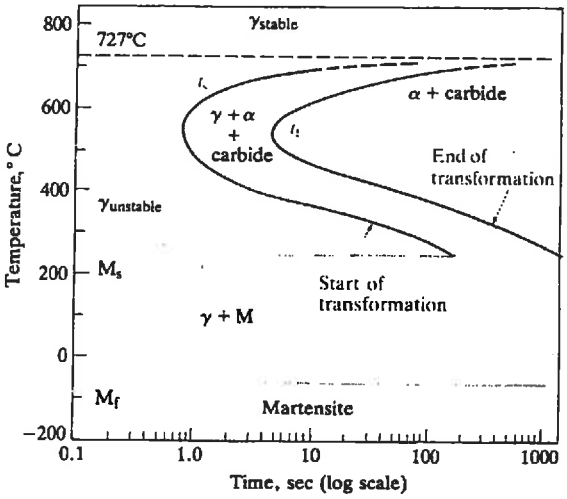


Fig 2 Isothermal diagram for a 0.8% carbon steel

6. (a) Describe the Jominy test. What useful information does it provide?

(b) The diagram above shows the isothermal transformation curve for a eutectoid (0.8%) carbon steel. Thin sections of the steel are heated to 800°C for 1 hour, then heat treated as follows:

(i) Quenched to 350°C, held for 750 s, and quenched to room temperature.

(ii) Quenched to 650°C, held for 500 s, and quenched to room temperature.

(iii) Quenched to 300°C, held for 10 s, and quenched to room temperature.

(iv) Quenched to 300°C, held for 10 s, quenched to room temperature, reheated to 400°C, held for 3600 s, cooled slowly to room temperature.

For each of the above cases describe the microstructure of the heat treated material and comment on the final mechanical properties obtained.

(c) Subjecting the heat treated part, as in (b) (iii) above, to a further quench in liquid nitrogen, followed by annealing at 100 °C often gives an improvement in properties. Explain.

7. (a) Name and briefly describe some nondestructive testing methods that might be helpful in detecting cracks parallel to the surface of welded stainless steel pipe?

(b) In an investigation of a traffic accident, one of the drivers claimed that the headlights were not working in the other vehicle. Laboratory examination of the lamp filament showed that this was not the case. Explain what test(s) were done and the general nature of the results obtained. How would the results have differed should the headlights had been off, as claimed?

(c) Discuss some methods that are employed to improve the fracture toughness of ceramic materials.