THE UNIVERSITY OF ZAMBIA
SCHOOL OF ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING

MEC 2309 – PROPERTIES OF ENGINEERING MATERIALS I

TERM II TEST **ACADEMIC YEAR 2018**

SEPTEMBER 2019

Answer all questions.
All questions carry equal marks.
Time allowed: Two (2) hours.

Q1.

As a Trainee Engineer at Zambia's leading Foundry Company, you have been assigned to produce rollers for industrial use from hard steel. Based on your assessment, you realise that to easily form the steel into the desired roller shape, the steel ought to be ductile.

(a) From your knowledge of heat treatment of material, describe the steps you would employ to attain ductility in steel to allow for easy forming. [15 marks]

(b) Considering that rollers are exposed to impact loading when in operation and, as a result, is expected to be hard enough to resist deformation, explain the process you would follow to restore hardness in steel after forming. [10 marks]

SOLUTION:

(a) To attain ductility in steel material to enable easy forming, the heat treatment process known as annealing can be applied. The process will involve treating steel up to a temperature slightly below the critical point, and then cooling it very slowly to room temperature, so that the resulting microstructure will possess high ductility and toughness, but low hardness.

During annealing process, the steel should be heated to the appropriate temperature, soaking it at that temperature, and allow it to cool by shutting off the furnace without removing the steel. Annealing reduces the requirements of load and energy required to deform the steel, and enable the metal to undergo large strains without failure.

(b) To gain high hardness sufficient for steel material to resist deformation due to impact, a heat treatment process known as 'hardening' can be used. The process of hardening involves heating of steel to a critical temperature, soak it at an appropriate temperature until all pearlite is transformed into austenite, and then quenching it rapidly in water or oil.

The temperature at which austentizing rapidly takes place depends upon the carbon content in the steel used. The soaking time should be prolonged enough to ensure that the core of the material is also fully transformed into the microstructure of a hardened steel part as ferrite, martensite, or cementite.

Q2.

(a) **What are ceramic materials and are some of their examples?** **[06 marks]**

(b) **List and explain four properties that can be identified for ceramic materials.** **[10 marks]**

(c) **Discuss the application of glass as an engineering material.** **[09 marks]**

<u>SOLUTION:</u>

(a) *Ceramics are a special type of engineering material commonly extracted from the earth crust and used for a number of engineering applications. Ceramics can be categorized as traditional ceramics and advanced ceramics. Ceramic materials like clay are categorized as traditional ceramics and normally they are made of clay, silica, and feldspar.*

Advanced ceramics are special type of ceramics used mainly for electrical, electronic, optical, and magnetic applications and include materials like Barium Titanate (BaTiO3), and piezoelectric materials.

(b) *Ceramics typically possess as properties; high melting points, low electrical and thermal conductivity values, and high compressive strengths. Also they are generally hard and brittle with very good chemical and thermal stability.*

(c) *Glass is used in many engineering application ranging from simple application like kitchen ware to advanced application in in construction depending on the types. Some purposes of glass can be for use in natural lighting, doors, windows, balconies etc.*

Q3.

For a 99.65 wt% Fe and 0.35 wt% C alloy at a temperature just below the eutectoid temperature, determine the following:

(a) The fractions of total ferrite and cementite phases. [08 marks]

(b) The fractions of the pro-eutectoid ferrite and pearlite. [08 marks]

(c) The fraction of eutectoid ferrite. [09 marks]

Assume that the maximum carbon solubility in ferrite is 0.022% C; eutectoid composition is 0.76% C and the cementite line is at 7.6% C.

SOLUTION:

(a) This part of the problem is solved by applying the lever rule expressions employing a tie line that extends all the way across the α + Fe_3C phase field. Thus $C_0^{'}$ = 0.35 (0.35% C), and

(i) wt% α:

$$W_\alpha = \frac{6.70 - 0.35}{6.70 - 0.022}$$

$W_\alpha = 0.95\%$

(i) wt% Fe_3C:

$$W_{\mathrm{Fe_3C}} = \frac{0.35 - 0.022}{6.70 - 0.022}.$$

$W_{Fe3C} = 0.05\%$

(b) the fractions of pro-eutectoid ferrite (p) and pearlite (α') are determined by using the lever rule, and a tie line that extends to the eutectoid composition, i.e. from 0.022 to 0.76% C.:

