

MATERIALS ENGINEERING

MT30001

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Offered by:

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Concept questions

What type of bonding is expected for each of the following materials: brass, rubber, barium sulfide, xenon, bronze, nylon, aluminum phosphide?

Brass: an alloy, the bonding is metallic

Rubber: a polymer, bonding is covalent with van der Waals

Barium sulfide: a compound, the bonding is predominantly ionic

Xenon: inert gas, the bonding is van der Waals

Bronze: an alloy, the bonding is metallic

Nylon: a polymer, bonding is covalent with van der Waals

Aluminum phosphide: a compound, the bonding is predominantly covalent

Why are poly-crystalline materials mostly isotropic?

The individual grains in a material are predominantly anisotropic (i.e. Different properties along different directions). In a polycrystal however, the grains are randomly distributed and hence the properties are averaged out along all directions. As a result, the polycrystals are mostly isotropic. There are several processing routes like rolling, wire drawing etc. where even in polycrystals the grains are oriented along certain directions. These materials are anisotropic

Mention two reasons why interstitial diffusion is normally more rapid than vacancy diffusion

Interstitial diffusion is normally more rapid than vacancy diffusion, because

1. Interstitial atoms, being smaller, are more mobile
2. The probability of finding an empty adjacent interstitial site is greater than for a substitutional vacancy adjacent to a host atom

Why are metals with HCP structure more brittle than BCC or FCC metals?

HCP metals are more brittle than BCC and FCC metals because the number of slip systems available in HCP metals are far less than BCC and FCC metals

FCC: 12 slip systems

BCC: 48 slip systems

HCP: only 3 slip systems

What is the magnitude of the maximum stress that exists at the tip of an internal crack having a radius of curvature of 2.5×10^{-4} mm and a crack length of 2.5×10^{-2} mm when a tensile stress of 170 MPa is applied?

The maximum stress at the tip of an internal crack of length a and radius of curvature ρ is

$$\sigma_m = 2\sigma \sqrt{\frac{a}{\rho}}$$

Using the parameters mentioned in the problem, the maximum stress at the tip of the internal crack:

$$\sigma_m = 2 \times 170 \times \sqrt{\frac{0.025}{0.00025}} = 2404 \text{ MPa}$$

A specimen of a 4340 steel alloy having a plane strain fracture toughness of 45 MPa√m is exposed to a stress of 1000 MPa. Will this specimen experience fracture if it is known that the largest crack is 0.75 mm long? Assume that the parameter Y has a value of 1.0.

For the specified fracture toughness and the largest crack size mentioned, the maximum fracture stress that the material may survive is

$$\sigma_c = \frac{K_{IC}}{Y\sqrt{\pi a}} = \frac{45}{1.0 \times \sqrt{3.142 \times 0.75 \times 0.001}} = 927 \text{ MPa}$$

As the applied stress is > this maximum fracture stress, the material will possibly experience fracture

Mention two non-destructive testing methods used to detect the internal flaws in a material

- 1) Ultrasonic testing
- 2) X-ray imaging

A fatigue test was conducted in which the mean stress was 50 MPa and the stress amplitude was 225 MPa.

(a) Compute the maximum and minimum stress levels.

(b) Compute the stress ratio.

$$\text{Mean stress} = \frac{\sigma_{\max} + \sigma_{\min}}{2} = 50 \text{ MPa} \quad \text{Stress amplitude} = \frac{\sigma_{\max} - \sigma_{\min}}{2} = 225 \text{ MPa}$$

Solving, $\sigma_{\max} = 275 \text{ MPa}$ and $\sigma_{\min} = -175 \text{ MPa}$

$$\text{Stress ratio} = \frac{\sigma_{\min}}{\sigma_{\max}} = \frac{-175}{275} = -0.64$$

List four measures that may be taken to increase the resistance to fatigue of a metal alloy

- 1) Polish the surface to remove stress amplification sites
- 2) Reduce the number of internal defects (pores, etc.)
- 3) Modify the design to eliminate notches and sudden contour changes
- 4) Harden the outer surface of the structure by case hardening (carburizing, nitriding) or shot peening

If creep becomes important at temperatures $> 0.4T_m$, mention the approx. temperatures for creep in the metals nickel, copper, iron, tungsten, lead, and aluminium

Nickel: $0.4 \times (1455 + 273) = 691\text{K}$ or $418\text{ }^\circ\text{C}$

Copper: $0.4 \times (1085 + 273) = 543\text{K}$ or $270\text{ }^\circ\text{C}$

Iron: $0.4 \times (1538 + 273) = 725\text{K}$ or $452\text{ }^\circ\text{C}$

Tungsten: $0.4 \times (3410 + 273) = 1473\text{K}$ or $1200\text{ }^\circ\text{C}$

