

MCEG 2023 Materials Science and Engineering

FALL 2020

Title of Assignment: Homework 10

TOPICS COVERED IN HOMEWORK 10

1. Mechanical Properties of Metals

Solution of Homework 10

Due on Oct. 15, 2020

7.1 To provide some perspective on the dimensions of atomic defects, consider a metal specimen that has a dislocation density of 10^4 mm^{-2} . Suppose that all the dislocations in 1000 mm^3 (1 cm^3) were somehow removed and linked end to end. How far (in miles) would this chain extend? Now suppose that the density is increased to 10^{10} mm^{-2} by cold working. What would be the chain length of dislocations in 1000 mm^3 of material?

Solution

The dislocation density is just the total dislocation length per unit volume of material (in this case per cubic millimeters). Thus, the total length in 1000 mm^3 of material having a density of 10^4 mm^{-2} is just

$$(10^4 \text{ mm}^{-2})(1000 \text{ mm}^3) = 10^7 \text{ mm} = 10^4 \text{ m} = 6.2 \text{ mi}$$

Similarly, for a dislocation density of 10^{10} mm^{-2} , the total length is

$$(10^{10} \text{ mm}^{-2})(1000 \text{ mm}^3) = 10^{13} \text{ mm} = 10^{10} \text{ m} = 6.2 \times 10^6 \text{ mi}$$

ABOVE AVERAGE

MCEG 2023 Materials Science and Engineering

Student Name (Print): Bujato Daniel

Last name **First name**

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7.1

Relation between meters and miles.

$$1 \text{ m} = 0.000062$$

Calculate the chain length corresponding to the specimen dislocation density of 10^5 mm^{-2}

Chain length = Volume of metal specimen X Dislocation density

$$\text{Volume of metal specimen} = 1000 \text{ mm}^3$$

$$\text{Dislocation density} = 10^5 \text{ mm}^{-2}$$

$$\text{Chain length} = 1000 \times 10^5$$

$$= 10^8 \text{ mm} \times \left(\frac{1 \text{ m}}{1000 \text{ mm}} \right)$$

$$= 10^5 \text{ m} \times \left(\frac{0.000062}{1 \text{ m}} \right)$$

$$= 62 \text{ mi}$$

Therefore, the chain length corresponding to the specimen dislocation density of 10^5 mm^{-2} is

62 mi

Calculate the chain length corresponding to the specimen dislocation density of 10^9 mm^{-2}

Chain length = Volume of metal specimen X Dislocation density

$$\text{Volume of metal specimen} = 1000 \text{ mm}^3$$

$$\text{Dislocation density} = 10^9 \text{ mm}^{-2}$$

$$\text{Chain length} = 1000 \times 10^9$$

$$= 10^{12} \text{ mm} \times \left(\frac{1 \text{ m}}{1000 \text{ mm}} \right)$$

$$= 10^9 \text{ m} \times \left(\frac{0.000062}{1 \text{ m}} \right)$$

$$= 6.2 \times 10^5 \text{ mi}$$

Therefore, the chain length corresponding to the specimen dislocation density of 10^9 mm^{-2} is

$6.2 \times 10^5 \text{ mi}$

AVERAGE

MCEG 2023 Materials Science and Engineering

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DESTINY ARIAS

Homework #10

7.1 dislocation density: 10^4 mm^{-2}

Suppose all dislocations in 1000 mm^3 were removed & linked end to end. How far would chain extend (in miles)?

Suppose density is increased to 10^{10} mm^{-2} by cold working.

What would be the chain length of dislocations in 1000 mm^3 of material?

$$\text{chain length} = (\text{vol. of metal specimen}) (\text{dislocation density})$$

$$1 \text{ m} = .00002 \text{ mi}$$

$$10^4 \times 1000^3 = 10^7 \text{ mm}$$

$$10^7 \text{ mm} \times (1 \text{ m} / 1000 \text{ mm}) = 10^4 \text{ m}$$

$$10^4 \text{ m} \times (.00002 \text{ mi} / 1 \text{ m}) = \boxed{0.2 \text{ mi}}$$

chain length corresponding to specimen dislocation density of 10^4 mm^{-2} is 0.2 miles.

$$10^{13} \text{ mm} \times (1 \text{ m} / 1000 \text{ mm}) = 10^{10} \text{ m}$$

$$10^{10} \text{ m} \times (.00002 \text{ mi} / 1 \text{ m}) = 0.2 \times 10^6 \text{ mi}$$

chain length corresponding to specimen dislocation density of 10^{10} mm^{-2} is 0.2×10^6 miles.

BELOW AVERAGE

Student Name (print): Abram Karen

Last Name First Name

7.1

To provide some perspective on the dimensions of atomic defects, consider a metal specimen with a dislocation density of 10^4 mm^{-2} . Suppose that all the dislocations in 1000 mm^3 (1 cm^3) were somehow removed and linked end to end. How far (in miles) would this chain extend? Now suppose that the density is increased to 10^{10} mm^{-2} by cold working. What would be the chain length of dislocations in 1000 mm^3 of material?

Homework 10

7.1) $(10^4 \text{ mm}^{-2})(1000 \text{ mm}^3) = 10^7 \text{ mm} = 10^4 = 6.2 \text{ mi}$

$\rightarrow (10^{10} \text{ mm}^{-2})(1000 \text{ mm}^3) = 10^{13} \text{ mm} = 10^{10} \text{ m}$

$\rightarrow 6.2 \times 10^6 \text{ mi}$

CamScanner

MCEG 2023 Materials Science and Engineering

FALL 2020

Title of Assignment: Homework 11

TOPICS COVERED IN HOMEWORK 11

1. Mechanical Properties of Metals

Solution of Homework 11

Due on Oct. 20, 2020

7.12 Consider a metal single crystal oriented such that the normal to the slip plane and the slip direction are at angles of 43.1° and 47.9° , respectively, with the tensile axis. If the critical resolved shear stress is 20.7 MPa (3000 psi), will an applied stress of 45 MPa (6500 psi) cause the single crystal to yield? If not, what stress will be necessary?

Solution

This problem calls for us to determine whether or not a metal single crystal having a specific orientation and of given critical resolved shear stress will yield. We are given that $\phi = 43.1^\circ$, $\lambda = 47.9^\circ$, and that the values of the critical resolved shear stress and applied tensile stress are 20.7 MPa (3000 psi) and 45 MPa (6500 psi), respectively. From Equation 7.2

$$\tau_R = \sigma \cos \phi \cos \lambda = (45 \text{ MPa})(\cos 43.1^\circ)(\cos 47.9^\circ) = 22.0 \text{ MPa} \quad (3181 \text{ psi})$$

Since the resolved shear stress (22.0 MPa) is greater than the critical resolved shear stress (20.7 MPa), the single crystal will yield.

7.13 A single crystal of aluminum is oriented for a tensile test such that its slip plane normal makes an angle of 28.1° with the tensile axis. Three possible slip directions make angles of 62.4° , 72.0° , and 81.1° with the same tensile axis.

(a) Which of these three slip directions is most favored?

(b) If plastic deformation begins at a tensile stress of 1.95 MPa (280 psi), determine the critical resolved shear stress for aluminum.

Solution

We are asked to compute the critical resolved shear stress for Al. As stipulated in the problem, $\phi = 28.1^\circ$, while possible values for λ are 62.4° , 72.0° , and 81.1° .

(a) Slip will occur along that direction for which $(\cos \phi \cos \lambda)$ is a maximum, or, in this case, for the largest $\cos \lambda$. Cosines for the possible λ values are given below.

$$\cos(62.4^\circ) = 0.46$$

$$\cos(72.0^\circ) = 0.31$$

$$\cos(81.1^\circ) = 0.15$$

Thus, the slip direction is at an angle of 62.4° with the tensile axis.

(b) From Equation 7.4, the critical resolved shear stress is just

$$\begin{aligned} \tau_{\text{crss}} &= \sigma_y (\cos \phi \cos \lambda)_{\text{max}} \\ &= (1.95 \text{ MPa}) [\cos (28.1^\circ) \cos (62.4^\circ)] = 0.80 \text{ MPa} \quad (114 \text{ psi}) \end{aligned}$$

7.18 The critical resolved shear stress for iron is 27 MPa (4000 psi). Determine the maximum possible yield strength for a single crystal of Fe pulled in tension.

Solution

In order to determine the maximum possible yield strength for a single crystal of Fe pulled in tension, we simply employ Equation 7.5 as

$$\sigma_y = 2\tau_{\text{crss}} = (2)(27 \text{ MPa}) = 54 \text{ MPa} \quad (8000 \text{ psi})$$

7.22 Describe in your own words the three strengthening mechanisms discussed in this chapter (i.e., grain size reduction, solid-solution strengthening, and strain hardening). Be sure to explain how dislocations are involved in each of the strengthening techniques.

These three strengthening mechanisms are described in Sections 7.8, 7.9, and 7.10.

ABOVE AVERAGE

MCEG 2023 Materials Science and Engineering

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First name

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Very neat

7.12

Consider the given metal single crystal:

The angle between tensile axis and the normal to the slip plane is: $\phi = 43.1^\circ$

The angle between the tensile axis and the slip direction is: $\lambda = 47.9^\circ$

Critical resolved shear stress for single crystal to yield is: $\tau_{crss} = 20.7 \text{ Mpa}$

Applied tensile stress is: $\sigma = 45 \text{ Mpa}$

Consider equation for resolved shear stress-dependence on applied stress and orientation stress direction relative to slip plane normal and slip direction.

$$\tau_R = \sigma \cos \phi \cos \lambda$$

$$\tau_R = 45 (\cos 43.1^\circ) (\cos 47.9^\circ)$$

$$\tau_R = 22.028 \text{ MPa} > \tau_{crss}$$

Therefore, the resolved shear stress is greater than the critical resolved shear stress. So, the single crystal will yield.

7.13

a) Slip will occur along that direction for which $(\cos \phi \cos \lambda)$ is maximum. In the case, that is for the largest value of $\cos \lambda$.

The value of $\cos \phi$ is constant since slip plane angle is constant that is 28.1° . Therefore, $(\cos \phi \cos \lambda)$ is majorly depends on λ only.

Calculate the cosine for the possible λ values are as follows:

slip directions, λ	$\cos \lambda$
62.4°	0.4632
72.0°	0.3090
81.1°	0.1547

From the table,

The value of $\cos \lambda$ is maximum, when $\lambda = 62.4^\circ$

Therefore, the most favorable slip direction is at an angle

62.4

with the tensile axis.

b) Calculate the critical resolved shear stress for aluminum as follows:

Consider the critical resolved shear stress equation.

$$\tau_{cr} = \sigma_y (\cos \phi \cos \lambda)_{max}$$

Here the yield stress is σ_y , the angle between the normal to the slip plane and the applied stress is ϕ and the angle between the slip and stress direction is λ .

$$\sigma_y = 1.95 \text{ MPa}$$

$$\phi = 28.1^\circ$$

$$\lambda = 62.4^\circ$$

$$\tau_{cr} = 1.95 (\cos 28.1^\circ) (\cos 62.4^\circ)$$

$$= 0.7969 \text{ MPa}$$

$$\approx 0.8 \text{ MPa}$$

Therefore, the critical resolved shear stress for aluminum is

0.8 MPa (114psi)

7.18

Critical resolved shear stress for iron, $\tau_{crss} = 27 \text{ MPa}$ (4000 psi)

Consider equation for yield strength of a single crystal: dependence on the critical resolved shear stress and the orientation of most favorably oriented slip system.

$$\sigma_y = \frac{\tau_{crss}}{(\cos \phi \cos \lambda)_{max}}$$

The minimum stress necessary to introduce yielding occurs when a single crystal is oriented such that under these conditions, $\lambda = 45^\circ$ and $\phi = 45^\circ$

$$\text{then } \sigma_y = 2\tau_{crss}$$

$$\sigma_y = 2 \times (27 \text{ MPa}) \quad \text{or} \quad 2 \times (4000 \text{ psi})$$

$$\sigma_y = 54 \text{ MPa} \quad \text{or} \quad 8000 \text{ psi}$$

$$\sigma_y = 54 \text{ MPa or } 8000 \text{ psi}$$

$\sigma_y = 54 \text{ MPa or } 8000 \text{ psi}$
--

7.22

1. Grain Size reduction- This is an easy way to improve the strength of the material i.e. by making grain size smaller. Smaller grains have greater ratios of surface area to volume, which means a greater number of grain boundaries, therefore more the number of grain boundaries more will be the restriction to the movement of dislocation, slip will be arrested and thus hardness of material increases.
2. Solid solution strengthening- The reason for strengthening improvement by solid solution strengthening is lattice distortion caused by solid impurities, thus more distortions lead to a greater number of dislocations which increase randomness and movement of dislocations stopped and lead to increase in strength of material. For more improvement increase the concentration of solute, increase the atomic size difference between solute and solvent atoms.
3. Strain hardening- In this permanent deformation is done to the material to increase its strength. Permanent deformation leads to a greater number of dislocations which increase randomness and movement of dislocations stopped and thus strength increases.

AVERAGE

MCEG 2023 Materials Science and Engineering

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	Last name	First name

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HW #11

7.12 Given

$$\phi = 43.1^\circ$$

$$\lambda = 47.9^\circ$$

$$\tau_c = 20.7 \text{ MPa}$$

$$\tau_c = 45 \text{ MPa}$$

Relevant Equations/Solution

$$\tau_R = \sigma \cos \phi \cos \lambda =$$

$$(45 \text{ MPa})(\cos 43.1^\circ)(\cos 47.9^\circ) = \boxed{22 \text{ MPa}}$$

* 22 greater than 20.7, single crystal yield.

7.13 Given

$$\phi = 28.1^\circ$$

$$\lambda = 62.4^\circ, 72^\circ, 81.1^\circ$$

Solution

$$\cos(62.4^\circ) = 0.46$$

$$\cos(72.0^\circ) = 0.31$$

$$\cos(81.1^\circ) = 0.15$$

$$\tau_{\text{max}} = \sigma_y (\cos \phi \cos \lambda)_{\text{max}}$$

$$= 1.95 \text{ MPa} [\cos 28.1^\circ \cos 62.4^\circ]$$

$$= \boxed{0.80 \text{ MPa}}$$

7.18

Given

$$J_{\text{critical}} = 27 \text{ MPa}$$

$$\sigma_y = ?$$

Solution

From Equation 7.5

$$\sigma_y = 2 J_{\text{critical}}$$

$$= 2(27 \text{ MPa}) = \boxed{54 \text{ MPa}}$$

7.22 Describe 3 strengthening mechanisms

- a) Grain size reduction: directly related to the plastic deformation achieved by creating the obstruction to mobility of dislocations.
- b) Solid Solution Strengthening: By adding impurity, that will be placed in substitutional solid solution strengthening.
- c) Strengthening by strain hardening: Strength is achieved by plastic deformation. The density of dislocation increases when the percentage of cold working is increased.

BELOW AVERAGE

MCEG 2023 Materials Science and Engineering

Student Name (Print): Ojo Temitayo
Last name First name

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Homework 11

7.12 Step 1:

$$\phi = 43.1^\circ$$

$$\lambda = 47.9^\circ$$

$$\tau_{CRSS} = 20.1 \text{ MPa}$$

$$\sigma = 45 \text{ MPa}$$

Step 2:

$$\tau_R = \sigma \cos \phi \cos \lambda$$

$$\tau_R = 45 (\cos 43.1^\circ) (\cos 47.9^\circ)$$

$$(\tau_R = 22.028 \text{ MPa}) > \tau_{CRSS}$$

Since the resolved shear stress is greater than the critical resolved shear stress, so, the single crystal will yield.

7.13a) $(\cos \phi \cos \lambda)$ is maximum

$\cos \phi$ is constant as well as 28.1°

Slip directions, λ $\cos \lambda$

$$62.4^\circ \quad 0.4632$$

$$72.0^\circ \quad 0.3090$$

$$81.1^\circ \quad 0.1541$$

Value of $\cos \lambda$ is maximum when $\lambda = 62.4^\circ$

$$(b) \tau_{cr} = \sigma_y (\cos \phi \cos \lambda)_{\max}$$

Yield stress σ_y

Substitute 1.95 MPa for σ_y , 28.1° for ϕ and 62.4° for λ

$$\tau_{cr} = 1.95 (\cos 28.1^\circ) (\cos 62.4^\circ)$$

$$= 0.7969 \text{ MPa}$$

$$\approx 0.8 \text{ MPa}$$

$$0.8 \text{ MPa} (114 \text{ psi})$$

7.18 Step 1 :

$$\tau_{crss} = 27 \text{ MPa (4000 PSI)}$$

$$\sigma_y = \frac{\tau_{crss}}{(\cos \phi \cos \lambda)_{\max}}$$

$$\lambda = 45^\circ \text{ and } \phi = 45^\circ$$

$$\sigma_y = 2 \tau_{crss}$$

$$\sigma_y = 2 \times (27 \text{ MPa}) \text{ or } 2 \times (4000 \text{ PSI})$$

$$\sigma_y = 54 \text{ MPa or } 8000 \text{ PSI}$$

$$\sigma_y = 54 \text{ MPa or } 8000 \text{ PSI}$$

7.22 Strengthening Mechanisms:

(a) Grain Size reduction - This^{is} an easy way to improve the strength of the material i.e. by making grain size smaller. Smaller grains have greater ratios of surface area to volume, which means a greater number of grain boundaries, therefore more the number of grain boundaries more will be the restriction to the movement of dislocation, slip will be arrested and thus hardness of material increases.

(b) Solid Solution Strengthening - The reason for strengthening improvement by solid solution strengthening is lattice distortion caused by solid impurities, thus more distortions lead to more number of dislocations which increase randomness and movement of dislocations stopped and lead to increase in strength of material. For more improvement increase the concentration of solute, increase the atomic size difference between solute and solvent atoms.

(c) Strain hardening - In this permanent deformation is done to the material to increase its strength. Permanent deformation leads

to more number of dislocations which increase randomness and movement of dislocations stopped and thus strength increases.

MCEG 2023 Materials Science and Engineering

FALL 2020

Title of Assignment: Homework 12

TOPICS COVERED IN HOMEWORK 12

1. Mechanical Properties of Metals

Solution of Homework 12
Due on Oct. 22, 2020

7.27 (a) Show, for a tensile test, that

$$\%CW = \left(\frac{\epsilon}{\epsilon + 1} \right) \times 100$$

if there is no change in specimen volume during the deformation process (i.e., $A_0 l_0 = A_d l_d$).

(b) Using the result of part (a), compute the percent cold work experienced by naval brass (the stress-strain behavior of which is shown in Figure 6.12) when a stress of 400 MPa (58,000 psi) is applied.

Solution

(a) From Equation 7.8

$$\%CW = \left(\frac{A_0 - A_d}{A_0} \right) \times 100 = \left(1 - \frac{A_d}{A_0} \right) \times 100$$

Which is also equal to

$$\left(1 - \frac{l_0}{l_d} \right) \times 100$$

since $A_d/A_0 = l_0/l_d$, the conservation of volume stipulation given in the problem statement. Now, from the definition of engineering strain (Equation 6.2)

$$\epsilon = \frac{l_d - l_0}{l_0} = \frac{l_d}{l_0} - 1$$

Or,

$$\frac{l_0}{l_d} = \frac{1}{\epsilon + 1}$$

Substitution for l_0/l_d into the %CW expression above gives

$$\%CW = \left(1 - \frac{l_0}{l_d} \right) \times 100 = \left(1 - \frac{1}{\epsilon + 1} \right) \times 100 = \left(\frac{\epsilon}{\epsilon + 1} \right) \times 100$$

(b) From Figure 6.12, a stress of 400 MPa (58,000 psi) corresponds to a strain of 0.13. Using the above expression

$$\%CW = \left(\frac{\epsilon}{\epsilon + 1} \right) \times 100 = \left(\frac{0.13}{0.13 + 1.00} \right) \times 100 = 11.5\%CW$$

- 7.36 (a) What is the driving force for recrystallization?
(b) What is the driving force for grain growth?

Answer

- (a) The driving force for recrystallization is the difference in internal energy between the strained and unstrained material.
(b) The driving force for grain growth is the reduction in grain boundary energy as the total grain boundary area decreases.

- 7.37 (a) From Figure 7.25, compute the length of time required for the average grain diameter to increase from 0.01 to 0.1 mm at 500°C for this brass material.
(b) Repeat the calculation at 600°C.

Solution

- (a) At 500°C, the time necessary for the average grain diameter to grow to increase from 0.01 to 0.1 mm is approximately 3500 min.
(b) At 600°C the time required for this same grain size increase is approximately 150 min.

7.38 Consider a hypothetical material that has a grain diameter of 6.3×10^{-2} mm. After a heat treatment at 500°C for 4 h, the grain diameter has increased to 1.10×10^{-1} mm. Compute the grain diameter when a specimen of this same original material (i.e., $d_0 = 6.3 \times 10^{-2}$ mm) is heated for 5.5 h at 500°C . Assume the n grain diameter exponent has a value of 2.0.

