

98-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 O 16.00

(2) Properties of Metals

<u>Metal</u>	<u>Symbol</u>	<u>Crystal Structure</u>	<u>Atomic Mass (g/mol)</u>	<u>Density (g/cm³)</u>	<u>Melting Temperature (°C)</u>
Aluminum	Al	FCC	26.98	2.70	660
Boron	B	R ¹	10.81	2.30	2300
Iron	Fe	BCC ²	55.85	7.87	1538
Lead	Pb	FCC	207.19	11.36	327
Magnesium	Mg	HCP	24.31	1.74	650
Nickel	Ni	FCC	58.71	8.90	1453
Silicon	Si	FCC	28.08	2.33	1410

Note: ¹ rhombic, ² at room temperature

(3) Constants and Conversions

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

(4) 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}

K

$$=^{\circ}\text{C} + 273$$

Questions:

1. (a) Using a diagram show that the resolved shear stress in the slip plane (Schmid's law) is:

$$\tau = \sigma \cos \phi \cos \lambda$$

where, ϕ = angle between the applied force and the normal to the slip plane,

λ = angle between the applied force and the slip direction,

σ = applied tensile stress

- (b) A force of 875 lb is applied to a 0.15 in diameter nickel wire having a yield strength of 45,000 psi and a tensile strength of 55,000 psi. Determine whether the wire will
- (i) deform plastically
 - (ii) experience necking
2. (a) Name and describe three types of imperfections found in crystals.
- (b) A metallographic sample of iron has an ASTM grain size of 6. Calculate the number of grains observed in an area 2 in x 3 in inch taken at a magnification of 200X.
- (c) What are the main constituents of concrete. Explain what happens when concrete cures. How does the water/cement ratio affect the properties of the concrete?
3. Draw a thermal equilibrium diagram representing the system between two metals X and Y given the following data:
- (i) X melts at 1000°C and Y at 800°C;
 - (ii) X is soluble in Y in the solid state to the extent of 10.0% at 700°C and 2.0% at 0°C;
 - (iii) Y is soluble in X in the solid state to the extent of 20.0% at 700°C and 8.0% at 0°C;
 - (iv) a eutectic is formed at 700°C containing 40.0% X and 60.0% Y.

Describe what happens when an alloy containing 70.0% X is cooled slowly from 950°C to 0°C. Calculate the amount of liquid present (if any) at 800°C.

Sketch the microstructures of an alloy containing 15% Y:

- (a) after it has cooled slowly to 0°C;
 (b) after it has been heated for some time at 700°C and then water quenched.