Lead: $0.4 \times (327 + 273) = 240\text{K}$ or $-33\text{ }^\circ\text{C}$

Aluminium: $0.4 \times (660 + 273) = 373\text{K}$ or $100\text{ }^\circ\text{C}$

Cite three variables that determine the microstructure of an alloy at room temperature

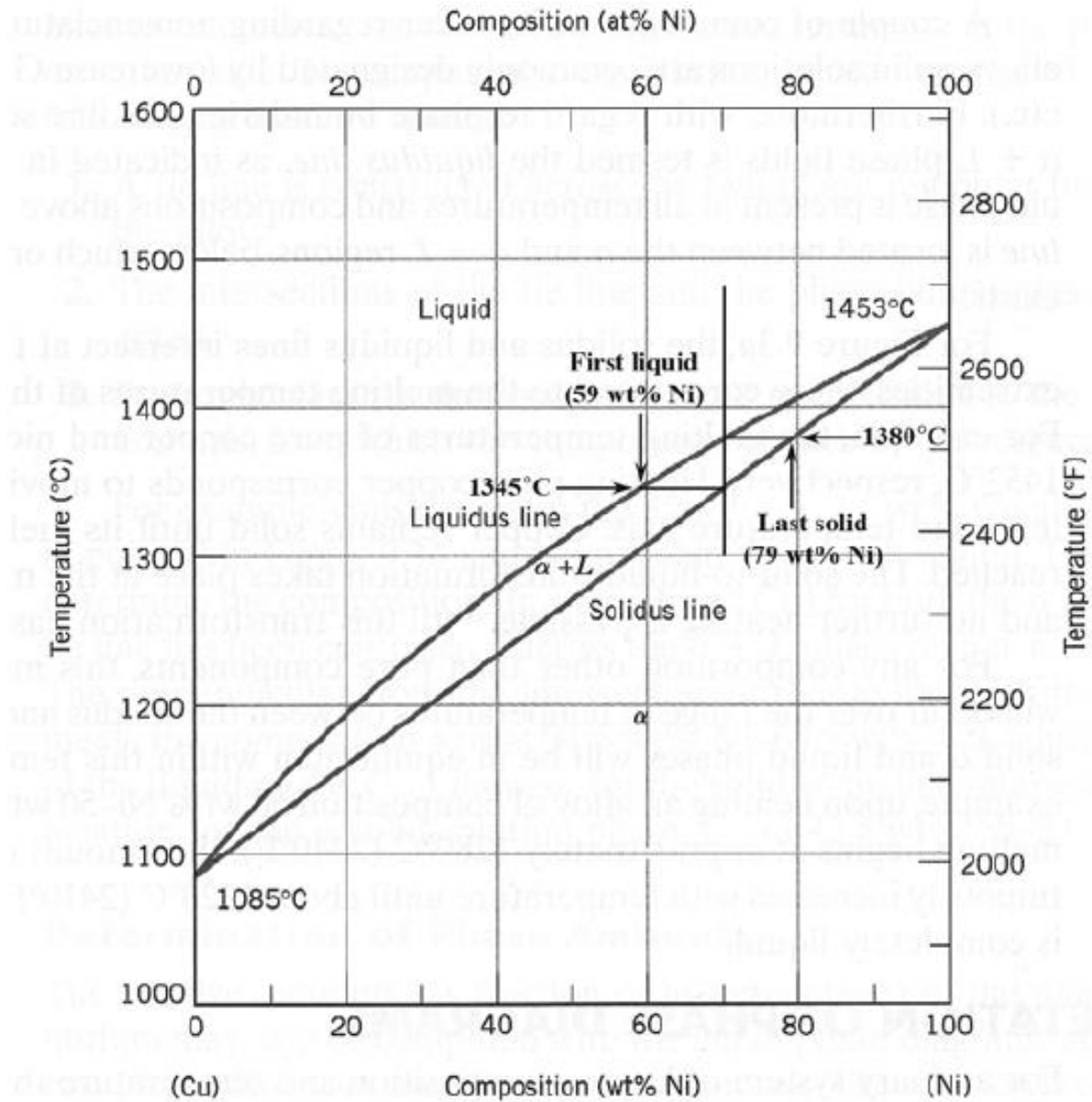
Three variables that determine the microstructure of an alloy are:

- 1) the alloying elements present
- 2) the concentrations of these alloying elements
- 3) the heat treatment of the alloy

A copper-nickel alloy of composition 70 wt% Ni-30 wt% Cu is slowly heated from a temperature of 1300°C .