Solution

To solve this problem requires that we use Equation 7.9 with $n = 2$. It is first necessary to solve for the parameter K in this equation, using values given in the problem statement of d_0 (6.3×10^{-2} mm) and the grain diameter after the 4-h heat treatment (1.10×10^{-1} mm). The computation for K using a rearranged form of Equation 7.9 in which K becomes the dependent parameter is as follows:

$$\begin{aligned} K &= \frac{d^2 - d_0^2}{t} \\ &= \frac{(1.10 \times 10^{-1} \text{ mm})^2 - (6.3 \times 10^{-2} \text{ mm})^2}{4 \text{ h}} \\ &= 2.03 \times 10^{-3} \text{ mm}^2/\text{h} \end{aligned}$$

It is now possible to solve for the value of d after a heat treatment of 5.5 h using a rearranged form of Equation 7.9:

$$\begin{aligned} d &= \sqrt{d_0^2 + Kt} \\ &= \sqrt{(6.3 \times 10^{-2} \text{ mm})^2 + (2.03 \times 10^{-3} \text{ mm}^2/\text{h})(5.5 \text{ h})} \\ &= 1.23 \times 10^{-1} \text{ mm} \end{aligned}$$

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7.27

Very neat

Given data

During the deformation process there is no change in the specimen volume

(i.e., $A_d l_d = l_0 A_0$)

a) Percent cold work (%CW) will depend on original and deformed cross-sectional areas, i.e.,

$$\%CW = \left(\frac{A_0 - A_d}{A_0} \right) \times 100$$

$$\%CW = \left(1 - \frac{A_d}{A_0} \right) \times 100$$

From data given in the problem, $A_d l_d = l_0 A_0$

$$\text{Then, } \frac{A_d}{A_0} = \frac{l_0}{l_d}$$

$$\%CW = \left(1 - \frac{A_d}{A_0} \right) \times 100$$

$$\%CW = \left(1 - \frac{l_0}{l_d} \right) \times 100$$

From definition of engineering strain,

$$\epsilon = \frac{l_d - l_0}{l_0}$$

$$\epsilon = \frac{l_d}{l_0} - 1$$

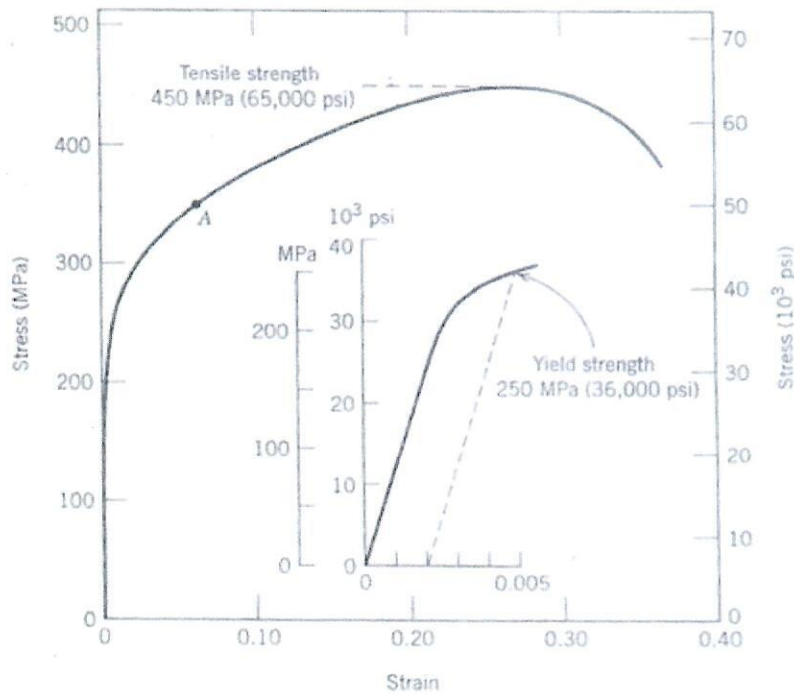
$$\frac{l_0}{l_d} = \frac{1}{1 + \epsilon}$$

Then $\%CW = \left(1 - \frac{l_0}{l_d} \right) \times 100$ becomes,

$$\%CW = \left(1 - \frac{1}{1 + \epsilon} \right) \times 100$$

$$\%CW = \left(\frac{\epsilon}{\epsilon + 1} \right) \times 100$$

b) Naval brass stress strain behavior



A stress of 400 MPa corresponds to a strain of 0.16. Using the above diagram,

$$\%CW = \left(\frac{\epsilon}{\epsilon + 1} \right) \times 100$$

$$\%CW = \left(\frac{0.16}{0.16 + 1} \right) \times 100$$

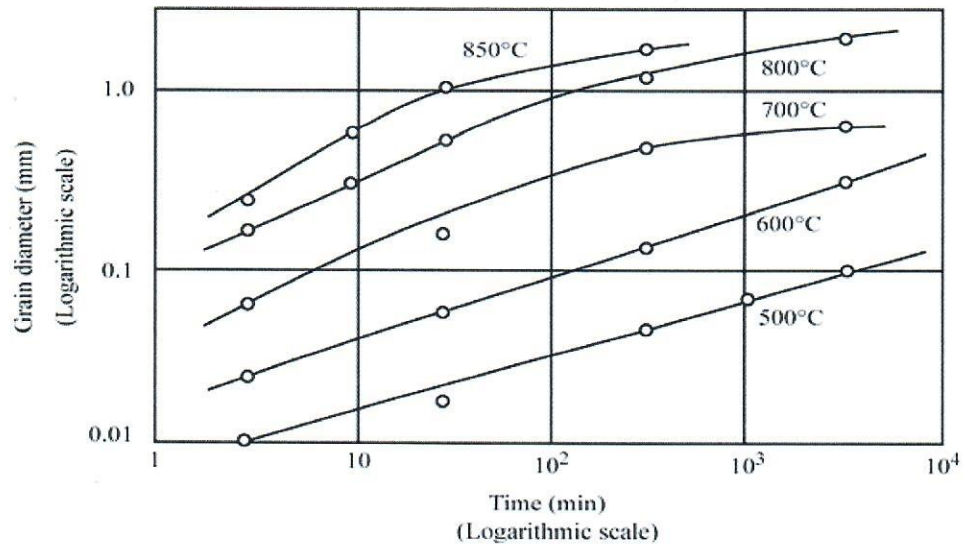
$$\%CW = 13.8$$

7.36

a) The driving force for recrystallization is the difference in internal energy between the strained and unstrained material.

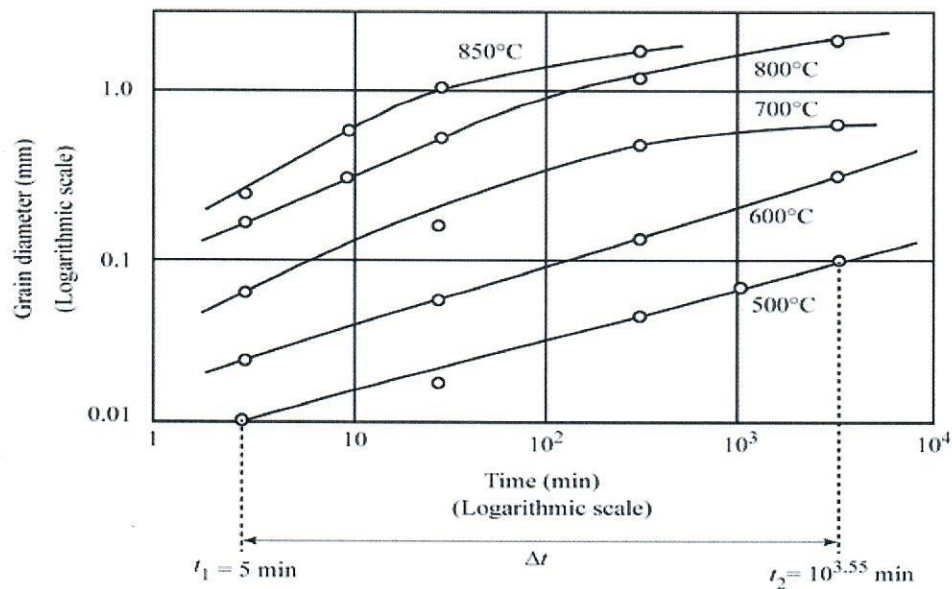
b) The driving force for grain growth is the reduction in grain boundary energy as the total grain boundary are decreases.

7.37



a) $\Delta t = t_2 - t_1$

Here, the time at which average grain diameter is 0.01 mm at 500°C is t_1 and the time at which average grain diameter is 0.1 mm at 500°C is t_2



From the above graph, we obtain the values of t_1 and t_2 as,

$t_1 = 5$ mins

$t_2 = 10^{3.55}$ mins

Calculate the length of time required for the average grain diameter to increase from 0.01 mm to 0.1 mm

Substitute 5 mins to t_1 and $10^{3.55}$ mins to t_2

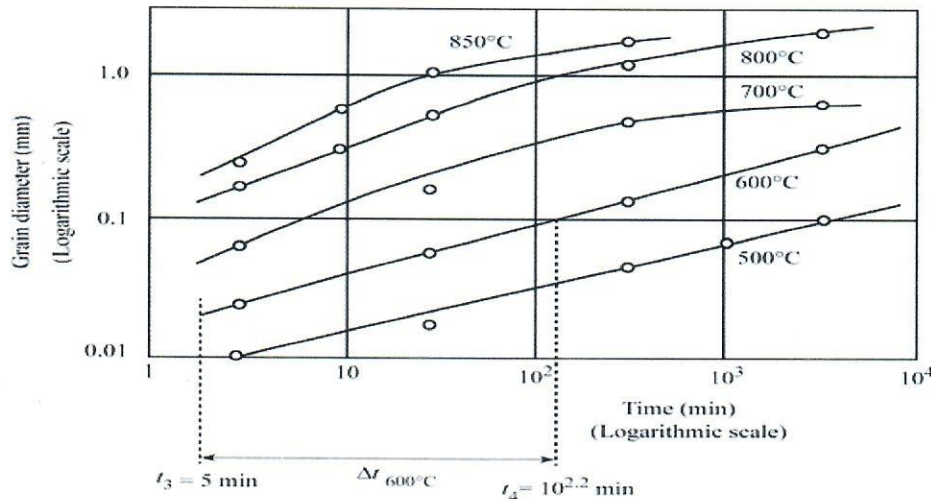
$$\begin{aligned}\Delta t &= t_2 - t_1 \\ &= 10^{3.55} - 5 \\ &= 3543.13 \text{ mins} \\ &\approx 3500 \text{ mins}\end{aligned}$$

At 500°C, the length of time required for the average grain diameter to increase from 0.01 mm to 0.1 mm at 500°C for brass is approximately

3500 mins

b) $\Delta t_{600^\circ\text{C}} = t_4 - t_3$

Here, The time at which average grain diameter is 0.01 mm at 600°C is t_3 and the time at which average grain diameter is 0.1 mm at 600°C is t_4



From the graph above, we obtain the value of t_3 and t_4 as,

$$t_3 = 5 \text{ mins}$$

$$t_4 = 10^{2.2} \text{ mins}$$

Calculate the length of time required for the average grain diameter to increase from 0.01 mm to 0.1 mm

Substitute 5 min for t_3 and $10^{2.2}$ mins for t_4

$$\begin{aligned}\Delta t_{600^\circ\text{C}} &= t_4 - t_3 \\ &= 10^{2.2} - 5 \\ &= 153.49 \text{ mins} \\ &\approx 150 \text{ mins}\end{aligned}$$

At 600°C, the length of time required for the average grain diameter to increase from 0.01 mm to 0.1 mm at 600°C for brass is approximately

150 mins

7.38

Calculate the time independent constant K

$$d^2 - d_0^2 = Kt$$

Here, d is the grain diameter, d_0 is the initial grain diameter, K is the time independent constant, t is the time.

$$d_0 = 6.3 \times 10^{-2} \text{ mm}$$

$$d^2 = 1.10 \times 10^{-1} \text{ mm}$$

$$t = 4 \text{ h}$$

$$n = 2$$

$$\frac{(1.10 \times 10^{-1})^2 - (6.3 \times 10^{-2})^2}{4}$$

$$K = 20.3275 \times 10^{-4} \text{ mm}^2/\text{h}$$

$$K = 20.3275 \times 10^{-4} \text{ mm}^2/\text{h}$$

If the treatment would be done with same initial grain $d_0 = 6.3 \times 10^{-2} \text{ mm}$ for $t = 5.5 \text{ h}$ then,

$$d^n - d_0^n = Kt$$

$$d^n = d_0^n + Kt$$

$$d^2 = (6.3 \times 10^{-2})^2 + 20.3275 \times 10^{-4} \times 5.5$$

$$d = \sqrt{39.69 \times 10^{-4} + 111.125 \times 10^{-4}}$$

$$d = 12.308 \times 10^{-2} \text{ mm}$$

$$d = 12.308 \times 10^{-2} \text{ mm}$$

AVERAGE

MCEG 2023 Materials Science and Engineering

Student Name (Print): Lira Anette

Last name **First name**

Homework Requirements:

- 1) Draw a **box** around the final answer. Correct units, where applicable, must be displayed on the final answer for each homework problem. Incorrect or the omission of units on the final answer may be penalized, particularly when units are not carried throughout calculations that support the final answer.
- 2) Hand-written or MS Word generated homework should be submitted electronically before the deadlines.
- 3) All homework must be presented neatly. Use ink or dark pen. The following item is **NOT** acceptable: very light pencil.
- 4) Put this cover sheet on **top** of your homework. Print your **name** clearly on page 1.
- 5) All homework will follow the above requirements.

HOMEWORK 12

7.27

(a)

$$A_0 l_0 = A_d l_d$$

$$\frac{A_d}{A_0} = \frac{l_0}{l_d}$$

$$\% CW = \left(1 - \frac{l_0}{l_d}\right) \times 100$$

$$\epsilon = \frac{l_d}{l_0} - 1$$

$$\frac{l_d}{l_0} = \epsilon + 1$$

$$\frac{l_0}{l_d} = \frac{1}{\epsilon + 1}$$

$$\% CW = \left(1 - \frac{1}{\epsilon + 1}\right) \times 100 = \left(\frac{\epsilon}{\epsilon + 1}\right) \times 100$$

(b)

~~$\% CW = \left(\frac{l_0}{l_d} - 1\right) \times 100$~~

~~$\epsilon = 0.12$~~

~~$\% CW = \left(\frac{0.12}{0.12 + 1}\right) \times 100$~~

$\epsilon = 0.12$

$$\% CW = \left(\frac{0.12}{0.12 + 1}\right) \times 100$$

$$= 10.714\%$$

↑

FINAL ANSWER

7.36

(a) The driving force for recrystallization is the difference in internal energy between the strained and unstrained material.

(b) The driving force for grain growth is the reduction in grain boundary energy as the total grain boundary area decreases

7.37

(a) $\Delta t = t_2 - t_1, \dots$

average grain diameter is 0.01 mm at 500°C is t_1 and time at which average grain diameter is 0.1 mm at 500°C is t_2

$$t_1 = 5 \text{ mins}$$

$$t_2 = 10^{3.55} \text{ mins}$$

$$\begin{aligned}\Delta t &= t_2 - t_1 \\ &= 10^{3.55} - 5 \\ &= 3543.13 \text{ mins}\end{aligned}$$

$$\approx 3500 \text{ mins}$$

(b) Calculate the length of time ($\Delta t_{600^\circ\text{C}}$)

$$\Delta t_{600^\circ\text{C}} = t_4 - t_3$$

$$\begin{aligned}t_3 &= 5 \text{ mins} \\ t_4 &= 10^{2.2}\end{aligned}$$

$$\Delta t_{600^\circ\text{C}} = t_4 - t_3$$

$$\begin{aligned}&= 10^{2.2} - 5 \\ &= 153.49 \text{ mins} \\ &\approx 150 \text{ mins}\end{aligned}$$

or
 154 mins

7.38

initial grain diameter (d_0) = 6.3×10^{-2} mm

After heat treatment, grain diameter (d) = 1.10×10^{-1} mm

grain diameter exponent (n) = 2

Formula, $D^n - D_0^n = K(t - t_0)$

t = time for that
period we are doing heat treatment

t_0 = initial time (can take 0)

first,

$$K = \frac{d^n - d_0^n}{t} = \frac{(1.10 \times 10^{-1})^2 - (6.3 \times 10^{-2})^2}{4}$$

$$K = 20.3275 \times 10^{-4} \text{ mm}^2/\text{h}$$

$d_0 = 6.3 \times 10^{-2}$ mm for 5.5h

$$d^n - d_0^n = Kt$$

$$d^n = d_0^n + Kt$$

$$d^2 = (6.3 \times 10^{-2})^2 + 20.3275 \times 10^{-4} (5.5)$$

$$d = \sqrt{39.69 \times 10^{-4} + 111.80125 \times 10^{-4}}$$

$$d = 12.308 \times 10^{-2} \text{ mm}$$

BELOW AVERAGE

MCEG 2023 Materials Science and Engineering

Student Name (Print):	<u>Jangda</u>	<u>Aamna</u>
	Last name	First name

Homework Requirements:

- 1) Draw a **box** around the final answer. Correct units, where applicable, must be displayed on the final answer for each homework problem. Incorrect or the omission of units on the final answer may be penalized, particularly when units are not carried throughout calculations that support the final answer.
- 2) Hand-written or MS Word generated homework should be submitted electronically before the deadlines.
- 3) All homework must be presented neatly. Use ink or dark pen. The following item is **NOT** acceptable: very light pencil.
- 4) Put this cover sheet on **top** of your homework. Print your **name** clearly on page 1.
- 5) All homework will follow the above requirements.

HW #12

7.27 Given

$$\%CW = \left(\frac{\epsilon}{\epsilon + 1} \right) \times 100$$

Solution

$$\begin{aligned} \%CW &= \left(\frac{A_o - A_d}{A_o} \right) \times 100 = \left(1 - \frac{A_d}{A_o} \right) \times 100 \\ &= \left(1 - \frac{l_o}{l_d} \right) \times 100 \end{aligned}$$

$$\epsilon = \frac{l_d - l_o}{l_o} = \frac{l_d}{l_o} - 1$$

$$\frac{l_o}{l_d} = \frac{1}{\epsilon + 1}$$

$$\begin{aligned} \%CW &= \left(1 - \frac{l_o}{l_d} \right) \times 100 = \left(1 - \frac{1}{\epsilon + 1} \right) \times 100 \\ &= \left(\frac{\epsilon}{\epsilon + 1} \right) \times 100 \end{aligned}$$

$$\begin{aligned} \text{b)} \quad \%CW &= \left(\frac{\epsilon}{\epsilon + 1} \right) \times 100 \\ &= \left(\frac{0.13}{0.13 + 1} \right) \times 100 \end{aligned}$$

$$= \boxed{11.5\% \text{ CW}}$$

7.36) What is the driving force for recrystallization / grain growth.

Solutions

- a) Recrystallization: difference in internal energy between the strained and unstrained material.
- b) Grain growth: reduction in grain boundary as total grain boundary area decreases.

7.37) From Figure 7.25

Given

$$d_1 = 0.01 \text{ mm} \quad d_2 = 0.1 \text{ mm}$$

$$T_1 = 500^\circ \text{C} \quad \text{- Brass materials}$$

- a) At 500°C , the time necessary for the average grain diameter to grow to increase from $0.1 \rightarrow 0.1 \text{ mm}$ is approximately 3500 min.
- b) At 600°C , the time required for this same grain size increase is about 150 min.

7.38) Given

$$d = 6.3 \times 10^{-2} \text{ mm}$$

$$d_0 = 1.1 \times 10^{-2} \text{ mm}$$

$$T_1 = 500^\circ\text{C}$$

$$t = 4 \text{ h}$$

$$T_2 = 500^\circ\text{C}$$

$$t = 5.5 \text{ h heated.}$$

Solution

$$K = \frac{d^2 - d_0^2}{t} = \frac{(6.3 \times 10^{-2})^2 - (2.1 \times 10^{-2})^2}{4}$$

$$= 1.87 \times 10^{-3} \text{ mm}^2/\text{h}$$

$$d = \sqrt{d_0^2 + Kt}$$

$$= \sqrt{(2.1 \times 10^{-2})^2 + (1.87 \times 10^{-3})(5.5)}$$

$$= \boxed{5.1 \times 10^{-2} \text{ mm}}$$

MCEG 2023 Materials Science and Engineering

FALL 2020

Title of Assignment: Homework 13

TOPICS COVERED IN HOMEWORK 13

1. Mechanical Properties of Metals
2. Dislocations and Strengthening Mechanisms

Solution of Homework 13

Due on Nov. 12, 2020

9.1 Consider the sugar–water phase diagram of Figure 9.1.

- (a) How much sugar will dissolve in 1500 g water at 90°C (194°F)?
- (b) If the saturated liquid solution in part (a) is cooled to 20°C (68°F), some of the sugar will precipitate out as a solid. What will be the composition of the saturated liquid solution (in wt% sugar) at 20°C?
- (c) How much of the solid sugar will come out of solution upon cooling to 20°C?

(a) We are asked to determine how much sugar will dissolve in 1500 g of water at 90°C. From the solubility limit curve in Figure 9.1, at 90°C the maximum concentration of sugar in the syrup is about 77 wt%. It is now possible to calculate the mass of sugar using Equation 4.3 as

$$C_{\text{sugar}} (\text{wt}\%) = \frac{m_{\text{sugar}}}{m_{\text{sugar}} + m_{\text{water}}} \times 100$$

$$77 \text{ wt}\% = \frac{m_{\text{sugar}}}{m_{\text{sugar}} + 1500 \text{ g}} \times 100$$

Solving for m_{sugar} yields $m_{\text{sugar}} = 5022 \text{ g}$

(b) Again using this same plot, at 20°C the solubility limit (or the concentration of the saturated solution) is about 64 wt% sugar.