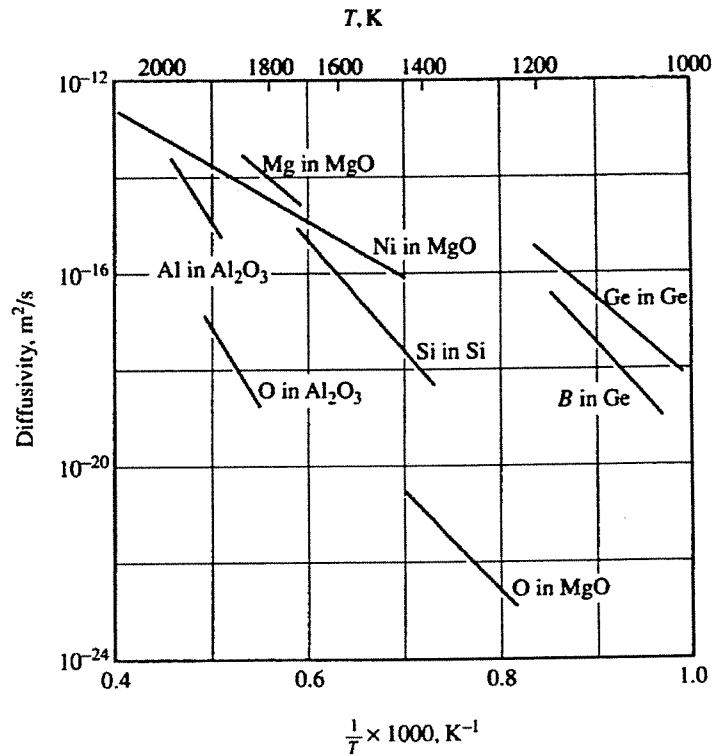


Fig 1 Diffusivity data for some nonmetallic systems

4. (a) Refer to Fig 1 above.
- At a given temperature, why would you expect the diffusivity of oxygen in MgO to be less than that of Mg in MgO? Explain.
 - Similarly, at a given temperature, why does the diffusivity of Mg in MgO lie close to, but higher than that of Ni in MgO?
 - Show that the units of diffusivity are m²/s.
- (b) An insulating brick (true specific gravity = 2.71) weighs 1.69 kg dry, 2.27 kg when the open pores are saturated with kerosene, and 1.30 kg when suspended in kerosene (specific gravity = 0.82). Calculate the:
- True volume, apparent pore volume, and bulk volume (cm³).
 - Closed porosity (%).

5. (a) Show that the minimum cation-anion radius ratio for four-fold coordination is 0.225.
- (b) Calculate the lattice constant a_0 (nm) for lead. Use your value to find the planar density of atoms ($\text{atom}\cdot\text{mm}^{-2}$) on the (110) planes, and the linear density of atoms ($\text{atoms}\cdot\text{mm}^{-1}$) in the [111] direction.
6. (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 60 cm long solid connecting rod of diameter 10 mm consists of borosilicate glass fibres oriented lengthwise in polystyrene. If the rod contains 75% glass and 25% plastic, determine the increase in length of the rod when an axial load of 500N is applied. State all assumptions made.

<u>Material</u>	<u>Density, $\text{g}\cdot\text{cm}^{-3}$</u>	<u>Young's Modulus, GPa</u>
Glass	2.40	70
Polystyrene	1.05	2.8

7. (a) Investigation of an automobile accident revealed that an axle for a rear wheel was broken. The axle could have failed by fatigue thus causing the accident, or have failed in impact as a consequence of the accident. What features of the axle and fracture surface would you look for in an attempt to establish the cause of failure?
- (b) What nondestructive testing method(s) might be helpful in detecting a crack that is parallel to the surface of a steel plate?
- (c) A welded austenitic stainless steel pipe corroded badly in the HAZ parallel to the weld. Explain why this corrosion occurred and what you could do to prevent this from happening again?

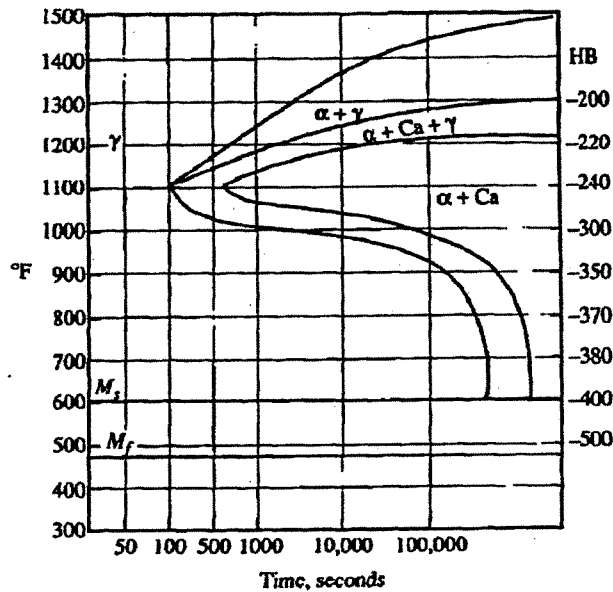


Fig 2 Temperature Time Transition diagram for 1035 carbon steel

8. (a) Fig 2 shows the TTT diagram for a 0.35% carbon steel. The hardness data are for fully transformed structures.
- (i) A foundry finds that castings made of this steel are hard and unmachinable (400 HB) in the as-cast condition. Name two possible microstructures that could be responsible.
 - (ii) The same foundry hears that a competitor is annealing its castings with a cycle called an *isothermal anneal*. This involves heating of the castings, followed by isothermal transformation to a structure of 250 HB max. Draw a time-temperature chart giving this result, labelling *temperatures* and isothermal transformation *time* accurately.
- (b) How would you expect a 2024-T4 aluminum alloy (solution-treated and naturally aged) to compare with a 2024-T6 (solution-treated and artificially aged) and 2024-T8 (solution-treated, cold worked and artificially aged) alloys. Explain your answers.
- (c) Sketch microstructures for three types of cast iron. Indicate principal differences in mechanical properties of these irons.