(i) wt% p:

$$W_p = \frac{0.35 - 0.022}{0.76 - 0.022}$$

$W_p = 0.44\%$

(ii) wt% α':

$$W_{\alpha'} = \frac{0.76 - 0.35}{0.76 - 0.022}$$

$W_{\alpha'} = 0.56\%$

(c) All ferrite is either as pro-eutectoid or eutectoid (in pearlite). Therefore, the sum of these two ferrite fractions will equal the fraction of total ferrite, that is:

$$W_{\alpha'} + W_{\alpha c} = W_\alpha$$

Where $W_{\alpha c}$ denotes the fraction of the total alloy that is eutectoid ferrite. Values of W_{α} and $W_{\alpha'}$ were determined parts (a) and (b) as 0.95 and 0.56, respectively. Therefore:

$$W_{\alpha c} = W_{\alpha} - W_{\alpha} = 0.95 - 0.56$$

$$\underline{\mathbf{W_{\alpha c} = 0.39\%}}$$

Q4.

(a) **What is a solid solution? Give one example of a solid solution.** **[03 marks]**

(b) **Differentiate between interstitial and substitutional solid solutions?** **[10 marks]**

(c) **With suitable sketches, give two examples of substitutional solid solutions.** **[06 marks]**

(d) **State and briefly explain two factors that influence the formation of interstitial solid solutions.** **[06 marks]**

SOLUTION:

(a) A Solid Solution is when in the solid state, the atoms of the solute are present in the lattice of the solvent. A solid solution is not a chemical compound, it is a mixture of or more elements or phases.

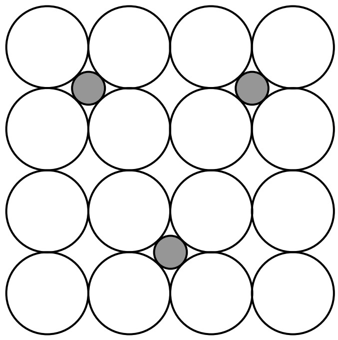
(b) Difference between interstitial and substitutional solid solutions

(i) An interstitial solid solution is the one where solute atoms lodge in the interstices (or inter-atomic spaces) of the solvent lattice, when atoms of the solute occupy the interstitial spaces (interstices) in the lattice of the solvent.

Interstitial solid solution

Solvent atoms

Solute atoms



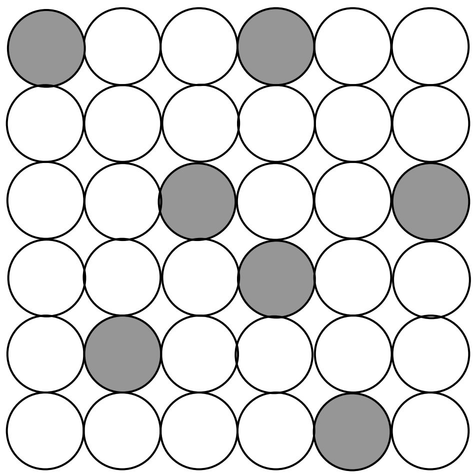
Usually small atoms lodge in the interstices of the larger atoms of the solvent matrix.

(ii) A substitutional solid solution is when the solute atoms replace some solvent atoms so that they lie at normal atom sites of the crystal structure, i.e. the solute atom incorporate into the solvent crystal lattice substitutionally by replacing a solvent atom in the lattice.

Substitutional solid solution

Solvent atoms

Solute atoms



(c) Interstitial solid solutions depend on **atomic size** and **crystal structure**.

(i) ***Effect of Crystal Structure***

Type of solid solution & limits of stability are governed by the relative sizes of solute and solvent atoms. The radius of atoms is not constant. For any atom, it depends on the *coordination number (CN).* In a close-packed lattice (fcc & hcp) CN = 12; in a bcc lattice, CN = 8; in a diamond it is 4, etc.

In close-packed lattices, there are two kinds of spaces, (a) with four atoms and (b) with six atoms arranged symmetrically around the void. Centres of the surrounding atoms lie at the corners of tetrahedra and octahedra, respectively, so the voids are known as *tetrahedral* and *octahedral* spaces.

(ii) ***Effect of Atomic Size***

In interstitial solid solutions, solute atom must be small enough to fit into a space between solvent atoms without causing excessive distortion. Appreciable solid solubility occurs when solute diameter is about 0.4 – 0.6 or less of the solvent diameter.

Apart from the inert gases, nearly all atom diameters lie in the range 0.21 to 0.36nm (i.e. 2.1×10^{-10} to 3.6×10^{-10} m). Metals lie in the range 0.25nm to 0.32nm. The atoms small enough to form interstitial solid solutions are H, O, Li, Na, C, N and B.

END OF MEC 2309 TEST

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