DEC 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) Candidates are to attempt five, and only five, questions for a full paper. Two questions must be from Section A, two questions must be from Section B, with the fifth question from either section.

(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	Ti	47.9	Fe	55.85	Cu	63.54		

(2) Constants and Conversions

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

(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, $CW = \frac{A_o - A_f}{A_o}$

Crack Growth, $\frac{da}{dN} = C\,(\Delta K)^n$

Fracture Toughness, $K_{I_c} = f\sigma\sqrt{\pi a_c}$

Grain Size, $\mathcal{N} = 2^{n-1}$

SECTION A

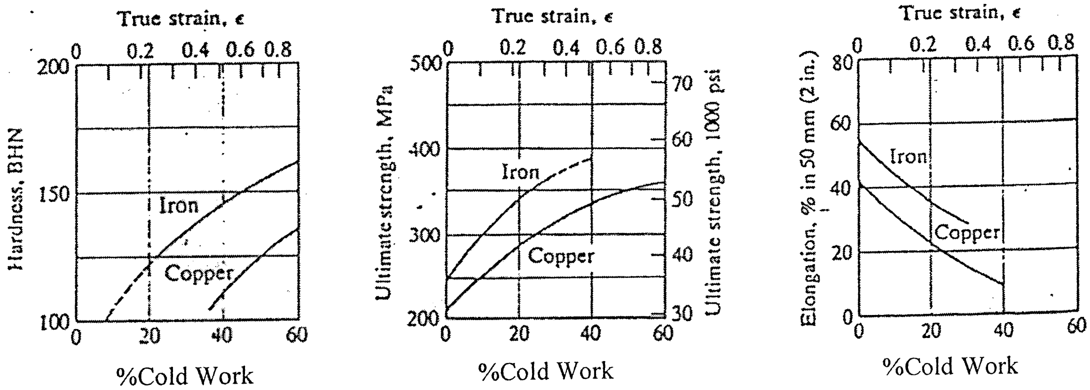

Fig 1. Cold Work vs Mechanical Properties (Iron and Copper)

1. (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 1, 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.

2. (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.

3. A complete stress-strain curve is often not determined in the daily gathering of data. From the information in the table below, determine the yield strength, tensile strength, modulus of elasticity, percent reduction of area, and percent elongation. The initial gauge length is 2.00 in, initial diameter 0.505 in, and diameter after failure 0.423 in.

Load (lb)	Gauge Length (in)
2000	2.001 (all elastic deformation)
6000	2.004 (all plastic deformation)
8500 (maximum)	2.300 (all plastic deformation)
7800 (failed)	2.450 (after failure)

4. (a) Above 882°C, titanium has a BCC structure with a = 0.332 nm. Below this temperature, the metal has a HCP structure with a = 0.2978 nm and c = 0.4735 nm. Determine the percent change in volume when titanium cools through 882°C (i.e. transforms from BCC to HCP).

(b) Describe the Charpy impact test. What relation, if any, is there between the measured impact energy and the stress-strain diagram obtained from tensile tests? What advantages, if any, would the impact test results have in comparison with the tensile test results?