(c) The mass of sugar in this saturated solution at 20°C (m'_{sugar}) may also be calculated using Equation 4.3 as follows:

$$64 \text{ wt}\% = \frac{m'_{\text{sugar}}}{m'_{\text{sugar}} + 1500 \text{ g}} \times 100$$

which yields a value for m'_{sugar} of 2667 g. Subtracting the latter from the former of these sugar concentrations yields the amount of sugar that precipitated out of the solution upon cooling m''_{sugar} ; that is

$$m''_{\text{sugar}} = m_{\text{sugar}} - m'_{\text{sugar}} = 5022 \text{ g} - 2667 \text{ g} = 2355 \text{ g}$$

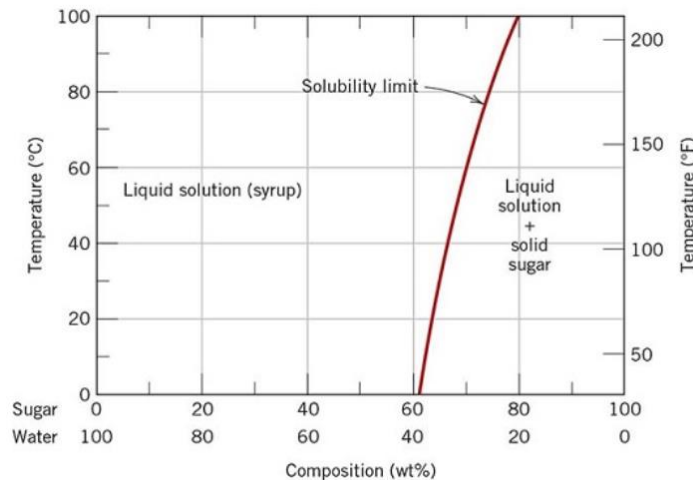
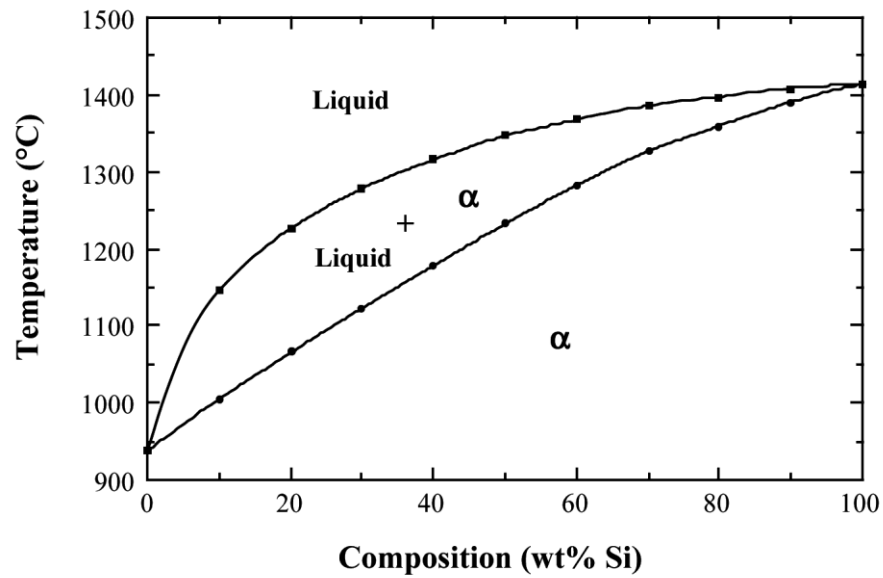


Figure 9.1 The solubility of sugar ($\text{C}_{12}\text{H}_{22}\text{O}_{11}$) in a sugar–water syrup.

9.7 Given here are the solidus and liquidus temperatures for the germanium-silicon system. Construct the phase diagram for this system and label each region.

Composition (wt% Si)	Solidus Temperature (°C)	Liquidus Temperature (°C)
0	938	938
10	1005	1147
20	1065	1226
30	1123	1278
40	1178	1315
50	1232	1346
60	1282	1367
70	1326	1385
80	1359	1397
90	1390	1408

The germanium-silicon phase diagram is constructed below.

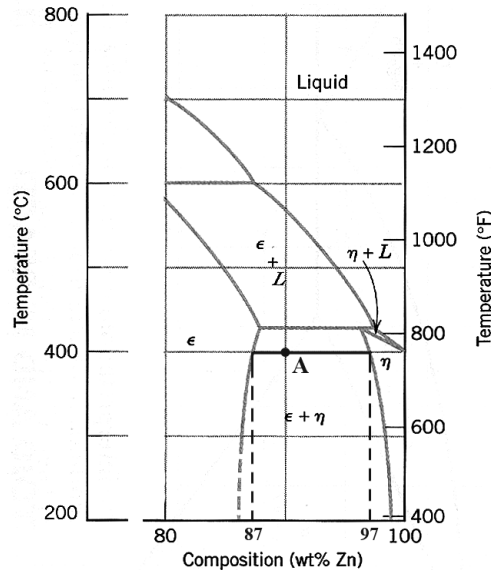


9.10 a-d

Cite the phases that are present and the phase compositions for the following alloys:

- (a) 90 wt% Zn-10 wt% Cu at 400°C (750°F)
- (b) 75 wt% Sn-25 wt% Pb at 175°C (345°F)
- (c) 55 wt% Ag-45 wt% Cu at 900°C (1650°F)
- (d) 30 wt% Pb-70 wt% Mg at 425°C (795°F)

(a) That portion of the Cu-Zn phase diagram (Figure 9.19) that pertains to this problem is shown below; the point labeled “A” represents the 90 wt% Zn-10 wt% Cu composition at 400°C.

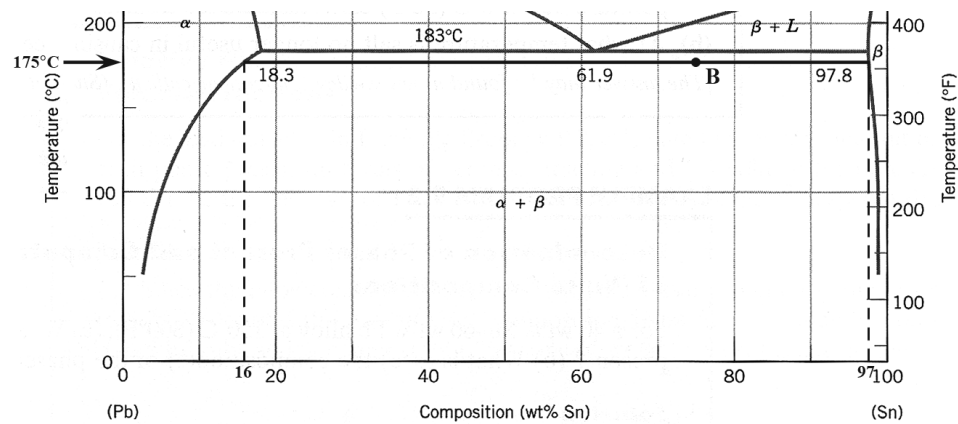


As may be noted, point A lies within the $\epsilon + \eta$ phase field. A tie line has been constructed at 400°C; its intersection with the ϵ -($\epsilon + \eta$) phase boundary is at 87 wt% Zn, which corresponds to the composition of the ϵ phase. Similarly, the tie-line intersection with the ($\epsilon + \eta$)- η phase boundary occurs at 97 wt% Zn, which is the composition of the η phase. Thus, the phase compositions are as follows:

$$C_{\epsilon} = 87 \text{ wt\% Zn-13 wt\% Cu}$$

$$C_{\eta} = 97 \text{ wt\% Zn-3 wt\% Cu}$$

(b) That portion of the Pb-Sn phase diagram (Figure 9.8) that pertains to this problem is shown below; the point labeled “B” represents the 75 wt% Sn-25 wt% Pb composition at 175°C.

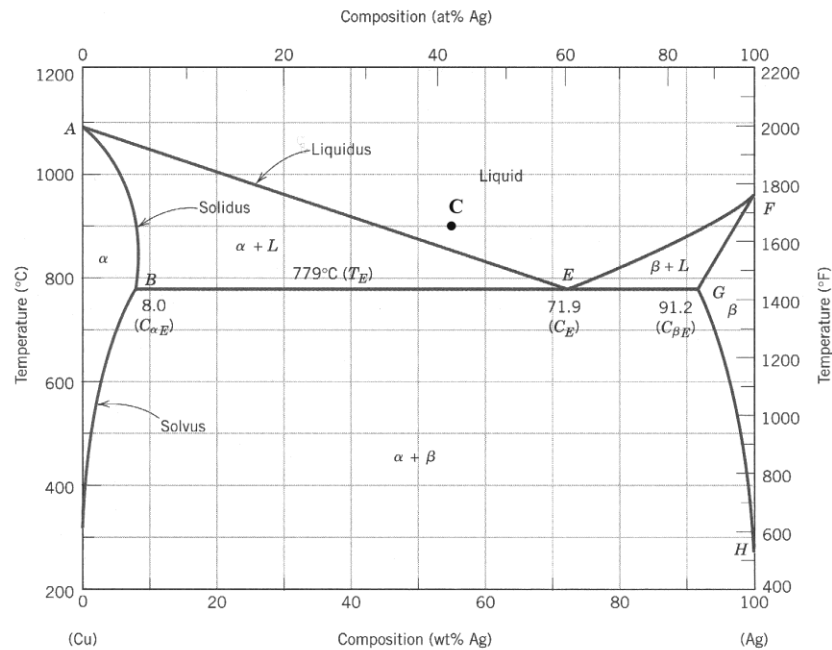


As may be noted, point B lies within the $\alpha + \beta$ phase field. A tie line has been constructed at 175°C; its intersection with the α -($\alpha + \beta$) phase boundary is at 16 wt% Sn, which corresponds to the composition of the α phase. Similarly, the tie-line intersection with the $(\alpha + \beta)$ - β phase boundary occurs at 97 wt% Sn, which is the composition of the β phase. Thus, the phase compositions are as follows:

$$C_{\alpha} = 16 \text{ wt\% Sn-84 wt\% Pb}$$

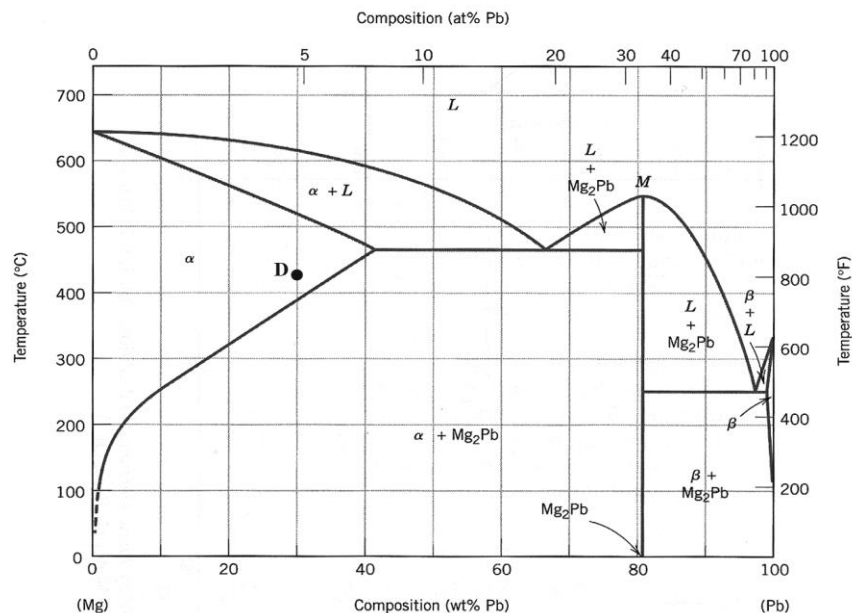
$$C_{\beta} = 97 \text{ wt\% Sn-3 wt\% Pb}$$

(c) The Ag-Cu phase diagram (Figure 9.7) is shown below; the point labeled “C” represents the 55 wt% Ag-45 wt% Cu composition at 900°C.



As may be noted, point C lies within the Liquid phase field. Therefore, only the liquid phase is present; its composition is 55 wt% Ag-45 wt% Cu.

(d) The Mg-Pb phase diagram (Figure 9.20) is shown below; the point labeled “D” represents the 30 wt% Pb-70 wt% Mg composition at 425°C.

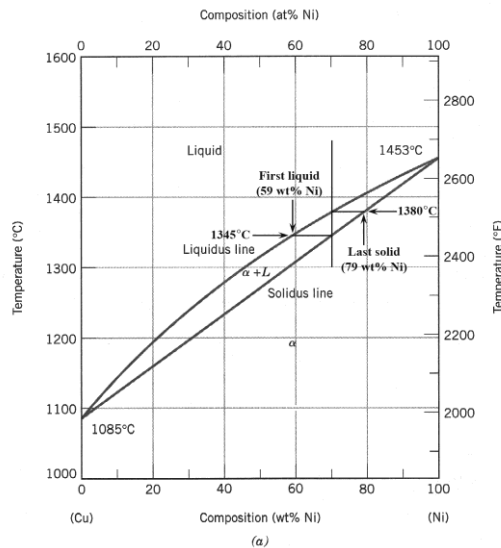


As may be noted, point D lies within the α phase field. Therefore, only the α phase is present; its composition is 30 wt% Pb-70 wt% Mg.

9.13 A copper-nickel alloy of composition 70 wt% Ni-30 wt% Cu is slowly heated from a temperature of 1300°C (2370°F).

- At what temperature does the first liquid phase form?
- What is the composition of this liquid phase?
- At what temperature does complete melting of the alloy occur?
- What is the composition of the last solid remaining prior to complete melting?

Shown below is the Cu-Ni phase diagram (Figure 9.3a) and a vertical line constructed at a composition of 70 wt% Ni-30 wt% Cu.

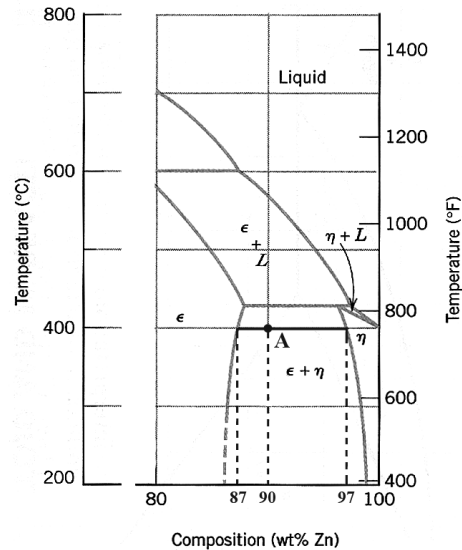


- Upon heating from 1300°C, the first liquid phase forms at the temperature at which this vertical line intersects the α -($\alpha + L$) phase boundary--i.e., about 1345°C.
- The composition of this liquid phase corresponds to the intersection with the ($\alpha + L$)-L phase boundary, of a tie line constructed across the $\alpha + L$ phase region at 1345°C--i.e., 59 wt% Ni.
- Complete melting of the alloy occurs at the intersection of this same vertical line at 70 wt% Ni with the ($\alpha + L$)-L phase boundary--i.e., about 1380°C.
- The composition of the last solid remaining prior to complete melting corresponds to the intersection with α -($\alpha + L$) phase boundary, of the tie line constructed across the $\alpha + L$ phase region at 1380°C--i.e., about 79 wt% Ni.

9.16 Determine the relative amounts (in terms of mass fractions) of the phases for the alloys and temperatures given in Problem 9.10.

This problem asks that we determine the phase mass fractions for the alloys and temperatures in Problem 9.10.

(a) From Problem 9.10a, ϵ and η phases are present for a 90 wt% Zn-10 wt% Cu alloy at 400°C, as represented in the portion of the Cu-Zn phase diagram shown below (at point A).



Furthermore, the compositions of the phases, as determined from the tie line are

$$C_{\epsilon} = 87 \text{ wt\% Zn-13 wt\% Cu}$$

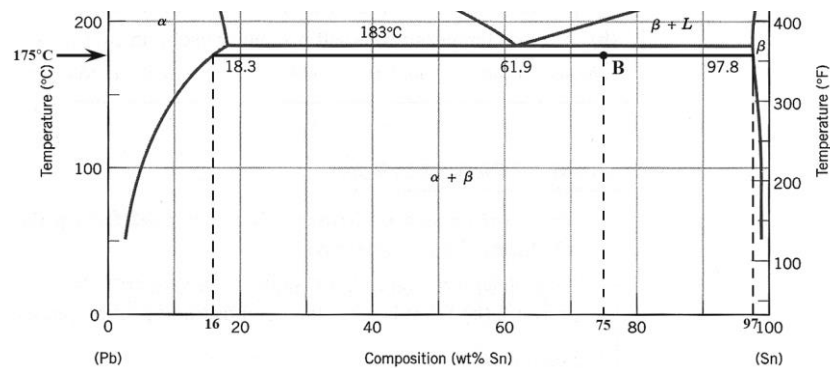
$$C_{\eta} = 97 \text{ wt\% Zn-3 wt\% Cu}$$

Inasmuch as the composition of the alloy $C_0 = 90 \text{ wt\% Zn}$, application of the appropriate lever rule expressions (for compositions in weight percent zinc) leads to

$$W_{\epsilon} = \frac{C_{\eta} - C_0}{C_{\eta} - C_{\epsilon}} = \frac{97 - 90}{97 - 87} = 0.70$$

$$W_{\eta} = \frac{C_0 - C_{\epsilon}}{C_{\eta} - C_{\epsilon}} = \frac{90 - 87}{97 - 87} = 0.30$$

(b) From Problem 9.10b, α and β phases are present for a 75 wt% Sn-25 wt% Pb alloy at 175°C, as represented in the portion of the Pb-Sn phase diagram shown below (at point B).



Furthermore, the compositions of the phases, as determined from the tie line are

$$C_{\alpha} = 16 \text{ wt\% Sn-84 wt\% Pb}$$

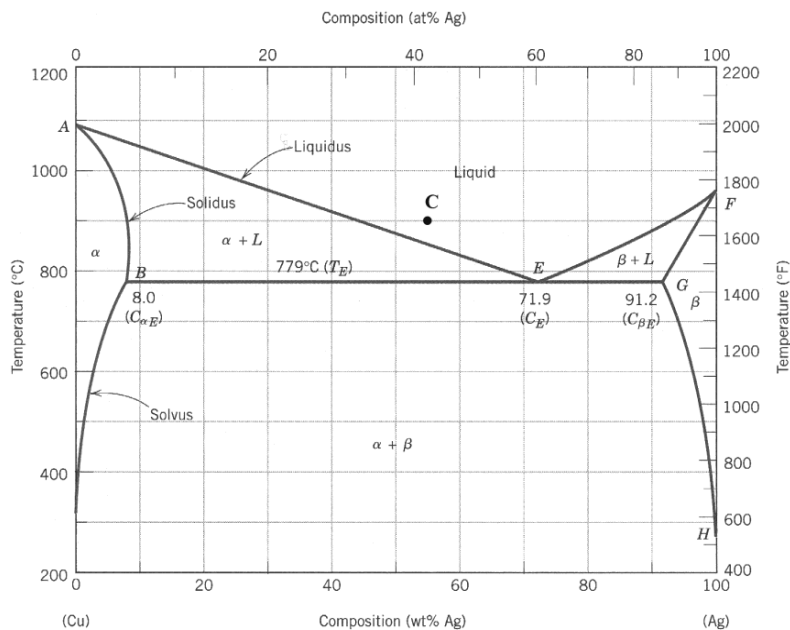
$$C_{\beta} = 97 \text{ wt\% Sn-3 wt\% Pb}$$

Inasmuch as the composition of the alloy $C_0 = 75 \text{ wt\% Sn}$, application of the appropriate lever rule expressions (for compositions in weight percent tin) leads to

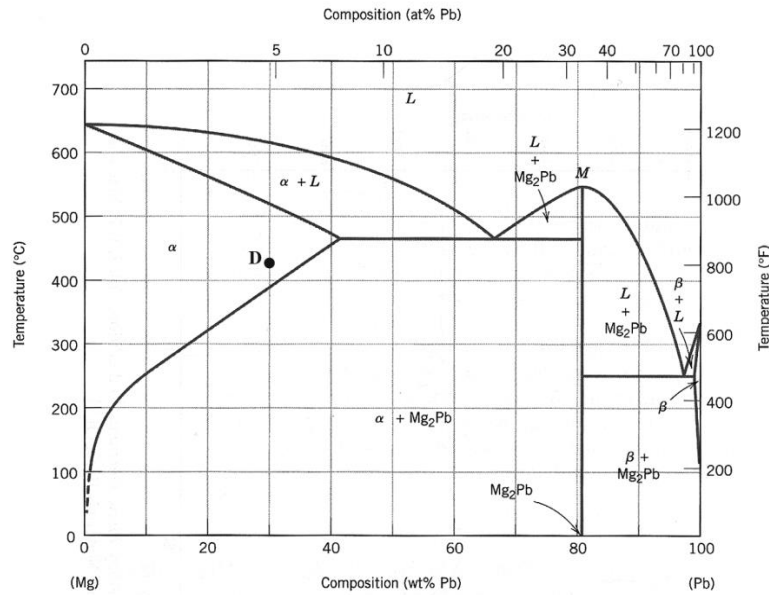
$$W_{\alpha} = \frac{C_{\beta} - C_0}{C_{\beta} - C_{\alpha}} = \frac{97 - 75}{97 - 16} = 0.27$$

$$W_{\beta} = \frac{C_0 - C_{\alpha}}{C_{\beta} - C_{\alpha}} = \frac{75 - 16}{97 - 16} = 0.73$$

(c) From Problem 9.10c, just the liquid phase is present for a 55 wt% Ag-45 wt% Cu alloy at 900°C, as may be noted in the Ag-Cu phase diagram shown below (at point C)—i.e., $W_L = 1.0$.