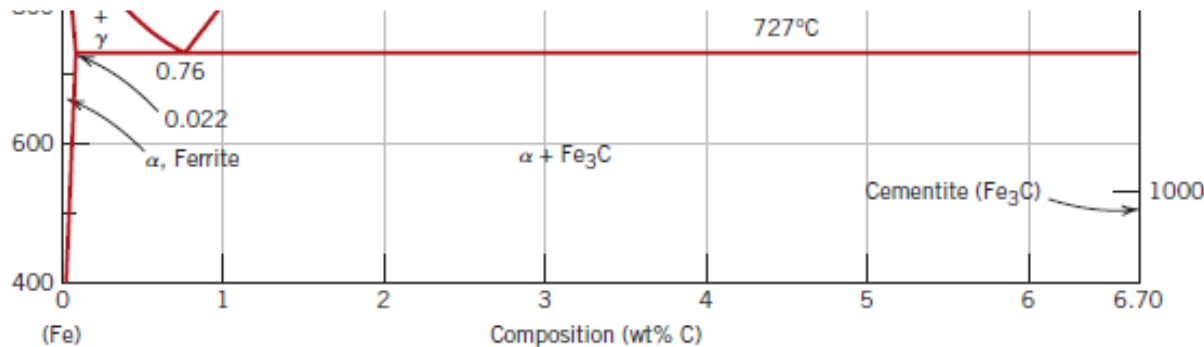
- (a) At what temperature does the first liquid phase form?*
- (b) What is the composition of this liquid phase?*
- (c) At what temperature does complete melting of the alloy occur?*
- (d) What is the composition of the last solid remaining prior to complete melting?*

Refer to phase diagram in the next slide



- (a) The first liquid phase forms when the composition line crosses the solidus line $\rightarrow 1345\text{ }^{\circ}\text{C}$
- (b) Composition of this liquid is the intersection of the horizontal line at $1345\text{ }^{\circ}\text{C}$ with the liquidus line $\rightarrow 59\text{ wt.\% Ni}$
- (c) Complete melting of the solid occurs when the vertical line crosses the liquidus line $\rightarrow 1380\text{ }^{\circ}\text{C}$
- (d) Composition of the last solid remaining prior to melting is the intersection of the horizontal line at $1380\text{ }^{\circ}\text{C}$ with the solidus line $\rightarrow 79\text{ wt.\% Ni}$

Compute the mass fractions of α ferrite and cementite in pearlite at room temperature



Lever rule needs to be used.

Lever rule expression for ferrite fraction calculation

$$W_{\alpha} = \frac{C_{\text{Fe}_3\text{C}} - C_0}{C_{\text{Fe}_3\text{C}} - C_{\alpha}} = \frac{6.70 - 0.76}{6.70 - 0.022} = 0.89$$

Hence, mass fraction cementite = $1.00 - 0.89 = 0.11$

In a hypoeutectoid steel, both eutectoid and proeutectoid ferrite exist. Explain the difference between them.

For a hypoeutectoid steel, the proeutectoid ferrite is a microconstituent that formed above the eutectoid temperature. The eutectoid ferrite is one of the constituents of pearlite that formed at a temperature below the eutectoid.

Briefly explain why fine pearlite is harder and stronger than coarse pearlite, which in turn is harder and stronger than spheroidite.

The hardness and strength of iron-carbon alloys that have microstructures consisting of α -ferrite and cementite phases depend on the boundary area between the two phases. The greater this area, the harder and stronger the alloy inasmuch as (1) these boundaries impede the motion of dislocations, and (2) the cementite phase restricts the deformation of the ferrite phase in regions adjacent to the phase boundaries. Fine pearlite is harder and stronger than coarse pearlite because the alternating ferrite-cementite layers are thinner for fine, and therefore, there is more phase boundary area.

Rank the following iron–carbon alloys and associated microstructures from the highest to the lowest tensile strength:

- (a) 0.25 wt%C with spheroidite,*
- (b) 0.25 wt%C with coarse pearlite,*
- (c) 0.60 wt%C with fine pearlite, and*
- (d) 0.60 wt%C with coarse pearlite.*

This ranking is as follows:

0.60 wt% C, fine pearlite

0.60 wt% C, coarse pearlite

0.25 wt% C, coarse pearlite

0.25 wt% C, spheroidite