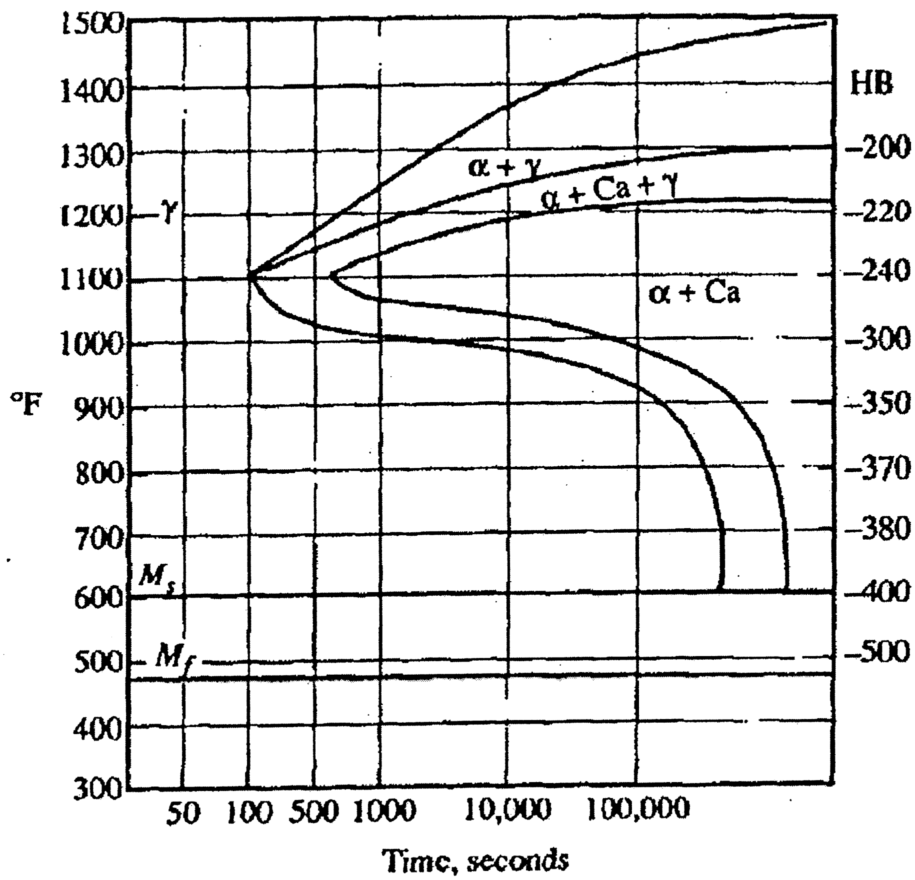

Fig 2. Temperature Time Transition Diagram for 1035 carbon steel

SECTION B

5. (a) Fig 2 shows the TTT diagram for a 0.35% carbon steel. The hardness data are for fully transformed structures. The symbol Ca is for carbide.

   (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) A tank is made of low alloy steel with a yield strength 600 MPa and plane strain fracture toughness 120 MPa.m$^{1/2}$. The steel is exposed to a stress not exceeding 70% of the yield strength. Calculate the minimum size of crack to cause failure. What methods are available to detect cracks of this size?

6. Analysis of a sample of polyacrylonitrile $(CH_2{\cdot}CH{\cdot}CN)_n$ gives the following data for six chain length groups:

Number of chains	Mean molecular weight of chains (g.mol^{-1})
10,000	3,000
18,000	6,000
17,000	9,000
15,000	12,000
9,000	15,000
4,000	18,000

Determine the weight average and number average molecular weights for this polymer. Based on the weight average molecular weight find the degree of polymerization.

7. (a) Indicate whether the following statements are correct or incorrect and justify each answer.

(i) A high concentration of oxidising acid may render a metal more corrosion resistant.

(ii) When an etched microstructure is observed under the microscope, the grain boundaries were anodic during the etching process.

(iii) Oxygen dissolved in water has no effect on the corrosion rate of iron that is exposed to water.

(iv) Aluminum rivets in a steel structure should have longer life against corrosion than steel rivets in an aluminum structure.

(b) In recent years automobile manufacturers have used galvanised steel sheet in body parts to combat corrosion. Considering the principal corrosive to be a dilute NaCl solution, write the ion-electron equations for the corrosion taking place before this changeover (in ordinary steel) and after (in galvanised steel).

(c) A sign manufacturer makes small signs of 18% Cr, 8% Ni, 0.08% C stainless steel by welding letters to a plate of the same material, using a weld rod of the same material. Corrosion occurs ¼ in from the weld.

(i) Write the ion-electron equations.

(ii) Why is the stainless steel not "stainless"?

(iii) What could be done to prevent the corrosion <u>without</u> changing the composition of the parts and without painting?

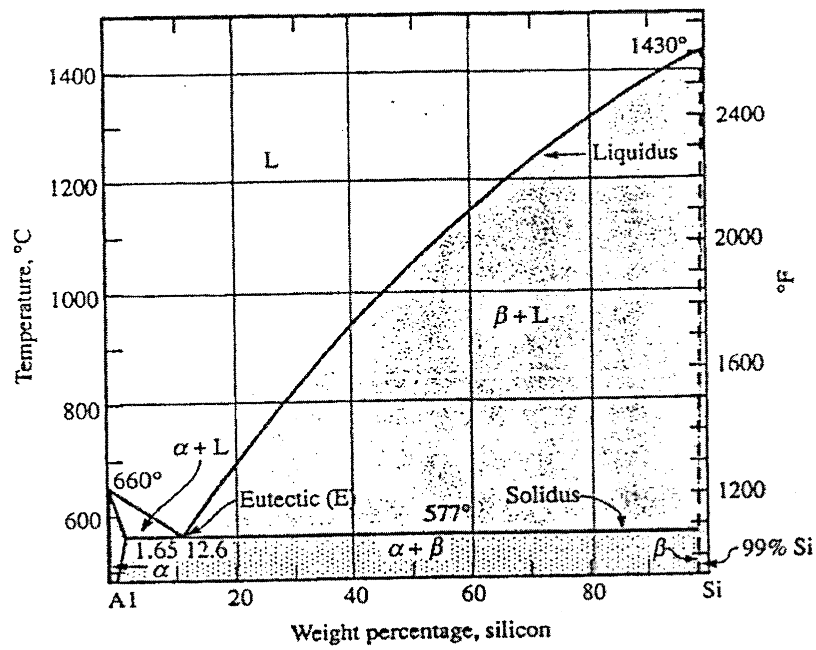

Fig 3. Aluminum – Silicon Phase Diagram

8. (a) Fig 3 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?

(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