(d) From Problem 9.10d, just the α phase is present for a 30 wt% Pb-70 wt% Mg alloy at 425°C, as may be noted in the Mg-Pb phase diagram shown below (at point D)—i.e., $W_{\alpha} = 1.0$.



9.30 Briefly explain why, upon solidification, an alloy of eutectic composition forms a microstructure consisting of alternating layers of the two solid phases.

Upon solidification, an alloy of eutectic composition forms a microstructure consisting of alternating layers of the two solid phases because during the solidification atomic diffusion must occur, and with this layered configuration the diffusion path length for the atoms is a minimum.

9.34 For a copper-silver alloy of composition 25 wt% Ag-75 wt% Cu and at 775°C (1425°F) do the following:

- Determine the mass fractions of α and β phases.
- Determine the mass fractions of primary α and eutectic microconstituents.
- Determine the mass fraction of eutectic α .

(a) This portion of the problem asks that we determine the mass fractions of α and β phases for an 25 wt% Ag-75 wt% Cu alloy (at 775°C). In order to do this it is necessary to employ the lever rule using a tie line that extends entirely across the $\alpha + \beta$ phase field. From Figure 9.7 and at 775°C, $C_\alpha = 8.0$ wt% Ag, $C_\beta = 91.2$ wt% Ag, and $C_{\text{eutectic}} = 71.9$ wt% Sn. Therefore, the two lever-rule expressions are as follows:

$$W_\alpha = \frac{C_\beta - C_0}{C_\beta - C_\alpha} = \frac{91.2 - 25}{91.2 - 8.0} = 0.796$$

$$W_\beta = \frac{C_0 - C_\alpha}{C_\beta - C_\alpha} = \frac{25 - 8.0}{91.2 - 8.0} = 0.204$$

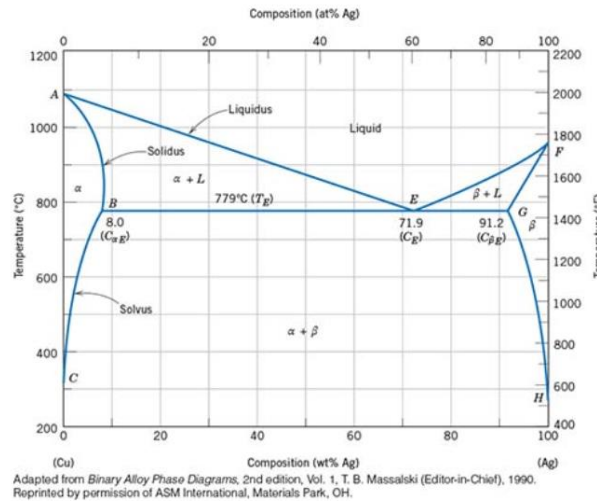


Figure 9.7 The copper-silver phase diagram.

(b) Now it is necessary to determine the mass fractions of primary α and eutectic microconstituents for this same alloy. This requires us to utilize the lever rule and a tie line that extends from the maximum solubility of Ag in the α phase at 775°C (i.e., 8.0 wt% Ag) to the eutectic composition (71.9 wt% Ag). Thus

$$W_{\alpha'} = \frac{C_{\text{eutectic}} - C_0}{C_{\text{eutectic}} - C_\alpha} = \frac{71.9 - 25}{71.9 - 8.0} = 0.734$$

$$W_e = \frac{C_0 - C_\alpha}{C_{\text{eutectic}} - C_\alpha} = \frac{25 - 8.0}{71.9 - 8.0} = 0.266$$

(c) And, finally, we are asked to compute the mass fraction of eutectic α , $W_{e\alpha}$. This quantity is simply the difference between the mass fractions of total α and primary α as

$$W_{e\alpha} = W_\alpha - W_{\alpha'} = 0.796 - 0.734 = 0.062$$

9.35 The microstructure of a lead-tin alloy at 180°C (355°F) consists of primary β and eutectic structures. If the mass fractions of these two microconstituents are 0.57 and 0.43, respectively, determine the composition of the alloy.

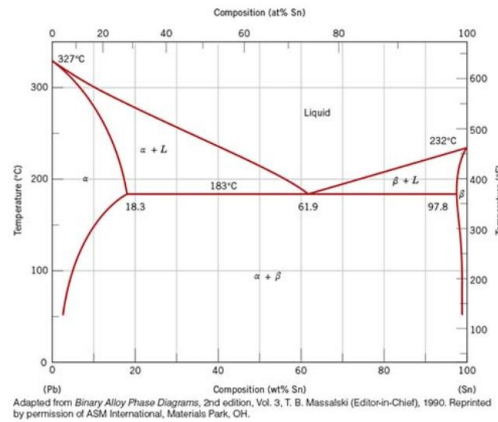


Figure 9.8 The lead-tin phase diagram.

Since there is a primary β microconstituent present, then we know that the alloy composition, C_0 is between 61.9 and 97.8 wt% Sn (Figure 9.8). Furthermore, this figure also indicates that $C_\beta = 97.8$ wt% Sn and $C_{\text{eutectic}} = 61.9$ wt% Sn. Applying the appropriate lever rule expression for $W_{\beta'}$

$$W_{\beta'} = \frac{C_0 - C_{\text{eutectic}}}{C_\beta - C_{\text{eutectic}}} = \frac{C_0 - 61.9}{97.8 - 61.9} = 0.57$$

and solving for C_0 yields $C_0 = 82.4$ wt% Sn.

ABOVE AVERAGE

MCEG 2023 Materials Science and Engineering

Student Name (Print): Ayoubi Ihab

Last name First name

Homework Requirements:

- 1) Draw a **box** around the final answer. Correct units, where applicable, must be displayed on the final answer for each homework problem. Incorrect or the omission of units on the final answer may be penalized, particularly when units are not carried throughout calculations that support the final answer.
- 2) Hand-written or MS Word generated homework should be submitted electronically before the deadlines.
- 3) All homework must be presented neatly. Use ink or dark pen. The following item is **NOT** acceptable: very light pencil.
- 4) Put this cover sheet on **top** of your homework. Print your **name** clearly on page 1.
- 5) All homework will follow the above requirements.

Mass of water, $m_{\text{water}} = 1500 \text{ g}$
 Temperature, $T = 90^\circ \text{C}$

$$a) C_{\text{sugar}} (\text{wt}\%) = \frac{m_{\text{sugar}}}{m_{\text{sugar}} + m_{\text{water}}} \times 100$$

From sugar-water phase diagram:
 Concentration of sugar in water is
 around 77%

$$\text{so } 77 (\text{wt}\%) = \frac{m_{\text{sugar}}}{m_{\text{sugar}} + 1500} \times 100$$

$$77 (\text{wt}\%) \times m_{\text{sugar}} + 77 \times 1500 = m_{\text{sugar}} \times 100$$

$$77 m_{\text{sugar}} - 100 m_{\text{sugar}} = -115500 \text{ g}$$

$$-23 m_{\text{sugar}} = -115500 \text{ g}$$

$$m_{\text{sugar}} = \frac{115500 \text{ g}}{23}$$

$$m_{\text{sugar}} = \boxed{5021.74 \text{ g}}$$

- b) The composition of the saturated liquid solution at 20°C
 the concentration of sugar in water is sugar-water phase diagram
 above is around 64%. Therefore $C_L = \boxed{64\%}$

$$c) C_{\text{sugar}} (\text{wt}\%) = \frac{m_{\text{sugar}}}{m_{\text{sugar}} + m_{\text{water}}} \times 100$$

$$64 (\text{wt}\%) = \frac{m_{\text{sugar}}}{m_{\text{sugar}} + 1500} \times 100$$

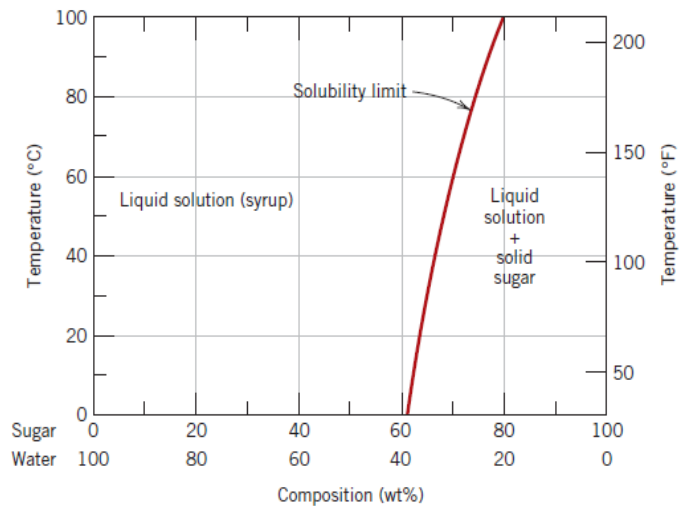
$$64 (\text{wt}\%) \times m_{\text{sugar}} + 64 \times 1500 = m_{\text{sugar}} \times 100$$

$$64 m_{\text{sugar}} - 100 m_{\text{sugar}} = -96000 \text{ g}$$

$$-36 m_{\text{sugar}} = -96000 \text{ g}$$

$$m_{\text{sugar}} = \frac{96000 \text{ g}}{36}$$

$$m_{\text{sugar}} = 2666.667 \text{ g}$$

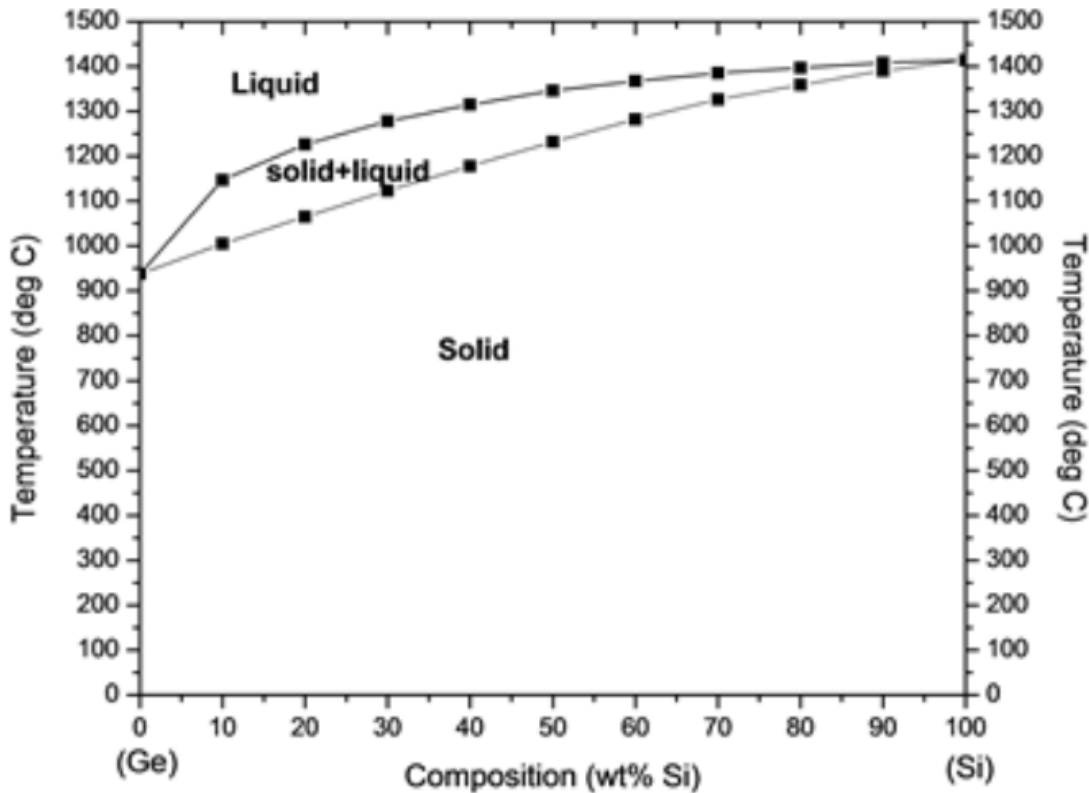


Amount of solid sugar come
 of solution, $m_s = 5021.74 - 2666.667$

$$m_s = \boxed{2355.073 \text{ g}}$$

2355.073 g of the solid sugar will
 come out of solution upon cooling

9.7



9.10

a) Refn to the copper-zinc phase diagram
location of alloy at 90% Zn and at 400°C
The phases present are $\epsilon + \eta$

the composition of ϵ -phase present in the
alloy phase at 400°C is around:

87 wt% Zn $\Rightarrow$ ϵ -phase is
87 wt% Zn - 13 wt% Cu

the composition of η -phase at 400°C:
97 wt% Zn $\Rightarrow$ alloy composition is

97 wt% Zn - 3 wt% Cu

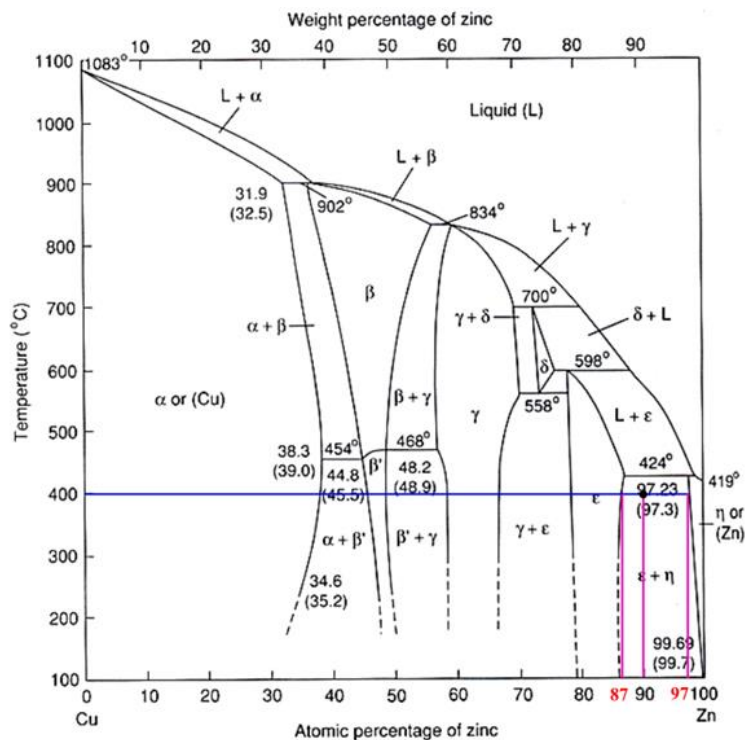
mass fraction of phases:

$$w_L = \frac{C_n - C_o}{C_n - C_e} = \frac{97 - 90}{97 - 87}$$

$$w_L = \frac{7}{10} = 0.7$$

$$w_n = \frac{C_o - C_e}{C_n - C_e} = \frac{90 - 87}{97 - 87}$$

$$w_n = \frac{3}{10} = 0.3$$



- b) 75 wt% Sn - 25 wt% Pb at 175 °C
 from the lead - Tin phase diagram.
 The phases present are $\alpha + \beta$
 The composition of α -phase at 175 °C
 is around 16 wt% Sn. Therefore the
 composition of α -phase in the alloy
 is 16 wt% Sn - 84 wt% Pb
 $C_\beta = 98 \text{ wt\% Sn} - 2 \text{ wt\% Pb}$

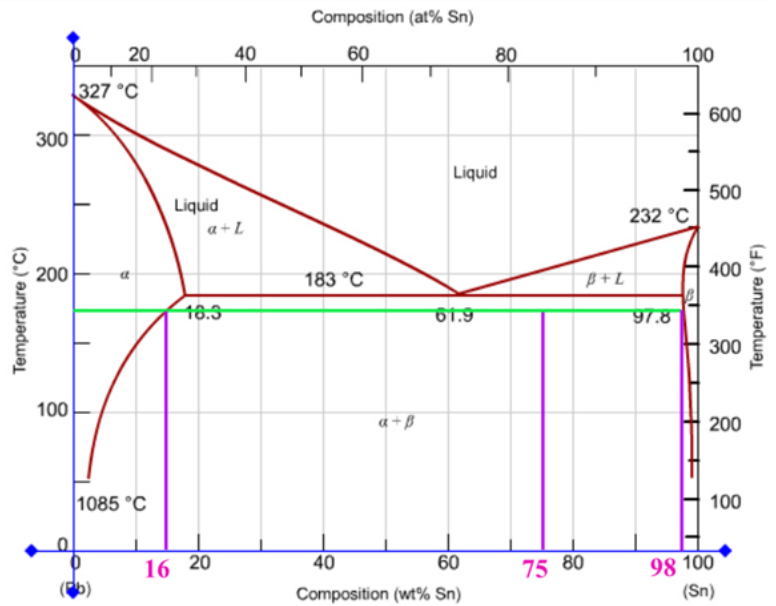
mass fractions of phases:

$$w_\alpha = \frac{C_\beta - C_0}{C_\beta - C_\alpha} = \frac{98 - 75}{98 - 16}$$

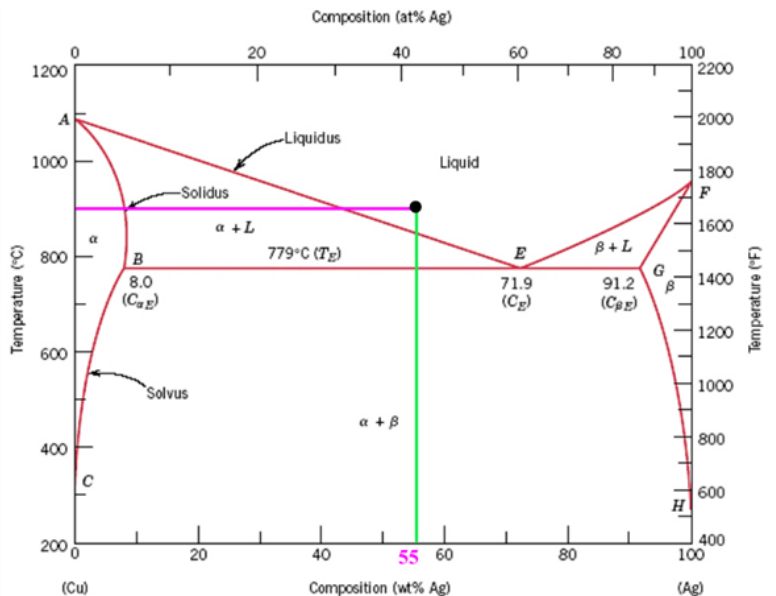
$$w_\alpha = \frac{23}{82} = \boxed{0.28}$$

$$w_\beta = 1 - w_\alpha = 1 - 0.28$$

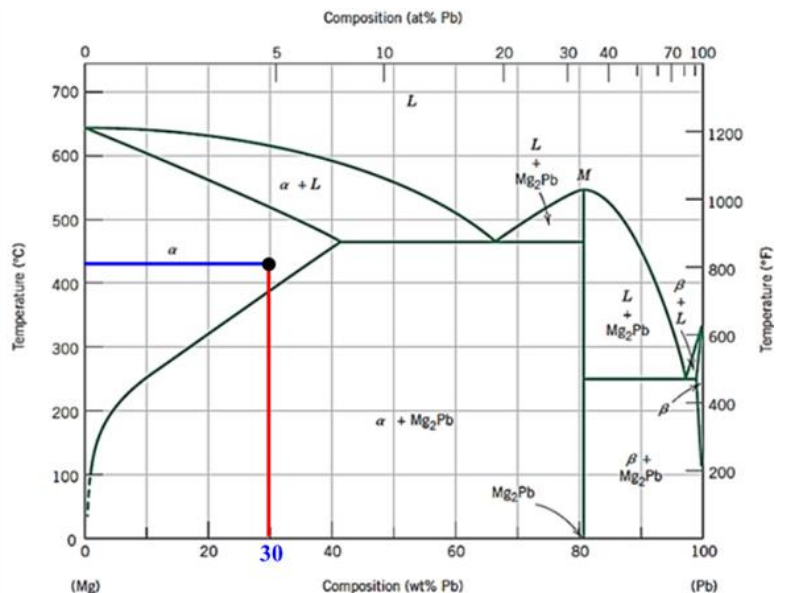
$$w_\beta = \boxed{0.72}$$



- c) 55 wt% Ag - 45 wt% Cu at 900 °C
 Refer to the copper - silver phase diagram.
 The phase present in the alloy 55 wt% Ag -
 45 wt% Cu at 900 °C only liquid phase will be the same
 as the alloy composition.
 $C_L = 55 \text{ wt\% Ag} - 45 \text{ wt\% Cu}$
 mass fraction $w_L = \boxed{1.0}$

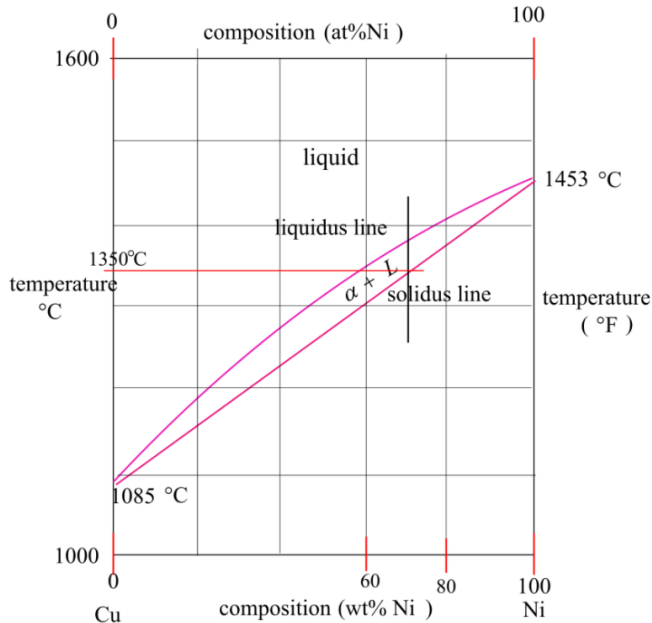


- d) 30 wt% Pb - 70 wt% Mg at 425 °C
 Refer to the Magnesium - lead phase diagram
 The region containing 30 wt% Pb at 425 °C has
 only α -phase in it. Therefore, there will be no
 alteration in the alloy composition
 30 wt% Pb - 70 wt% Mg
 $C_\alpha = 30 \text{ wt\% Pb} - 70 \text{ wt\% Mg}$
 mass fraction $w_\alpha = \boxed{1.0}$



9.13

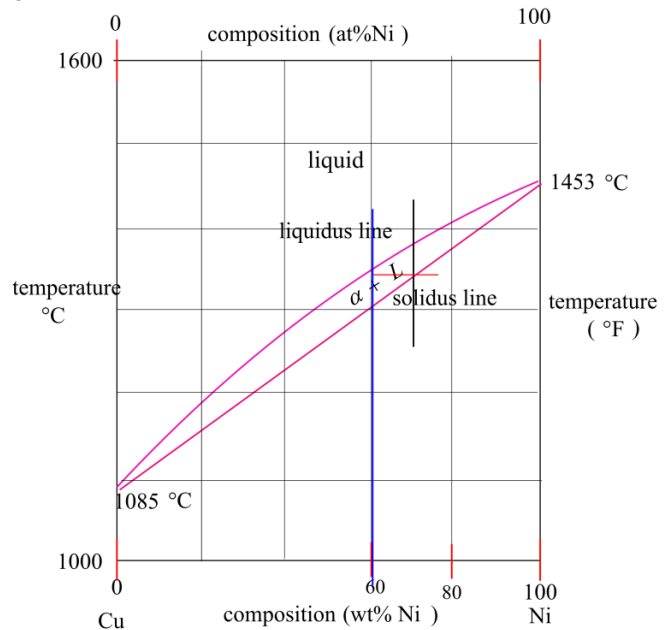
a-



From 70 wt% Ni, draw vertical lines, till it touches solidus line. Note the temperature at which vertical line touches solidus line. This is nothing but temperature at which first liquid forms.

