**DECEMBER 2013** **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 of the eight (5 of 8) 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 1.0 | Be 9.0 | C 12.0 | N 14.0 | O 16.0 | F 19.0 |
| Al 27.0 | Si 28.1 | Cl 35.5 | Fe 55.9 | Ni 58.7 | Cu 63.54 |

(2) Constants and Conversions

| | |
|---|---|
| Avagadro's number, $N_A$ | $= 0.602 \times 10^{24}$ $mol^{-1}$ |
| Boltzmann's constant, k | $= 13.8 \times 10^{-24}$ J/atom·K |
| Calorie | = 4.18 J |
| Electron volt, eV | $= 0.16 \times 10^{-18}$ J |
| Kelvin, K | $= {}^{o}C + 273$ |

(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 equations

Interplanar spacing $d_{hkl} = \frac{a_o}{\sqrt{h^2 + k^2 + l^2}}$ Boltzmann $\frac{n}{N} = Me^{-E/kT}$

Nernst $E = E_o + \frac{0.0592}{n}\log(C_{ion})$

**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, $\phi$ = angle between the applied force and the normal to the slip plane,
$\lambda$ = angle between the applied force and the slip direction,
$\sigma$ = applied tensile stress

What orientations would yield the maximum value for resolved shear stress? Express this maximum value as a function of the applied tensile stress.

(b) A force of 2500 lb is applied to a 0.25 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) X-ray data gives the lattice constant of silver to be 0.4073 nm and its structure face centered cubic. Calculate the density ($g.cm^{-3}$) and atomic radius (nm) of silver.

(b) Determine the planar density and packing fraction for silver in the (100), (110), and (111) planes. Which, if any, of these planes is close packed?

3. Beryllium melts at 1252 °C and silicon melts at 1414 °C. They are completely soluble as liquids, but completely insoluble as solids. They form a eutectic at 1090 °C containing 39% beryllium. Draw the thermal equilibrium diagram and label all fields. Explain, with the aid of sketches, what happens when liquid alloys containing (a) 90% beryllium, (b) 30% beryllium solidify completely during a slow cooling process. In each case determine the amount (%) of eutectic in the cooled solid.

4. At 500°C, a diffusion experiment indicates that 1 in $10^{10}$ atoms has enough activation energy to jump out of its lattice position into an interstitial site. At 600 °C, this fraction increases to 1 in $10^9$ atoms.

(a) Calculate the activation energy required for the jump. Give your answer in eV/atom and also in cal/mole.

(b) What fraction of the atoms has enough energy at 700 °C?

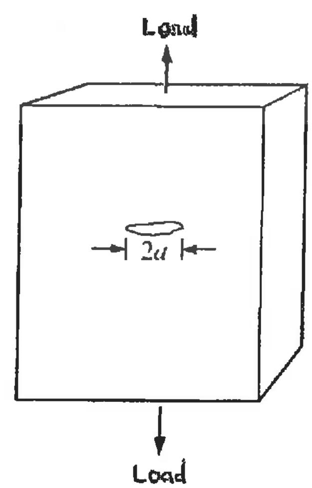
5. (a) The melt index is the rate at which a polymer is extruded under prescribed conditions through a die of specified length and diameter (ASTM-D-1238). The units are grams of polymer extruded in 10 minutes.

   (i) How does the melt index vary with molecular weight of the polymer?
   (ii) Explain why the weight average molecular weight would be more important as a measure of the melt index than would the number average molecular weight.

(b) The degree of polymerization of polytetrafluorethylene (PTFE or Teflon) is 8000. If all the polymer chains are of the same length, calculate:

   (i) The molecular weight of the chains
   (ii) The total number of chains in 1200 g of the polymer.

6. A large panel has a central crack through the thickness of $2a = 0.2$ in. as shown at the right. The panel is 20 in wide and 0.5 in thick and is made of a material of fracture toughness, $K_{Ic} = 24{,}000 \text{psi}\sqrt{\text{in}}$. The panel is cyclically loaded between zero stress and 13,000 psi. Calculate:




(i) the length of crack at which failure occurs

(ii) the number of fatigue cycles it takes to cause failure of the panel.

Hint: For a centre cracked panel, $K_{Ic} = \sigma\sqrt{\pi a}\, Y(a/w)$ and you may assume $Y(a/w) = 1$ as $a \ll w$. The growth of fatigue follows the law $\frac{da}{dN} = C(\Delta K)^m$ where $C = 1.8\times10^{-18}$ in/(cycle.psi $\sqrt{\text{in}}$), $\Delta K = K_{max} - K_{min}$, and $m = 3.0$.

7. (a) How do porosity and grain size affect the tensile strength of ceramic materials?

(b) What are glass network modifiers? How do they affect the silica-glass network? Why are they added to silica glass?

(c) What factors must be considered when designing a fibre reinforced composite?

8. (a) Fig 1 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) Thin Belleville (cupped spring) washers are often austempered. With the aid of a heat treatment diagram describe the procedure and explain why it is employed. Indicate any limitations that may exist in using the process.

(c) How would you expect the mechanical properties of 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. Give a clear explanation of your answers. You are expected to discuss the meaning of the terms in the brackets.