May 2019 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) Candidates are to attempt five, and only five, questions for a full 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	Al	26.98
Si	28.1	Fe	55.85	Cu	63.54	Mo	95.94		

(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

Cold Working, $CW = \frac{A_o - A_f}{A_o}$ Grain Size, $\mathcal{N} = 2^{n-1}$

Questions:

1. Molybdenum has a body centered cubic structure and lattice parameter, a_o, of 3.1468 Å. Calculate the atomic radius (Å) and density ($g.cm^{-3}$) of molybdenum.

   Sketch the unit cell. On your sketch show the (112) plane and [011] direction. What is the spacing (Å) between the (102) planes?

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:

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

   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:

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

   Which of the two expressions is more valid during necking? Why? (l_o and d_o are the initial sample gauge length and diameter, respectively).

   (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) What is a substitutional solid solution? What factors favour this type of solid solution in metals?

   (b) 18 grains are observed in an area 2in x 2in at a linear magnification of X400. Calculate the ASTM grain size number.

   (c) Describe how you would recognise a fatigue failure.

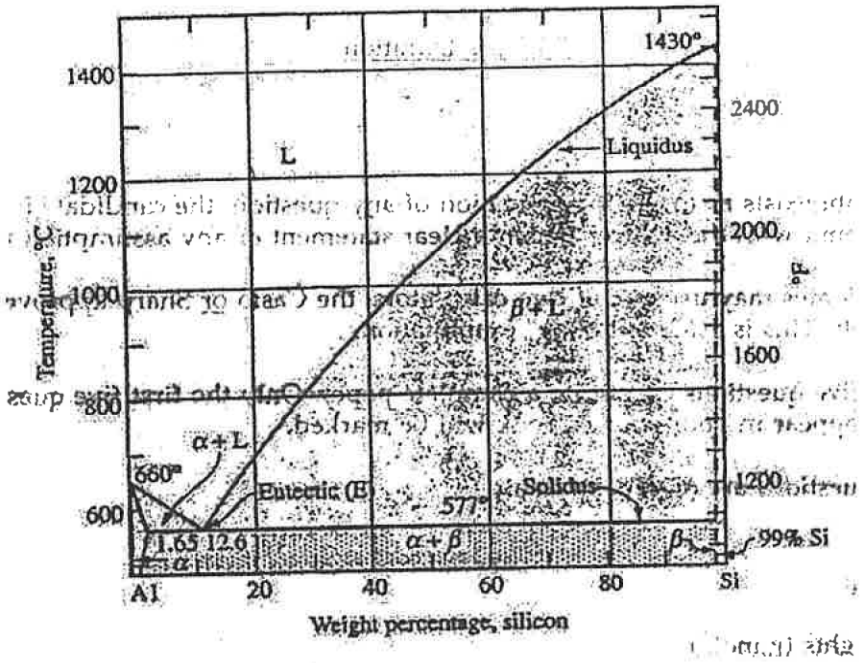

Fig 1. Aluminum – Silicon Phase Diagram

4. Fig 1 shows the Aluminum - Silicon phase diagram. An automobile engine block is cast using a 20% Si - 80% Al alloy. At what temperature will the casting start to solidify? At what temperature is solidification complete? Assuming slow cooling describe the microstructures present at room temperature. How much (if any) of the microstructure will be eutectic? Why would this composition be a good choice as a casting alloy compared with pure aluminum?

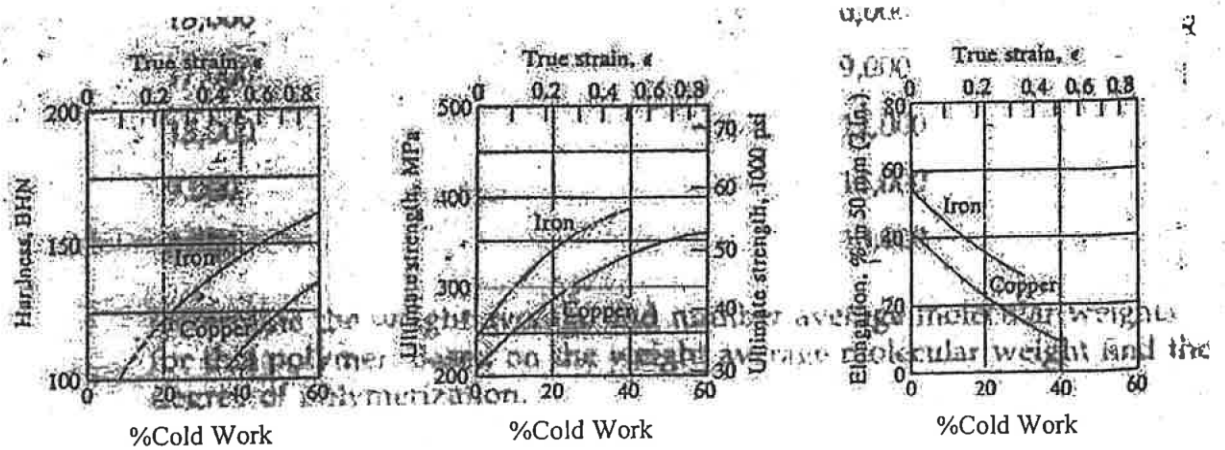

Fig 2. Cold Work vs Mechanical Properties (Iron and Copper)

5. (a) A copper wire must have a diameter 0.7 mm and an ultimate strength of >325 MPa (46,000 psi) together with a minimum ductility of 10% elongation in a tensile test. It is to be processed (drawing and annealing) from 10 mm diameter rod. Using the data in Fig 2, determine the diameter of the die to be used for the penultimate cold draw.

(b) What is a dislocation? Describe the role played by dislocations when a brass sheet is being cold rolled.

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) Sketch a schematic modulus vs temperature plot for amorphous polyethylene. On your sketch identify T_g and T_m (glass transition and melting temperatures). Indicate how the plot would change (if at all) should the polymer have:

(i) increasing crystallinity
(ii) increasing cross-linking

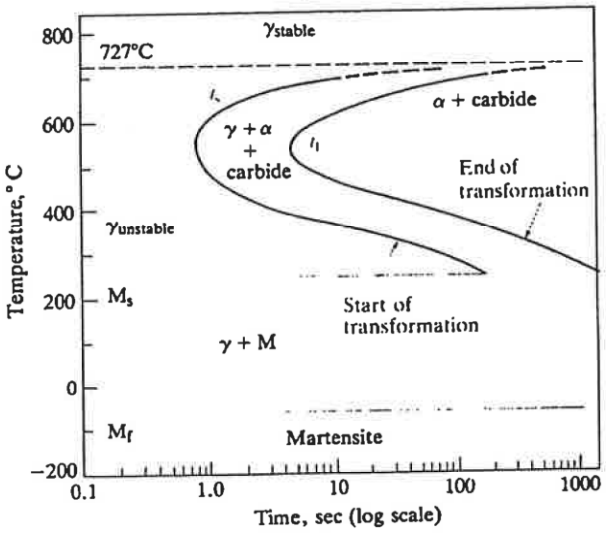

Fig 3 Isothermal diagram for a 0.8% carbon steel

7. (a) Describe the Jominey test. What useful information does it provide?

(b) Fig 3 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.

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

(iii) 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 to a further quench in liquid nitrogen, followed by annealing at 100 °C often gives an improvement in properties. Explain.