First liquid forming temperature is 1350°C

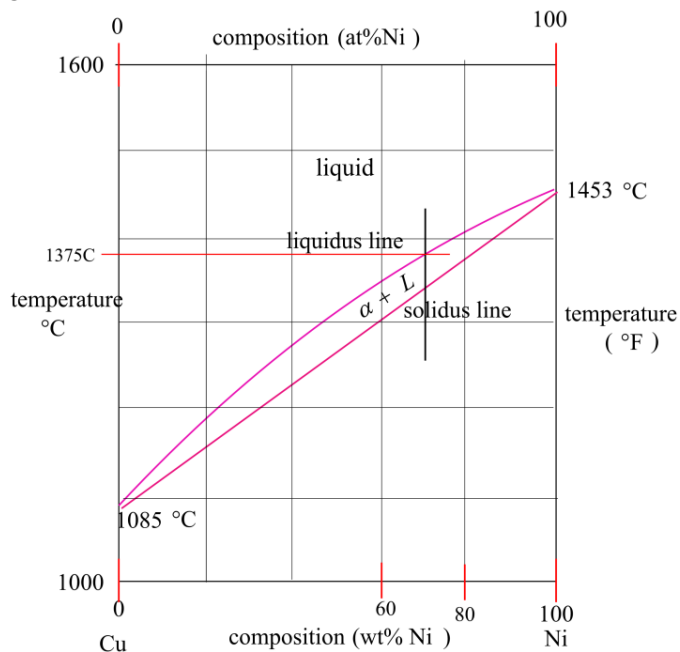
b-



From the previous point of intersection, draw a horizontal line to the liquidus line. And finally mark the composition related to this point at the bottom.

The composition of this liquid phase is 60 wt % Ni – 40 wt % Cu

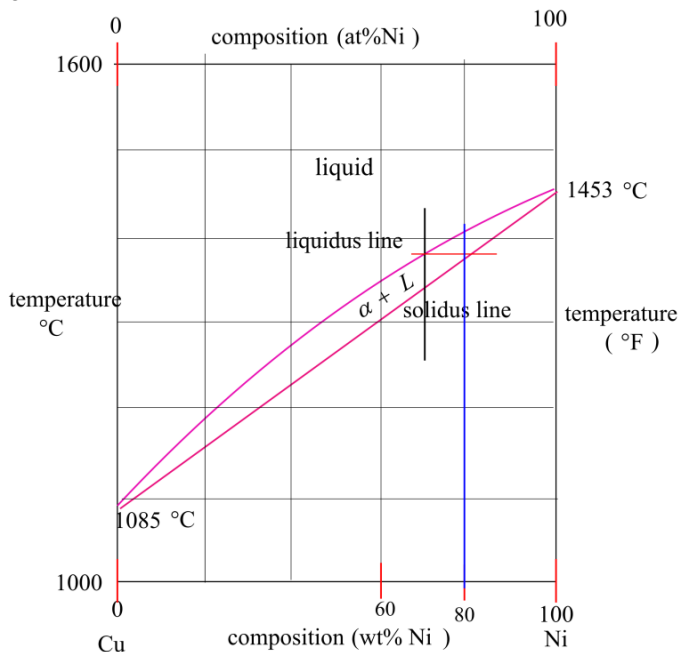
c-



From 70 wt% of Ni, draw a vertical line so that it touches liquidus line. Mark the temperature at this intersection point.

The complete melting of alloy occurs at 1375°C

d-



From the previous point of intersection, draw a horizontal line to the solidus lines. From this point, drop a vertical line to the x axis. This will give the composition of last solid remaining before melting.

The composition of last solid that remains before the complete melting is 80 wt % Ni – 20 wt % Cu

a) From the lead-tin phase figure for composition of 15 wt% Sn - 85 wt% Pb at 100°C
 ($\alpha + \beta$) phase is present.

the composition of an alloy C_0 is 5 wt% Sn - 95 wt% Pb.

the composition of an alloy C_β is 98 wt% Sn - 2 wt% Pb.

the mass fraction of α :

$$w_\alpha = \frac{C_\beta - C_0}{C_\beta - C_\alpha} = \frac{98 - 5}{98 - 5}$$

$$= \frac{83}{93}$$

$$= \boxed{0.89}$$

the mass fraction of β :

$$w_\beta = \frac{C_0 - C_\alpha}{C_\beta - C_\alpha} = \frac{15 - 5}{98 - 5}$$

$$= \frac{10}{93}$$

$$= \boxed{0.11}$$

b) From the Hg-Pb phase figure, for 25 wt% Pb - 75 wt% Hg at 425°C
 only α phase is present. therefore the mass fraction is $w_\alpha = 1$

c) From Cu-Ag phase figure, for the composition of 85 wt% Ag - 15 wt% Cu at 300°C
 (L + β) phase is present.

the composition of an alloy C_β is 92 wt% Ag

the composition of an alloy C_L is 77 wt% Ag

the mass fraction of L-phase

$$w_L = \frac{C_\beta - C_0}{C_\beta - C_L} = \frac{92 - 85}{92 - 77}$$

$$= \frac{7}{15}$$

$$= \boxed{0.47}$$

the mass fraction of β -phase

$$w_\beta = \frac{C_0 - C_L}{C_\beta - C_L} = \frac{85 - 77}{92 - 77}$$

$$= \frac{8}{15}$$

$$= \boxed{0.53}$$

d) From the Zn-Cu phase diagram, for the composition of 55 wt% Zn - 45 wt% Cu at 600°C ($\beta + \gamma$) phase is present.

the composition of an alloy C_β is 51 wt% Zn
the composition of an alloy C_γ is 58 wt% Zn

the mass fraction of β -phase:

$$W_\beta = \frac{C_\gamma - C_0}{C_\gamma - C_\beta} = \frac{58 - 55}{58 - 51} = \frac{3}{7} = \boxed{0.43}$$

the mass fraction of γ -phase

$$W_\gamma = \frac{C_0 - C_\beta}{C_\gamma - C_\beta} = \frac{55 - 51}{58 - 51} = \frac{4}{7} = \boxed{0.57}$$

9.30

4) beyond the solidification, alloys having eutectic composition must redistribute into two different solid components of α and β phases.

This transformation is followed by the atomic diffusion. Due to the atomic diffusion which is taking place at closer distances of separate solid phases, layer formation develops in the microstructure of eutectic composition. As a result of which there is a formation of microstructure that consists of alternate lamellae with α and β phases, simultaneously one after the other.

9.34

a) Refer to a phase diagram of (Ag-Cu) alloy, at 775°C the mass percentages are:

$a = 8\%$ of Ag $\rightarrow$ mass % of Ag in α

$b = 91.2\%$ of Ag $\rightarrow$ mass % of Ag in β

$c = 25\%$ of Ag $\rightarrow$ mass % of Ag in the entire alloy

$b_{eu} = 71.9\%$ of Ag $\rightarrow$ mass % of Ag in eutectic state.

the mass % of alpha phase:

$$X_\alpha = \frac{c - b}{a - b} = \frac{25 - 91.2}{8 - 91.2} = \boxed{0.796}$$

the mass % of beta phase:

$$X_\beta = \frac{c - a}{b - a} = \frac{25 - 8}{91.2 - 8} = \boxed{0.204}$$

b) The mass fraction of primary alpha phase:

$$X_{\alpha'} = \frac{c - b_{eu}}{a - b_{eu}} = \frac{25 - 71.9}{8 - 71.9} = \boxed{0.734}$$

the mass fraction of eutectic phase:

$$X_{\beta'} = \frac{c - a}{b_{eu} - a} = \frac{25 - 8}{71.9 - 8} = \boxed{0.266}$$

c) The mass fraction of eutectic alpha.

$$(X_\alpha)_{eu} = X_\alpha - X_{\alpha'} = 0.796 - 0.734 = \boxed{0.062}$$

from the graph lead-tin for the given temperature 180°C

$C_{\alpha} = 18.3 \text{ wt\% Sn}$ and $C_{\beta} = 97.8 \text{ wt\% Sn}$

the alloy composition:

$$W_{\beta} = \frac{C_0 - C_{\alpha}}{C_{\beta} - C_{\alpha}}$$

$$0.57 = \frac{C_0 - 61.9}{97.8 - 61.9}$$

$$C_0 - 61.9 = 0.57(97.8 - 61.9)$$

$$C_0 = 0.57(97.8 - 61.9) + 61.9$$

$$C_0 = 82.4 \text{ wt\% Sn.}$$

the composition of the alloy is $\boxed{82.4 \text{ wt\% Sn} - 17.6 \text{ wt\% Pb}}$

AVERAGE

MCEG 2023 Materials Science and Engineering

Student Name (Print): ___Nowlin___ ___Darrius___
 Last name First name

Homework Requirements :

1) Draw a box around the final answer. Correct units, where applicable, must be displayed on the final answer for each homework problem. Incorrect or the omission of units on the final answer may be penalized, particularly when units are not carried throughout calculations that support the final answer.

2) Hand-written or MS Word generated homework should be submitted electronically before the deadlines.

3)
All homework must be presented neatly. Use ink or a dark pen . The following item is NOT acceptable: very light pencil

4) Put this cover sheet on top of your homework . Print your name clearly on page 1.

5) All homework will follow the above requirements.

9.1

(a) Mass of water, $m_{\text{water}} = 1500\text{g}$

Temperature, $T = 20^\circ\text{C}$

$$C_{\text{sugar}}(\text{wt}\%) = \frac{m_{\text{sugar}}}{m_{\text{sugar}} + m_{\text{water}}} \times 100$$

where, m - mass, C - concentration

$$77(\text{wt}\%) = \frac{m_{\text{sugar}}}{m_{\text{sugar}} + 1500} \times 100$$

$$77(\text{wt}\%) \times m_{\text{sugar}} + 77 \times 1500 = m_{\text{sugar}} \times 100$$

$$77m_{\text{sugar}} - 100m_{\text{sugar}} = -115500\text{g}$$

$$-23m_{\text{sugar}} = -115500\text{g}$$

$$m_{\text{sugar}} = \frac{115500\text{g}}{23}$$

$$m_{\text{sugar}} = 5021.74\text{g}$$

mass of the sugar, $m_{\text{sugar}} = 5022\text{g}$

b) the concentration of sugar in water is around 64%

$$\rightarrow C_L = 64\%$$

$$c) C_{\text{sugar}}(\text{wt}\%) = \frac{m_{\text{sugar}}}{m_{\text{sugar}} + m_{\text{water}}} \times 100$$

$$64(\text{wt}\%) = \frac{m_{\text{sugar}}}{m_{\text{sugar}} + 1500} \times 100$$

$$64(\text{wt}\%) \times m_{\text{sugar}} + 64 \times 1500 = m_{\text{sugar}} \times 100$$

$$64m_{\text{sugar}} - 100m_{\text{sugar}} = -96000g$$

$$-36m_{\text{sugar}} = -96000g$$

$$m_{\text{sugar}} = \frac{96000g}{36}$$

$$m_{\text{sugar}} = 2666.667g$$

$$m_s = 5021.74 - 2666.667$$

$$= 2355.073g$$

$$m_s = 2355g$$

9.7

Copper-Zinc

Phase	Zn (wt%)	Cu (wt%)
E phase	80%	20
Liquid phase	95	5

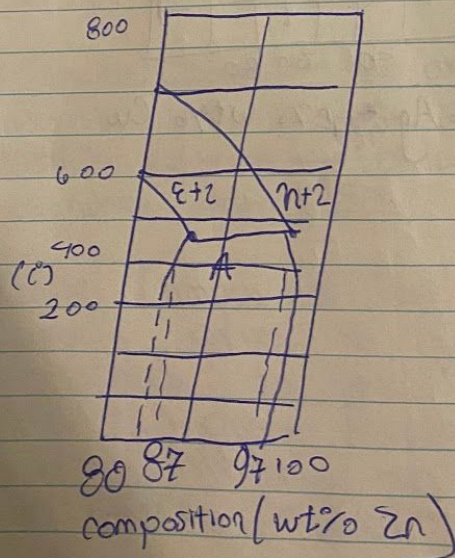
It is not possible to have a copper-zinc alloy. For the equilibrium, consists of an phase of composition 80 wt% Zn - 20 wt% Cu and also a liquid phase of composition 95 wt% Zn - 5 wt% Cu.

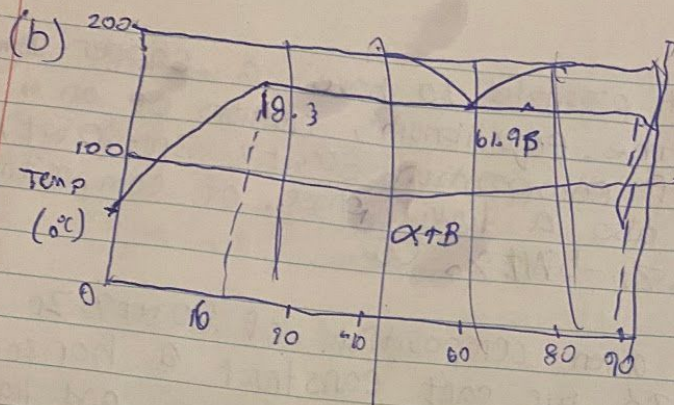
For this given composition of 80 wt% Zn and 97 wt% Zn, we can't construct a horizontal tie line which connects the ϵ phase, and liquid phase at any equilibrium temperature (in copper-zinc, Equilibrium temperature for liquid phase with 95 wt% Zn is around and Equilibrium temperature for ϵ phase with 80 wt% Zn is around.

Q.10

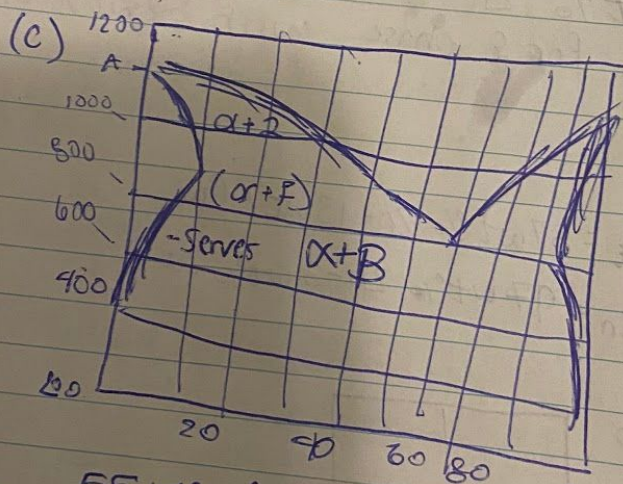
$$(a) C_{\epsilon} = 87 \text{ wt\% Zn} - 13 \text{ wt\% Cu}$$

$$C_L = 97 \text{ wt\% Zn} - 3 \text{ wt\% Cu}$$

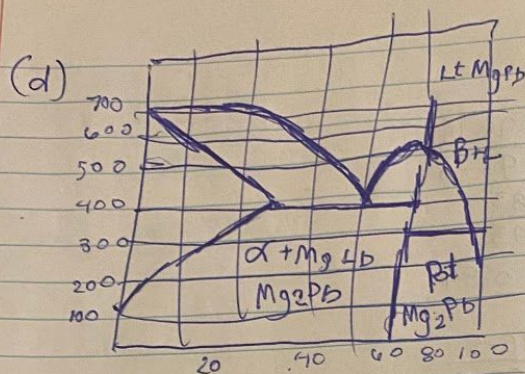




$C_\alpha = 16 \text{ wt\% Sn} - 84 \text{ wt\% Pb}$
 $C_\beta = 97 \text{ wt\% Sn} - 3 \text{ wt\% Pb}$



55 wt% Ag - 45 wt% Cu



9.13

(a) upon heating from 1300°C , the first liquid phase forms at the temperature at which this vertical line intersects $L + (L + \text{Mg}_2\text{Pb})$ about 1345°C

(b) The composition of this liquid corresponds to the intersection with the $(\alpha + L) - L$ phase boundary of a tie line constructed across the $(\alpha + L)$ phase region at 1345°C , ~~at~~ 59 wt% Ni

(c) Complete melting of the alloy occurs at the intersection of this same vertical line at 70 wt% Ni with the $(\alpha + L) - L$ phase boundary about 1380°C

(d) The composition of the β solid remaining prior to complete melting corresponds to the intersection with $\alpha - (\alpha + L)$ phase boundary, of the tie line constructed across the $\alpha + L$ phase at 1380°C about 79 wt% Ni

9.16

(a)

$$w_{\alpha} = \frac{98-15}{98-5}$$

$$= \frac{83}{93}$$

$$= 0.89$$

$$w_{\beta} = \frac{15-5}{98-5}$$

$$= \frac{10}{93}$$

$$= 0.11$$

mass fraction

α and β

0.89 & 0.11

(b) Mg-Pb 25 wt% Pb - 75 Mg at 925°C

$w_{\alpha} = 1$

mass fraction α -phase is 1

(c)

$$w_L = \frac{C_{\beta} - C_0}{C_{\beta} - C_L}$$

$$w_L = \frac{92-85}{92-77}$$

$$= \frac{7}{15}$$

0.47

$$W_B = \frac{C_0 - C_L}{C_P - C_L}$$

$$W_B = \frac{86 - 77}{92 - 77}$$

$$= \frac{8}{15}$$

$$= 0.53$$

The mass fraction of β -phase 0.53

$$(d) W_B = \frac{C_\gamma - C_0}{C_\gamma - C_\beta}$$

$$W_B = \frac{58 - 55}{58 - 51}$$

$$= \frac{3}{7}$$

$$\beta = 0.43$$

$$W_\gamma = \frac{55 - 51}{58 - 51}$$

$$= \frac{4}{7}$$

$$\gamma = 0.57$$

9.30

The transformation is followed by the atomic diffusion. Due to the atomic diffusion which taking place at closer distances of separate solid phases, layer formation develops in the microstructure of eutectic composition.

As a result of which there is a formation of microstructure that consists of alternate lamellae with α and β phases, simultaneously one after the other.

9.34

(a) 775°C

$$W_\alpha = \frac{C_\beta - C_1}{C_\beta - C_\alpha}$$

$$W_\alpha = \frac{91.2 - 25}{91.2 - 8} = 0.80$$

$$W_\beta = \frac{25 - 8}{91.2 - 8} = 0.20$$

(b) $W_\alpha = \frac{C_e - C_1}{C_e - C_\alpha}$

$$= \frac{71.9 - 25}{71.9 - 8} = 0.73$$

$$W_e = \frac{C_1 - C_\alpha}{C_e - C_\alpha} = \frac{25 - 8}{71.9 - 8} = 0.27$$

(c) $W_{\alpha} = W_{\alpha} - W_{\alpha'}$

$$W_{\alpha} = 0.80$$

$$W_{\alpha'} = 0.73$$

$$W_{\alpha} = W_{\alpha} - W_{\alpha'}$$

$$= 0.80 - 0.73$$

$$\boxed{= 0.07}$$

Q. 35

$$W_B = 0.57, C_B = 97.8 \text{ wt\% Sn}$$

$$C_C = 61.9 \text{ wt\%}$$

$$0.57 = \frac{C_0 - 61.9}{97.8 - 61.9}$$

$$\boxed{C_0 = 82.4 \text{ wt\% Sn} - 17.6 \text{ wt\% Pb}}$$

BELOW AVERAGE

F | W # 13

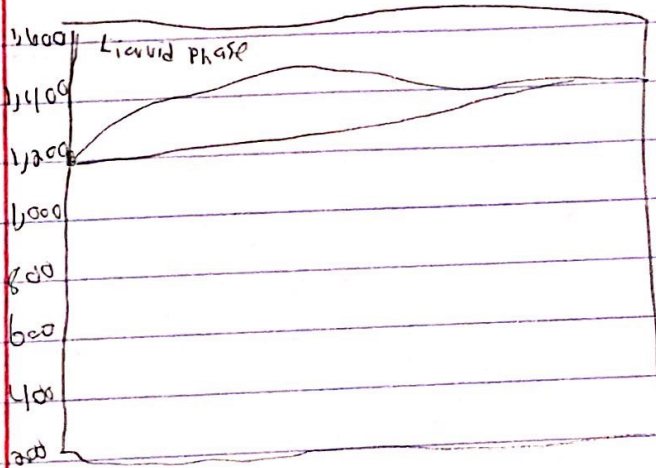
9.1. $C_{sugar} (wt\%) = \frac{m_{sugar}}{m_{sugar} + m_{water}} \times 100$

$77 wt\% = \frac{m_{sugar}}{m_{sugar} + 1500} \times 100$

$\frac{m_{sugar}}{m_{sugar} + 1500} = .77 = \boxed{5022g}$

a) b) c)

9.7



9.10 a) 87% wt by Zn and 13 wt% Cu
97 wt% Zn and 3 wt% Cu

b) 16 wt% Sn 84 wt% Pb
98 wt% Sn 2 wt% Pb

c) Liquid phase
55 wt% Ag - 45 wt% Cu

d) 30 wt% Pb - 70 wt% Mg

9.13 a) First liquid forming temperature is 1350°C

b) The composition of this liquid phase is 60 wt% Ni - 40 wt% Cu.

c) The complete melting of alloy occurs at 1375°C

d) 80 wt% Ni - 20 wt% Cu

9.14 a) $w_E = .79$, $w_A = .30$

b) $w_L = 1.0$

c) $w_B = .56$, $w_Y = .44$

d) $w_a = 1.0$

9.30 When it is cooled, there will be no change until it reaches the eutectic temperature, 183°C

9.34 a) At 775°C , $C_{\alpha} = 8 \text{ wt}\%$

$$w_X = \frac{C_B - C_0}{C_B - C_X} = \frac{91.2 - 25}{91.2 - 8} = .796$$

$$w_B = \frac{C_0 - C_X}{C_B - C_X} = \frac{25 - 8}{91.2 - 8} = .204$$

$$b) w_X = \frac{71.7 - 25}{91.7 - 8} = .734$$

$$w_b = \frac{25 - 8}{91.7 - 8} = .266$$

$$c) .796 - .734 = .062$$

9.35

$$\frac{C_0 - C_{eutectic}}{C_B - C_{eutectic}} = \frac{C_0 - 61.5}{97.8 - 61.5} = .52$$

$$C_0 = 82.4 \text{ wt\% Sn}$$

MCEG 2023 Materials Science and Engineering

FALL 2020

Title of Assignment: Homework 14

TOPICS COVERED IN HOMEWORK 14

1. Dislocations and Strengthening Mechanisms

Solution of Homework 14

Due on Nov. 17, 2020

9.44 Specify the liquidus, solidus, and solvus temperatures for the following alloys:

- (a) 50 wt% Ni-50 wt% Cu
- (b) 10 wt% Sn-90 wt% Pb
- (c) 55 wt% Zn-45 wt% Cu
- (d) 50 wt% Pb-50 wt% Mg
- (e) 1.5 wt% C-98.5 wt% Fe

Solution

Definitions of liquidus, solidus, and solvus lines are as follows:

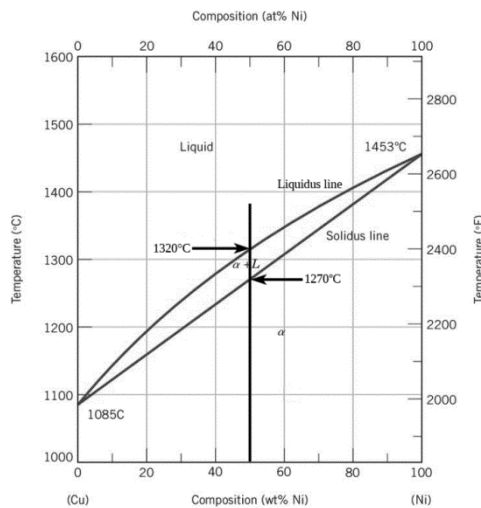
Liquidus—boundary between liquid and (liquid + solid) phase regions

Solidus—boundary between solid and (liquid + solid) phase regions

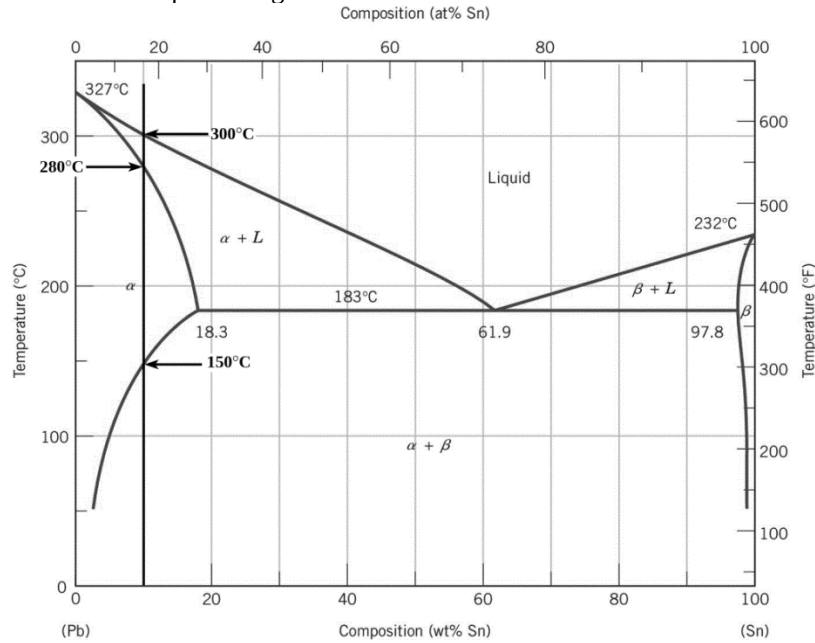
Solvus—boundary between a single solid phase region and a two solid phase region.

For this problem, a liquidus, solidus, or solvus temperature corresponds to the intersection between a vertical line (constructed at a specific composition) with the respective liquidus, solidus, or solvus line.

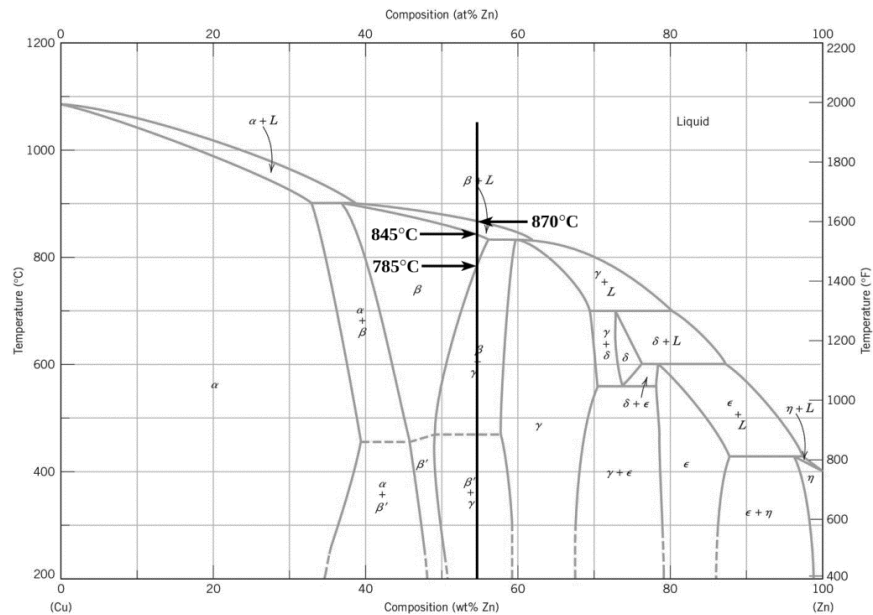
(a) The liquidus and solidus temperatures for a 50 wt% Ni-50 wt% Cu alloy (320°C, and 1270°C respectively) are noted on the Cu-Ni phase diagram shown below. For this alloy, there is no solvus line inasmuch as no two-solid-phase region exists for this system.



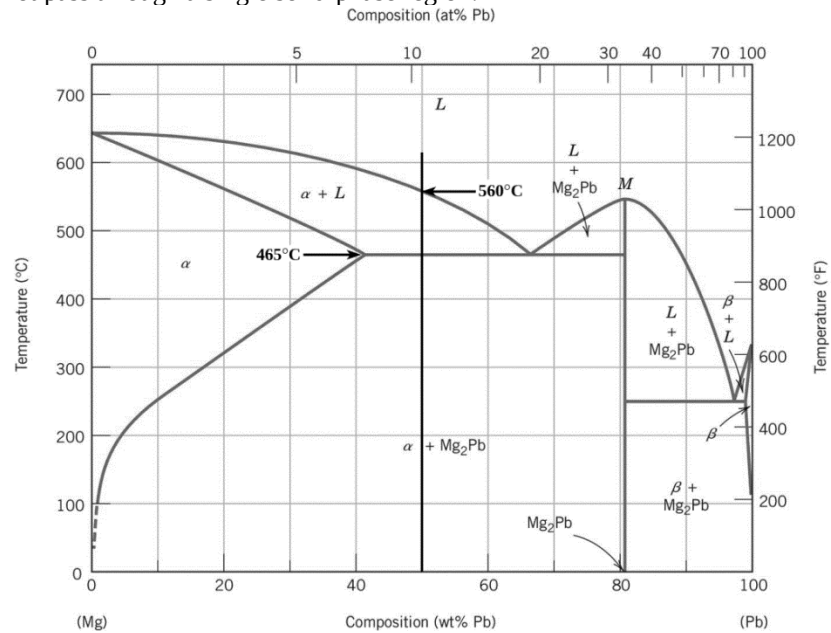
(b) The solvus, solidus, and liquidus temperatures for a 10 wt% Sn-90 wt% Pb alloy are 150°C, 280°C, and 300°C, respectively, as noted on the Pb-Sn phase diagram shown below.



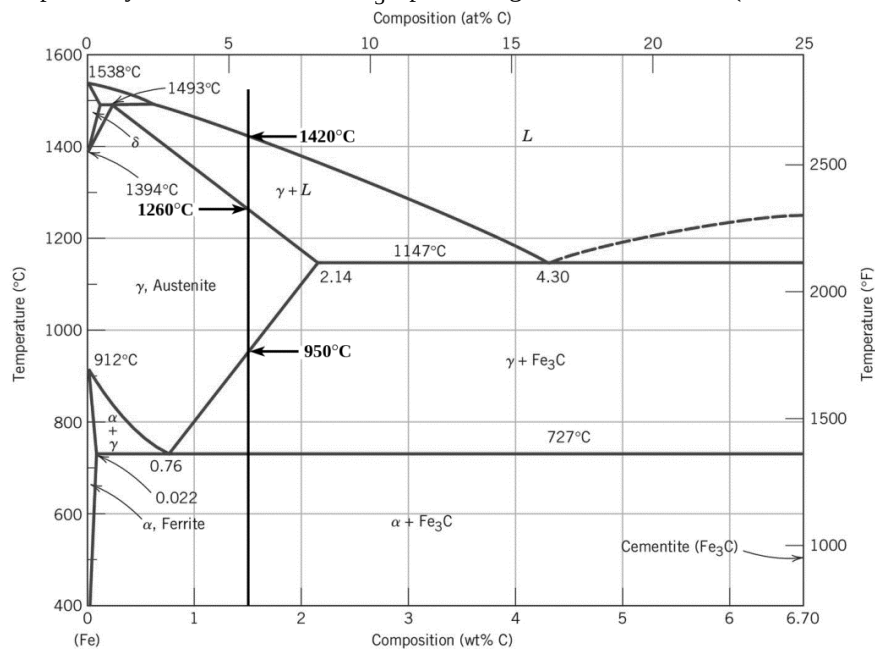
(c) The solvus, solidus and liquidus temperatures for a 55 wt% Zn-45 wt% Cu alloy are 785°C, 845°C, and 870°C, respectively, as noted on the Cu-Zn phase diagram shown below.



(d) The solidus and liquidus temperatures for a 50 wt% Pb-50 wt% Mg alloy are 465°C and 560°C, respectively, as noted on the Mg-Pb phase diagram shown below. For this alloy, there is no solvus line inasmuch as the vertical line at 50 wt% Pb does not pass through a single solid-phase region.



(e) The **solvus**, **solidus**, liquidus temperature for 1.5 wt% C-98.5 wt% Fe are 950°C, 1260°C, and 1420°C, respectively as noted on the Fe-Fe₃C phase diagram shown below. (note: red one are correction / added)



9.55 Consider 1.0 kg of austenite containing 1.15 wt% C, cooled to below 727°C (1341°F).

- What is the proeutectoid phase?
- How many kilograms each of total ferrite and cementite form?
- How many kilograms each of pearlite and the proeutectoid phase form?
- Schematically sketch and label the resulting microstructure.

Solution

(a) The proeutectoid phase will be Fe_3C since 1.15 wt% C is greater than the eutectoid composition (0.76 wt% C).

(b) For this portion of the problem, we are asked to determine how much total ferrite and cementite form. Application of the appropriate lever rule expression yields

$$W_{\alpha} = \frac{C_{\text{Fe}_3\text{C}} - C_0}{C_{\text{Fe}_3\text{C}} - C_{\alpha}} = \frac{6.70 - 1.15}{6.70 - 0.022} = 0.83$$

which, when multiplied by the total mass of the alloy (1.0 kg), gives 0.83 kg of total ferrite. For total cementite,

$$W_{\text{Fe}_3\text{C}} = \frac{C_0 - C_{\alpha}}{C_{\text{Fe}_3\text{C}} - C_{\alpha}} = \frac{1.15 - 0.022}{6.70 - 0.022} = 0.17$$

And the mass of total cementite that forms is $(0.17)(1.0 \text{ kg}) = 0.17 \text{ kg}$.

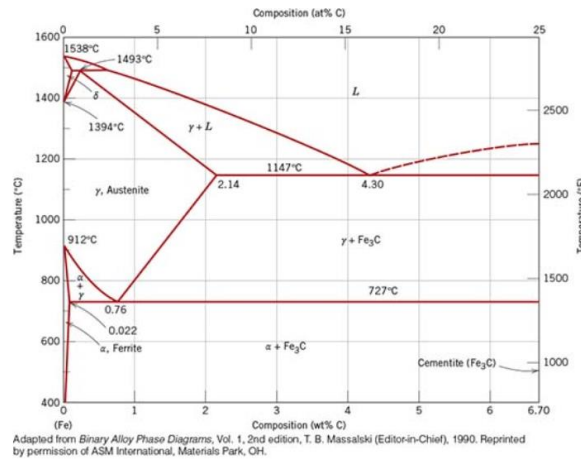


Figure 9.24 The iron-iron carbide phase diagram.

(c) Now we are asked to calculate how much pearlite and the proeutectoid phase (cementite) form. Applying Equation 9.22, in which $C'_1 = 1.15 \text{ wt\% C}$

$$W_p = \frac{6.70 - C'_1}{6.70 - 0.76} = \frac{6.70 - 1.15}{6.70 - 0.76} = 0.93$$

which corresponds to a mass of 0.93 kg. Likewise, from Equation 9.23

$$W_{\text{Fe}_3\text{C}'} = \frac{C'_1 - 0.76}{5.94} = \frac{1.15 - 0.76}{5.94} = 0.07$$

which is equivalent to 0.07 kg of the total 1.0 kg mass.

9.59 The microstructure of an iron–carbon alloy consists of proeutectoid ferrite and pearlite; the mass fractions of these two microconstituents are 0.286 and 0.714, respectively. Determine the concentration of carbon in this alloy.

Solution

This problem asks that we determine the carbon concentration in an iron-carbon alloy, given the mass fractions of proeutectoid ferrite and pearlite. From Equation 9.20

$$W_p = 0.714 = \frac{C'_0 - 0.022}{0.74}$$

which yields $C'_0 = 0.55 \text{ wt\% C}$.

9.62 Consider 2.0 kg of a 99.6 wt% Fe–0.4 wt% C alloy that is cooled to a temperature just below the eutectoid.

- How many kilograms of proeutectoid ferrite form?
- How many kilograms of eutectoid ferrite form?
- How many kilograms of cementite form?

Solution

In this problem, we are asked to consider 2.0 kg of a 99.6 wt% Fe–0.4 wt% C alloy that is cooled to a temperature below the eutectoid.

- Equation 9.21 must be used in computing the amount of proeutectoid ferrite that forms. Thus,

$$W_{\alpha'} = \frac{0.76 - C'_0}{0.74} = \frac{0.76 - 0.40}{0.74} = 0.49$$

Or, $(0.49)(2.0 \text{ kg}) = 0.98 \text{ kg}$ of proeutectoid ferrite forms.

- In order to determine the amount of eutectoid ferrite, it first becomes necessary to compute the amount of total ferrite using the lever rule applied entirely across the $\alpha + \text{Fe}_3\text{C}$ phase field, as

$$W_{\alpha} = \frac{C_{\text{Fe}_3\text{C}} - C'_0}{C_{\text{Fe}_3\text{C}} - C_{\alpha}} = \frac{6.70 - 0.40}{6.70 - 0.022} = 0.94$$

which corresponds to $(0.94)(2.0 \text{ kg}) = 1.88 \text{ kg}$. Now, the amount of eutectoid ferrite is just the difference between total and proeutectoid ferrites, or

$$1.88 \text{ kg} - 0.98 \text{ kg} = 0.90 \text{ kg}$$

- With regard to the amount of cementite that forms, again application of the lever rule across the entirety of the $\alpha + \text{Fe}_3\text{C}$ phase field, leads to

$$W_{\text{Fe}_3\text{C}} = \frac{C'_0 - C_{\alpha}}{C_{\text{Fe}_3\text{C}} - C_{\alpha}} = \frac{0.40 - 0.022}{6.70 - 0.022} = 0.057$$

which amounts to $(0.057)(2.0 \text{ kg}) = 0.114 \text{ kg}$ cementite in the alloy.

9.66 Compute the mass fraction of eutectoid ferrite in an iron-carbon alloy that contains 0.43 wt% C.

Solution

In order to solve this problem, it is necessary to compute mass fractions of total and proeutectoid ferrites, and then to subtract the latter from the former. To calculate the mass fraction of total ferrite, it is necessary to use the lever rule and a tie line that extends across the entire $\alpha + \text{Fe}_3\text{C}$ phase field as

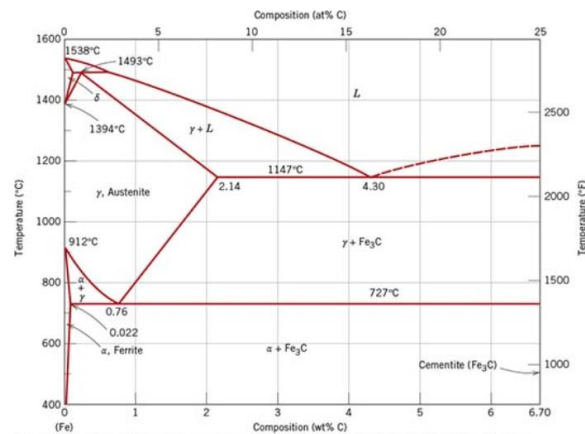
$$W_{\alpha} = \frac{C_{\text{Fe}_3\text{C}} - C_0}{C_{\text{Fe}_3\text{C}} - C_{\alpha}} = \frac{6.70 - 0.43}{6.70 - 0.022} = 0.939$$

Now, for the mass fraction of proeutectoid ferrite we use Equation 9.21 as

$$W_{\alpha'} = \frac{0.76 - C'_0}{0.74} = \frac{0.76 - 0.43}{0.74} = 0.446$$

And, finally, the mass fraction of eutectoid ferrite $W_{\alpha''}$ is just

$$\begin{aligned} W_{\alpha''} &= W_{\alpha} - W_{\alpha'} \\ &= 0.939 - 0.446 = 0.493 \end{aligned}$$



Adapted from Binary Alloy Phase Diagrams, Vol. 1, 2nd edition, T. B. Massalski (Editor-in-Chief), 1990. Reprinted by permission of ASM International, Materials Park, OH.

Figure 9.24 The iron-iron carbide phase diagram.

ABOVE AVERAGE

MCEG 2023 Materials Science and Engineering

Student Name (Print): Bujato Daniel

Last name **First name**

Homework Requirements:

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- 4) Put this cover sheet on top of your homework. Print your name clearly on page 1.
- 5) All homework will follow the above requirements.

Very neat

9.44

a) 50 wt% Ni - 50 wt% Cu

For this alloy the liquidus temperature is 1320°C (complete liquid) and the liquification start at 1280°C. From the figure the solidus temperature is around 1085°C and the solvus temperature 1200°C.

b) 10 wt% Sn – 90 wt% Pb

From the phase diagram: Liquid temperature 230°C

Solidus temperature 160°C

Solvus temperature 190°C

c) 55 wt% Zn - 45 wt% Cu

From the phase diagram: Liquidus line is 1050°C

Solidus temperature 200°C

Solvus temperature is 500°C

d) 50 wt% Pb – 50 wt% Mg

From phase diagram: Liquidus temperature 560°C

Solidus temperature 470°C

Solvus temperature 500°C

e) 1.5 wt% C – 98.5 wt% Fe

From the phase diagram: Liquidus temperature 1220°C

Solidus temperature 730°C

Solvus temperature 980°C

9.55

a) When 1kg of austenite containing 1.15% C is cooled below 727°C the pro-eutectoid phase is Fe₃C

b) To find the ferrite use the lever-rule expression:

$$W_a = \frac{C_{Fe_3C} - C_0}{C_{Fe_3C} - C_a}$$

Here, α phase composition is C_a , the composition of Fe₃C is C_{Fe_3C} , and C_0 is the composition of the alloy

$$C_{\text{Fe}_3\text{C}} = 6.70 \text{ wt\%}$$

$$C_0 = 1.15 \text{ wt\%}$$

$$C_a = 0.022 \text{ wt\%}$$

$$\begin{aligned} W_a &= \frac{C_{\text{Fe}_3\text{C}} - C_0}{C_{\text{Fe}_3\text{C}} - C_a} \\ &= \frac{6.70 - 1.15}{6.70 - 0.022} \\ &= 0.83 \end{aligned}$$

Therefore, the total mass of ferrite is 0.83 kg

Apply the lever-rule expression for cementite

$$W_{\text{Fe}_3\text{C}} = \frac{C_0 - C_a}{C_{\text{Fe}_3\text{C}} - C_a}$$

$$C_{\text{Fe}_3\text{C}} = 6.70 \text{ wt\%}$$

$$C_0 = 1.15 \text{ wt\%}$$

$$C_a = 0.022 \text{ wt\%}$$

$$\begin{aligned} W_{\text{Fe}_3\text{C}} &= \frac{C_0 - C_a}{C_{\text{Fe}_3\text{C}} - C_a} \\ &= \frac{1.15 - 0.022}{6.70 - 0.022} \\ &= 0.17 \end{aligned}$$

Therefore, the total mass of cementite is 0.17 kg

c) To find the mass percentage of pearlite using lever rule expression for hypereutectoid steel

$$W_P = \frac{6.70 - C'_1}{5.94}$$

C'_1 is the composition of the hypereutectoid alloy

$$\begin{aligned} W_P &= \frac{6.70 - 1.15}{5.94} \\ &= 0.93 \end{aligned}$$

Therefore, the total mass of pearlite is

$$0.93 \text{ kg}$$

To find the mass percentage of pro-eutectoid phase form using lever rule-expression for hypereutectoid steel

$$W_{\text{Fe}_3\text{C}'} = \frac{C'_1 - 0.76}{5.94}$$

$$C'_1 = 1.15 \text{ wt\%}$$

$$W_{\text{Fe}_3\text{C}} = \frac{1.15 - 0.76}{5.94}$$

$$= 0.07$$

Therefore, the total mass of pro-eutectoid cementite is

$$0.07 \text{ kg}$$

9.59

Microstructure of an iron-carbon alloy consists of proeutectoid ferrite and pearlite

Mass fraction of total proeutectoid ferrite $W_{\text{Fe}_3\text{C}} = 0.286$

Mass fraction of total pearlite, $W_P = 0.714$

The lever-rule expression for computation of pearlite mass fraction, $W_P = \frac{C'_0 - 0.022}{0.74}$

Since, $W_P = 0.714$

$$0.714 = \frac{C'_0 - 0.022}{0.74}$$

$$C'_0 - 0.002 = 0.714 \times 0.74$$

$$C'_0 - 0.002 = 0.52836$$

$$C'_0 = 0.52836 + 0.022$$

$$C'_0 = 0.5503 \text{ wt\%}$$

$$C'_0 = 0.5503 \text{ wt\%}$$

9.62

a)

$$W_{\alpha'} = \frac{0.76 - C_0'}{0.74}$$

Where, $W_{\alpha'}$ is the weight fraction of proeutectoid, C_0' is the weight composition of carbon in the alloy is 0.40

Substitute 0.40 for C_0' :

$$\begin{aligned} W_{\alpha'} &= \frac{0.76 - 0.40}{0.74} \\ &= 0.486 \end{aligned}$$

Calculate the weight of the proeutectoid:

$$\begin{aligned} \text{Weight of proeutectoid} &= 0.486 \times 2.0 \text{ kg} \\ &= 0.972 \text{ kg} \end{aligned}$$

Therefore, the amount of proeutectoid ferrite is 0.972 kg

b)

Compute the amount of eutectoid ferrite form and use Figure 10.35 and the lever arm to find the amount of total ferrite. Then subtract the amount of proeutectoid from the total ferrite to calculate the eutectoid fraction.

$$W_{\alpha} = \frac{C_{\text{Fe}_3\text{C}} - C_0'}{C_{\text{Fe}_3\text{C}} - C_{\alpha}}$$

Where, W_{α} is the weight fraction of total ferrite, $C_{\text{Fe}_3\text{C}}$ is the wt% C at the cementite side and C_{α} is the wt% of carbon at the α phase.

Substitute 6.70 for $C_{\text{Fe}_3\text{C}}$, 0.40 for C_0' , 0.022 for C_{α} :

$$\begin{aligned} W_{\alpha} &= \frac{6.70 - 0.40}{6.70 - 0.022} \\ &= 0.943 \end{aligned}$$

Calculate the weight of the ferrite:

$$\begin{aligned} \text{Weight of ferrite} &= 0.943 \times 2.0 \text{ kg} \\ &= 1.886 \text{ kg} \end{aligned}$$

Calculate the amount of the eutectoid ferrite:

$$\begin{aligned} \text{Amount of the eutectoid ferrite} &= 1.886 \text{ kg} - 0.972 \text{ kg} \\ &= 0.914 \text{ kg} \end{aligned}$$

Therefore, the amount of eutectoid ferrite is 0.914 kg

c)

Compute the amount of the cementite form and use the lever arm:

$$W_{\text{Fe}_3\text{C}} = \frac{C'_0 - C_\alpha}{C_{\text{Fe}_3\text{C}} - C_\alpha}$$

Substitute 6.70 for $C_{\text{Fe}_3\text{C}}$, 0.40 for C'_0 , 0.022 for C_α :

$$\begin{aligned} W_{\text{Fe}_3\text{C}} &= \frac{C'_0 - C_\alpha}{C_{\text{Fe}_3\text{C}} - C_\alpha} \\ &= \frac{0.40 - 0.022}{6.70 - 0.022} \\ &= 0.057 \end{aligned}$$

Calculate the amount of the cementite:

$$\begin{aligned} \text{Amount of the cementite} &= 0.057 \times 2.0 \text{ kg} \\ &= 0.114 \text{ kg} \end{aligned}$$

Therefore, the amount of cementite is 0.114 kg

9.66

Percentage of ferrite, $C'_0 = 0.43$

The lever-rule expression for total ferrite is, $W_\alpha = \frac{C_{\text{Fe}_3\text{C}} - C_0}{C_{\text{Fe}_3\text{C}} - C_\alpha}$

Since, $C_{\text{Fe}_3\text{C}} = 6.70 \text{ wt\%}$ and $C_\alpha = 0.022 \text{ wt\%}$

$$\begin{aligned} W_\alpha &= \frac{6.70 - 0.43}{6.70 - 0.022} \\ &= 0.9389 \end{aligned}$$

The lever-rule expression for proeutectoid ferrite is, $W_{\alpha'} = \frac{0.76 - C_0}{0.74}$

$$\begin{aligned} &= \frac{0.76 - 0.43}{0.74} \\ &= 0.445946 \end{aligned}$$

Then mass fraction of eutectoid ferrite,

$$\begin{aligned} W_{\alpha''} &= W_\alpha - W_{\alpha'} \\ &= 0.9389 - 0.445946 \\ &= 0.4929 \end{aligned}$$

$$\boxed{W_{\alpha''} = 0.49}$$

AVERAG

MCEG 2023 Materials Science and Engineering

Student Name (Print): Lira Anette

Last name **First name**

Homework Requirements:

- 1) Draw a **box** around the final answer. Correct units, where applicable, must be displayed on the final answer for each homework problem. Incorrect or the omission of units on the final answer may be penalized, particularly when units are not carried throughout calculations that support the final answer.
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- 5) All homework will follow the above requirements.

9.44

(a) 50 wt% Ni - 50 wt% Cu - for this alloy the liquidus temperature is 1320°C and the liquidification starts at 1280°C

from the figure the solidus temperature is around 1085°C
And the solvus temperature 1200°C

(b) 10 wt% Sn - 90 wt% Pb

from phase diagram: liquidus temperature is 230°C
solidus temperature is 160°C
solvus temperature is 190°C

(c) 55 wt% Zn - 45 wt% Cu

from phase diagram: - liquidus line is 1050°C
solidus temp is 200°C
solvus temp is 500°C

(d) 50 wt% Pb - 50 wt% Mg:

from phase diagram: - liquidus temp: 560°C
solidus temp: 470°C
solvus temp is 500°C

(e) 1.5 wt% - 98.5 wt% Fe

from phase diagram: liquidus temp: 1220°C
solidus temp: 730°C
solvus temp: 960°C

9.55

(a) When 1 Kg of austenite containing 1.15% C is cooled below 727°C the pro-eutectoid phase is Fe_3C

$$(b) W_{\text{Fe}_3\text{C}} = \frac{C_{\text{Fe}_3\text{C}} - C_0}{C_{\text{Fe}_3\text{C}} - C_{\alpha}} = \frac{6.70 - 1.15}{6.70 - 0.022} = \boxed{0.83 \text{ Kg}}$$

6.70 wt%
for $\text{C}_{\text{Fe}_3\text{C}}$

mass of ferrite

- 1.15 wt% for C_0
- 0.022 wt% for C_{α}

$$\therefore W_{\text{Fe}_3\text{C}} = \frac{C_0 - C_{\alpha}}{C_{\text{Fe}_3\text{C}} - C_{\alpha}} = \frac{1.15 - 0.022}{6.70 - 0.022} = \boxed{0.17 \text{ Kg}}$$

total mass of cementite

$$(c) W_P = \frac{C' - C_1}{5.94} \rightarrow W_P = \frac{6.70 - 1.15}{5.94} = \boxed{0.93 \text{ Kg}}$$

1.15 = C_1

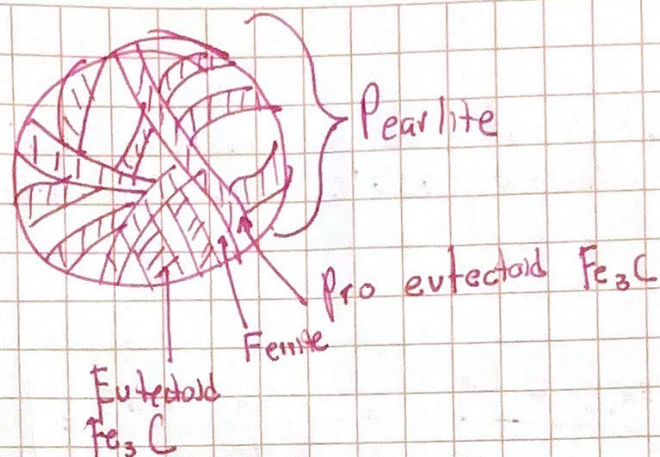
total mass of pearlite

$$W_{\text{Fe}_3\text{C}'} = \frac{C' - 0.76}{5.94} = \frac{1.17 - 0.76}{5.94}$$

$$= \boxed{0.07 \text{ Kg}}$$

← mass of pro-eutectoid cementite

d



9.59

mass of fraction of total proeutectoid ferrite $W_{FeC} = 0.286$
 Mass of total pearlite, $W_p = 0.714$

$$W_p = \frac{C_o - 0.022}{0.74}$$

$$0.714 = \frac{C_o' - 0.022}{0.74} (0.74)$$

$$0.52836 = \frac{C_o' - 0.022}{0.022}$$

$$C_o' = 0.55036$$

$$C_o' = 0.55 \text{ wt\%}$$

9.62

$$C'_0 = 0.40$$

$$a) W_a = \frac{0.76 - C'_0}{0.74} = \frac{0.76 - 0.40}{0.74} = 0.486$$

$$\text{Weight of proeutectoid} = 0.486 \times 2.0 \text{ Kg} = \boxed{0.972 \text{ Kg}}$$

$$b) W_a = \frac{C_{Fe_3C} - C'_0}{C_{Fe_3C} - C_a} = \frac{6.70 - 0.40}{6.70 - 0.022} = 0.943$$

$$C_{Fe_3C} = 6.70$$

$$C_a = 0.022$$

$$C'_0 = 0.40$$

$$\text{Weight of ferrite} = 0.943 (2.0 \text{ Kg}) \\ = 1.886 \text{ Kg}$$

$$\text{Amount of the eutectoid ferrite} = 1.886 - 0.972 \text{ Kg} = 0.914 \text{ Kg} \\ = \boxed{0.914 \text{ Kg}}$$

$$c) W_{Fe_3C} = \frac{C'_0 - C_a}{C_{Fe_3C} - C_a} = \frac{0.40 - 0.022}{6.70 - 0.022} = 0.057$$

$$C_a = 0.022$$

$$\text{amount of cementite} = 0.057 (2.0 \text{ Kg}) \\ = \boxed{0.114 \text{ Kg}}$$

9.66

$$C_a = 0.022 \text{ wt\%}$$

$$C_o = 0.43$$

$$C_{Fe3C} = 6.70 \text{ wt\%}$$

$$W_a = \frac{C_{Fe3C} - C_o}{C_{Fe3C} - C_a} = \frac{6.70 - 0.43}{6.70 - 0.022} = 0.9389$$

proeutectoid ferrite is $W_a = \frac{0.76 - C_o}{0.74}$

$$= \frac{0.76 - 0.43}{0.76} = 0.44$$

$$\begin{aligned} W_a &= W_a - W_a \\ &= 0.9389 - 0.44 \\ &= 0.4929 \end{aligned}$$

$$W_a = 0.49$$

BELOW AVERAGE

MCEG 2023 Materials Science and Engineering

Student Name (Print):

Garay

Last name

Gabriela

First name

Homework Requirements:

- 1) Draw a **box** around the final answer. Correct units, where applicable, must be displayed on the final answer for each homework problem. Incorrect or the omission of units on the final answer may be penalized, particularly when units are not carried throughout calculations that support the final answer.
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- 5) All homework will follow the above requirements.

Gabriela Garay

Homework 14

11/17/20

Equilibrium Diagrams having intermediate phases or compounds

9.44 - Specify the liquidus, solidus & solvus temperatures for the following alloys:

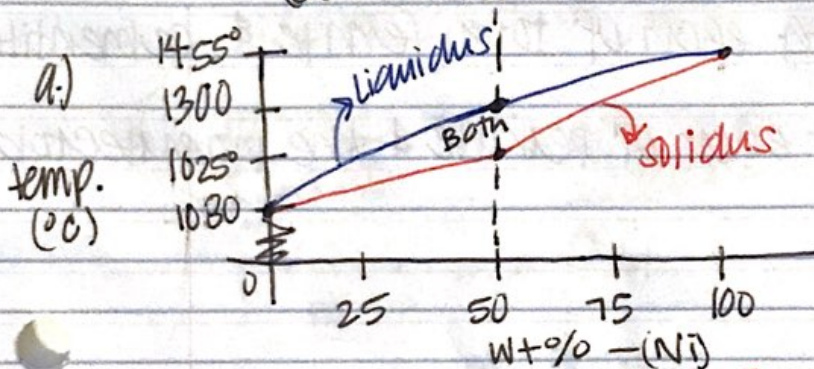
(a) 50 wt% Ni - 50 wt% Cu

(b) 10 wt% Sn - 90 wt% Pb

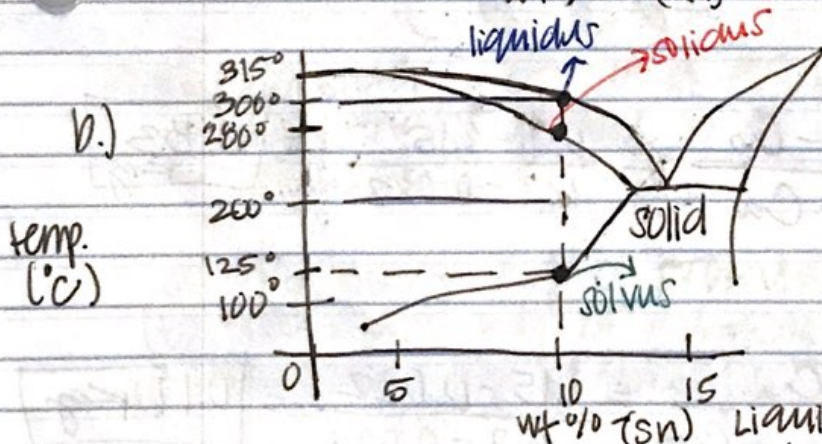
(c) 55 wt% Zn - 45 wt% Cu

(d) 50 wt% Pb - 50 wt% Mg

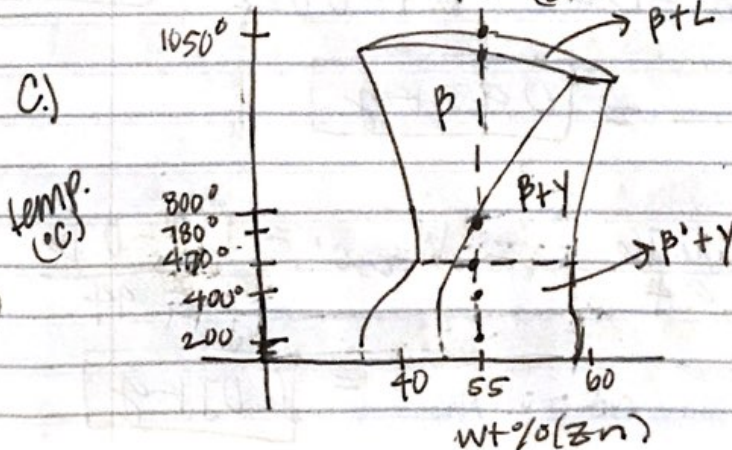
(e) 1.5 wt% C - 98.5 wt% Fe



Temps.	
Liquidus:	1300 °C
Solidus:	1250 °C
Solvus:	none



Temps.	
Liquidus:	315 °C
Solidus:	280 °C
Solvus:	125 °C



Temps.	
Liquidus:	1050 °C
Solidus:	780 °C
Solvus:	none

Fig. 9.20

Temps:

d.)

Liquidus: 550°C
Solidus: 450°C
Solvus: None

e.)

Temps:

Fig. 9.20

Liquidus: 1220°C
Solidus: 1333°C
Solvus: 970°C

9.55 (a-c):

consider 1 kg of austenite containing 1.15 wt% C, cooled to less than 727°C (1341°F)

(a) What's the proeutectoid phase?

(b) How many kg each of total ferrite & cementite form?

(c) How many kg each of pearlite & the proeutectoid phase form?

(a) It's Fe_3C .

(b) Formula:

$$W_{\text{Fe}_3\text{C}} = \frac{C_{\text{Fe}_3\text{C}} - C_0}{C_{\text{Fe}_3\text{C}} - C_{\alpha}} = \frac{6.7 - 1.15}{6.7 - 0.022} = 0.83 \text{ kg}$$

&

Formula:

$$W_{\text{Fe}_3\text{C}} = \frac{C_0 - C_{\alpha}}{C_{\text{Fe}_3\text{C}} - C_{\alpha}} = \frac{1.15 - 0.022}{6.7 - 0.022} = 0.17 \text{ kg}$$

$$\text{c.) } W_p = \frac{6.7 - C'_1}{5.94} = 0.93 \text{ kg}$$

$$\begin{aligned} \& W_{\text{Fe}_3\text{C}'} &= \frac{C'_1 - 0.76}{5.94} &= W_{\text{Fe}_3\text{C}'} &= \frac{1.17 - 0.76}{5.94} \\ & & & &= 0.07 \text{ kg} \end{aligned}$$

9.59: The microstructure of an iron-carbon alloy consists of proeutectoid ferrite & pearlite; the mass fract. of these two microconstituents are 0.286 & 0.714, respectively. Determine the concentration of carbon in this alloy.

$$W_p = 0.714$$

$$0.76 - 0.022 = 0.74$$

$$\therefore \frac{0.714}{(0.74)} = \frac{C_0 - 0.022}{(0.74)} \quad (0.74)$$

$$\frac{(0.714)(0.74)}{+ 0.022} = \frac{C_0 - 0.022}{+ 0.022}$$

$$\boxed{0.550 \text{ Wt\%}} = C_0$$

9.62: Consider 2 kg of a 99.6 wt% Fe-0.4 wt% C alloy that's cooled to a temp. just below the eutectoid.

- How many kg of proeutectoid ferrite form?
- How many kg of eutectoid ferrite form?
- How many kg of cementite form?

$$(a) W_d = \frac{0.76 - 0.40}{0.74} = (0.486 \text{ kg})(2 \text{ kg}) = \boxed{0.97 \text{ kg}}$$

$$(b) W_d = \frac{6.70 - 0.40}{6.70 - 0.022} = (0.94 \text{ kg})(2 \text{ kg}) = 1.89 \text{ kg}$$

$$\therefore (1.89 \text{ kg}) - (0.97 \text{ kg}) = \boxed{0.91 \text{ kg}}$$

$$(C) W_{Fe_3C} = \frac{0.40 - 0.022}{6.70 - 0.022} = (0.057 \text{ kg})(2 \text{ kg})$$

$$= \boxed{0.11 \text{ kg}}$$

9.66: compute the mass fraction of eutectoid ferrite in an iron-carbon alloy contains 0.43 wt % C.

$$W_{\alpha} = \frac{0.76 - 0.43}{0.74} = \underline{0.45 \text{ kg}} \rightarrow \text{mass of eutectoid ferrite}$$

& total mass fract.

$$W_{\alpha} = \frac{6.7 - 0.43}{6.7 - 0.022} = \underline{0.94 \text{ kg}}$$

$$\therefore (0.94 \text{ kg}) - (0.45 \text{ kg}) = \boxed{0.49 \text{ kg}}$$

MCEG 2023 Materials Science and Engineering

FALL 2020

Title of Assignment: Homework 15

TOPICS COVERED IN HOMEWORK 15

1. Dislocations and Strengthening Mechanisms

Solution of Homework 15
Due on Nov. 24, 2020

10.1 Name the two stages involved in the formation of particles of a new phase. Briefly describe each.

Solution

The two stages involved in the formation of particles of a new phase are *nucleation* and *growth*. The nucleation process involves the formation of normally very small particles of the new phase(s), which are stable and capable of continued growth. The growth stage is simply the increase in size of the new phase particles.

10.15 (a) Briefly describe the phenomena of superheating and supercooling.

(b) Why do these phenomena occur?

Solution

(a) Superheating and supercooling correspond, respectively, to heating or cooling above or below a phase transition temperature without the occurrence of the transformation.

(b) These phenomena occur because right at the phase transition temperature, the driving force is not sufficient to cause the transformation to occur. The driving force is enhanced during superheating or supercooling.

10.17 Briefly cite the differences between pearlite, bainite, and spheroidite relative to microstructure and mechanical properties.

Solution

The microstructures of pearlite, bainite, and spheroidite all consist of α -ferrite and cementite phases. For pearlite, the two phases exist as layers, which alternate with one another. Bainite consists of very fine and parallel needle-shaped particles of cementite that are surrounded an α -ferrite matrix. For spheroidite, the matrix is ferrite, and the cementite phase is in the shape of sphere-shaped particles.

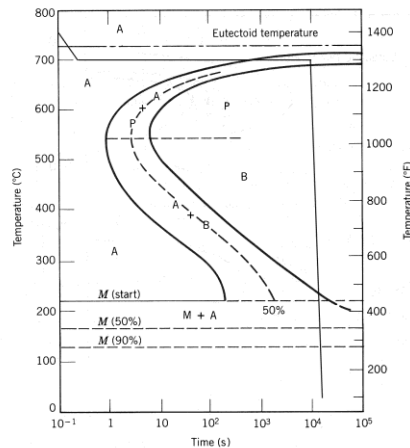
Bainite is harder and stronger than pearlite, which, in turn, is harder and stronger than spheroidite.

10.19 Using the isothermal transformation diagram for an iron–carbon alloy of eutectoid composition (Figure 10.23), specify the nature of the final microstructure (in terms of microconstituents present and approximate percentages of each) of a small specimen that has been subjected to the following time–temperature treatments. In each case assume that the specimen begins at 760°C (1400°F) and that it has been held at this temperature long enough to have achieved a complete and homogeneous austenitic structure.

(a) Cool rapidly to 700°C (1290°F), hold for 10^4 s, then quench to room temperature.

Solution

Below is Figure 10.23 upon which is superimposed the above heat treatment.



After cooling and holding at 700°C for 10^4 s, approximately 50% of the specimen has transformed to coarse pearlite. Upon cooling to room temperature, the remaining 50% transforms to martensite. Hence, the final microstructure consists of about 50% coarse pearlite and 50% martensite.

(b) Reheat the specimen in part (a) to 700°C (1290°F) for 20 h.

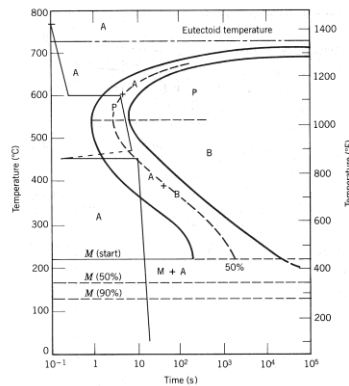
Solution

Heating to 700°C for 20 h the specimen in part (a) will transform both coarse pearlite and martensite to spheroidite.

(c) Rapidly cool to 600°C (1110°F), hold for 4 s, rapidly cool to 450°C (840°F), hold for 10 s, then quench to room temperature.

Solution

Below is Figure 10.23 upon which is superimposed the above heat treatment.

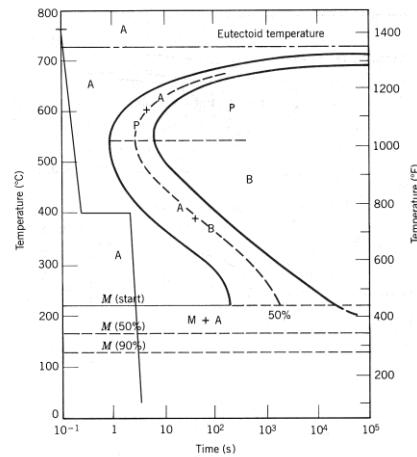


After cooling to and holding at 600°C for 4 s, approximately 50% of the specimen has transformed to pearlite (medium). During the rapid cooling to 450°C no transformations occur. **At 450°C we start timing again at zero time;** while holding at 450°C for 10 s, approximately 50 percent of the remaining unreacted 50% (or 25% of the original specimen) will transform to bainite. And upon cooling to room temperature, the remaining 25% of the original specimen transforms to martensite. Hence, the final microstructure consists of about 50% pearlite (medium), 25% bainite, and 25% martensite.

(d) Cool rapidly to 400°C (750°F), hold for 2 s, then quench to room temperature.

Solution

Below is Figure 10.23 upon which is superimposed the above heat treatment.

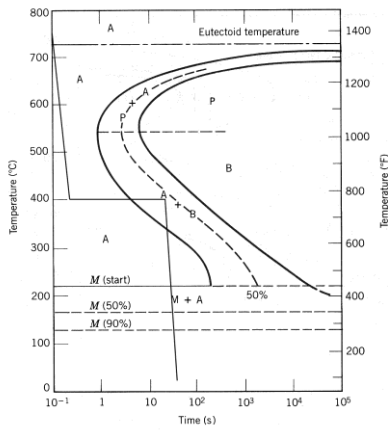


After cooling to and holding at 400°C for 2 s, no of the transformation begin lines have been crossed, and therefore, the specimen is 100% austenite. Upon cooling rapidly to room temperature, all of the specimen transforms to martensite, such that the final microstructure is 100% martensite.

(e) Cool rapidly to 400°C (750°F), hold for 20 s, then quench to room temperature.

Solution

Below is Figure 10.23 upon which is superimposed the above heat treatment.

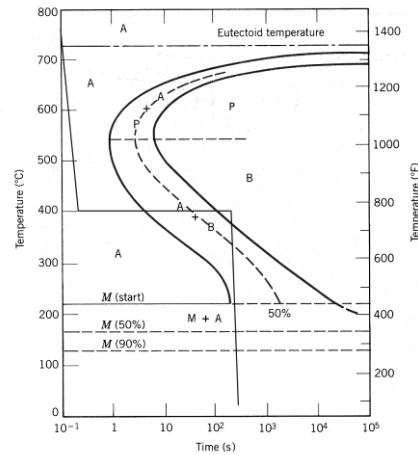


After cooling and holding at 400°C for 20 s, approximately 40% of the specimen has transformed to bainite. Upon cooling to room temperature, the remaining 60% transforms to martensite. Hence, the final microstructure consists of about 40% bainite and 60% martensite.

(f) Cool rapidly to 400°C (750°F), hold for 200 s, then quench to room temperature.

Solution

Below is Figure 10.23 upon which is superimposed the above heat treatment.

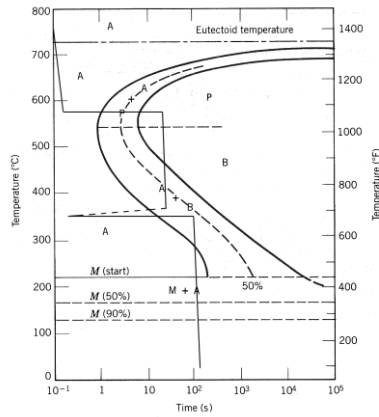


After cooling and holding at 400°C for 200 s, the entire specimen has transformed to bainite. Therefore, during the cooling to room temperature no additional transformations will occur. Hence, the final microstructure consists of 100% bainite.

(g) Rapidly cool to 575°C (1065°F), hold for 20 s, rapidly cool to 350°C (660°F), hold for 100 s, then quench to room temperature.

Solution

Below is Figure 10.23 upon which is superimposed the above heat treatment.

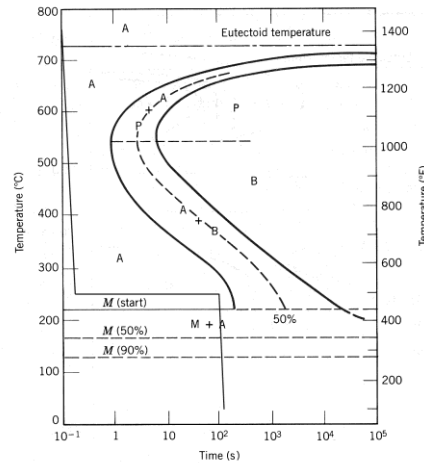


After cooling and holding at 575°C for 20 s, the entire specimen has transformed to fine pearlite. Therefore, during the second heat treatment at 350°C no additional transformations will occur. Hence, the final microstructure consists of 100% fine pearlite.

(h) Rapidly cool to 250°C (480°F), hold for 100 s, then quench to room temperature in water. Reheat to 315°C (600°F) for 1 h and slowly cool to room temperature.

Solution

Below is Figure 10.23 upon which is superimposed the above heat treatment.



After cooling and holding at 250°C for 100 s, no transformations will have occurred—at this point, the entire specimen is still austenite. Upon rapidly cooling to room temperature in water, the specimen will completely transform to martensite. The second heat treatment (at 315°C for 1 h)—not shown on the above plot—will transform the material to tempered martensite. Hence, the final microstructure is 100% tempered martensite.

10.24 Name the microstructural products of eutectoid iron–carbon alloy (0.76 wt% C) specimens that are first completely transformed to austenite, then cooled to room temperature at the following rates:

- (a) 200°C/s
- (b) 100°C/s
- (c) 20°C/s

Solution

We are called upon to name the microstructural products that form for specimens of an iron-carbon alloy of eutectoid composition that are continuously cooled to room temperature at a variety of rates. Figure 10.28 is used in these determinations.

- (a) At a rate of 200°C/s , only martensite forms.
- (b) At a rate of 100°C/s , both martensite and pearlite form.
- (c) At a rate of 20°C/s , only fine pearlite forms.

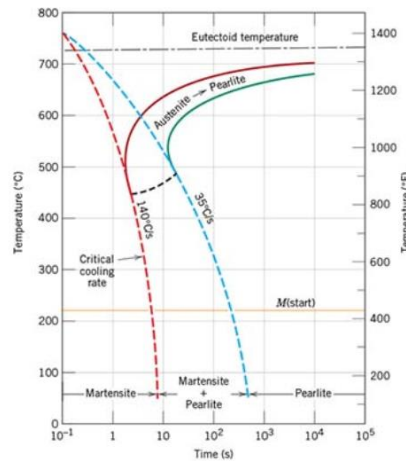


Figure 10.28 Continuous-cooling transformation diagram for a eutectoid iron–carbon alloy and superimposed cooling curves, demonstrating the dependence of the final microstructure on the transformations that occur during cooling.

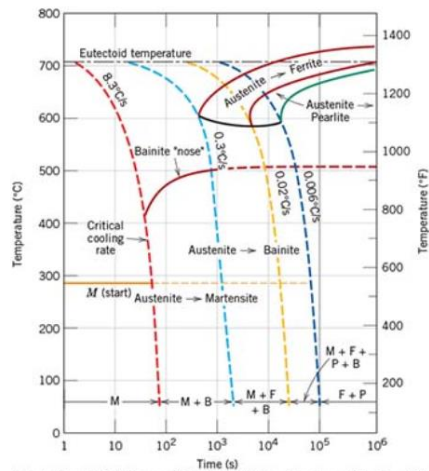
10.28 Name the microstructural products of 4340 alloy steel specimens that are first completely transformed to austenite, then cooled to room temperature at the following rates:

- (a) 10°C/s
- (b) 1°C/s
- (c) 0.1°C/s
- (d) 0.01°C/s

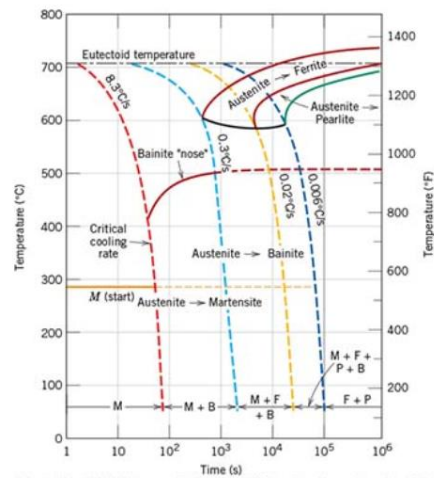
Solution

This problem asks for the microstructural products that form when specimens of a 4340 steel are continuously cooled to room temperature at several rates. Figure 10.29 is used for these determinations.

- (a) At a cooling rate of 10°C/s , only martensite forms.
- (b) At a cooling rate of 1°C/s , both martensite and bainite form.
- (c) At a cooling rate of 0.1°C/s , martensite, proeutectoid ferrite, and bainite form.
- (d) At a cooling rate of 0.01°C/s , martensite, proeutectoid ferrite, pearlite, and bainite form.



Adapted from H. E. McGannon (Editor), *The Making, Shaping and Treating of Steel*, 9th edition, United States Steel Corporation, Pittsburgh, 1971, p. 1096.



Adapted from H. E. McGannon (Editor), *The Making, Shaping and Treating of Steel*, 9th edition, United States Steel Corporation, Pittsburgh, 1971, p. 1096.

Figure 10.29 Continuous-cooling transformation diagram for an alloy steel (type 4340) and several superimposed cooling curves demonstrating dependence of the final microstructure of this alloy on the transformations that occur during cooling.

ABOVE AVERAGE

MCEG 2023 Materials Science and Engineering

Student Name (Print): Bujato Daniel

Last name First name

Homework Requirements:

- 1) Draw a **box** around the final answer. Correct units, where applicable, must be displayed on the final answer for each homework problem. Incorrect or the omission of units on the final answer may be penalized, particularly when units are not carried throughout calculations that support the final answer.
- 2) Hand-written or MS Word generated homework should be submitted electronically before the deadlines.
- 3) All homework must be presented neatly. Use ink or dark pen. The following item is **NOT** acceptable: very light pencil.
- 4) Put this cover sheet on **top** of your homework. Print your **name** clearly on page 1.
- 5) All homework will follow the above requirements.

Very neat

10.1

1. *Nucleation*: this is the formation of very small particles or nuclei of the phase, like embryo, from the parent phase. It exists in two types, the first type is the homogeneous nucleation, which forms at nonhomogeneous structure, such as container surfaces, insoluble impurities, grain boundaries and so on.

2. *Growth*: This is the growing stage of the nuclei after it becomes a stable nucleus and occurs when the embryo size becomes larger than the critical size r^* . This process will form new-phase particles inside the parent phase. The growth step does not stop the nucleation stage. The two processes occur at the same time to form more particles of the new phase until the parent phase has been completely changed into the new phase.

10.15

a) Superheating is heating above the phase transition temperature without the occurrence of the transformation whereas super cooling corresponds to cooling below phase transition temperature.

b) At the phase of transition temperature, the driving force is not enough to occur transformation. By superheating or super cooling driving force can be obtained.

10.17

Pearlite: is a two-phase microstructure found in cast irons and some steels. It is from the transformation of austenite of eutectoid composition. It consists of alternate layers of α -ferrite and cementite.

Bainite: is an austenitic transformation product found in cast irons and steels. It forms at temperatures between those at which pearlite and martensite transformation occurs. It consists of α -ferrite and a fine dispersion of cementite.

Spheroidite: consists of sphere like cementite particles within an α -ferrite matrix. It is relatively soft and is formed by an appropriate elevated temperature heat treatment of bainite, pearlite, or martensite.

Thus, the difference between the microstructure of the pearlite, bainite, and spheroidite are explained.

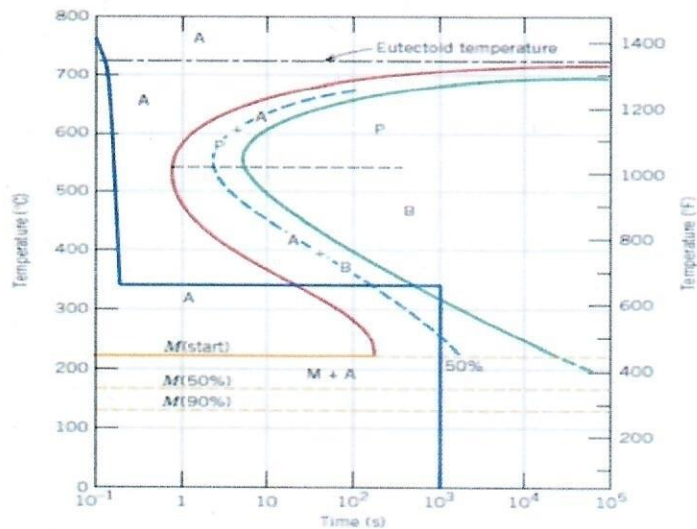
The mechanical strength of bainite is greater than pearlite due to the smaller size scale of the eutectoid lamella. The mechanical strength of pearlite is greater than of spheroidite.

Therefore, the order of the mechanical strength is

bainite>pearlite>spheroidite

10.19

a)

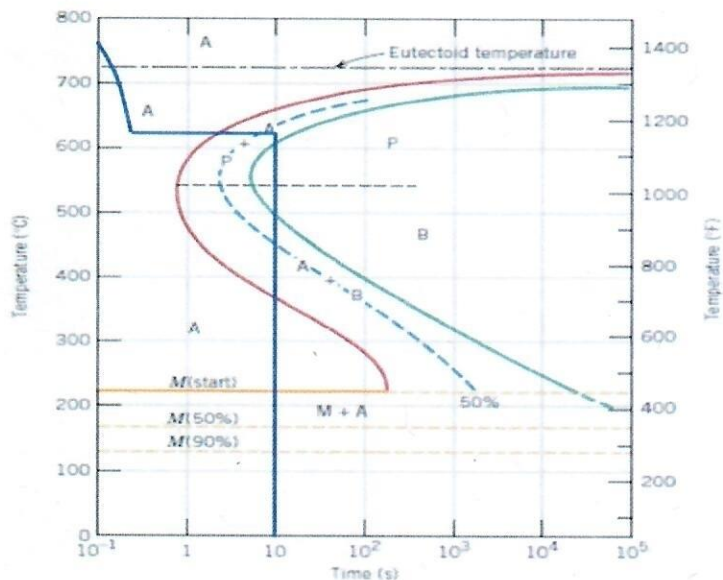


100% bainite is formed when the specimen is cooled rapidly to 350°C from 760°C and held for 10³s and cooled to room temperature. This can be from the transformation diagram.

Therefore, the microstructure formed is

100% bainite

b)

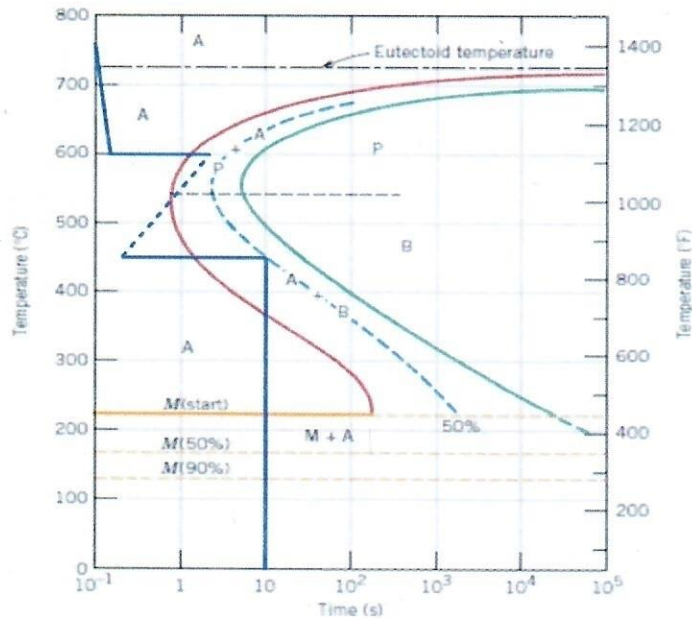


50% pearlite and 50% martensite are formed when the specimen is cooled rapidly to 625°C from 760°C and held for 10s and cooled to room temperature. This can be seen from the transformation diagram.

Therefore, the microstructure formed is

50% pearlite and 50% martensite

c)

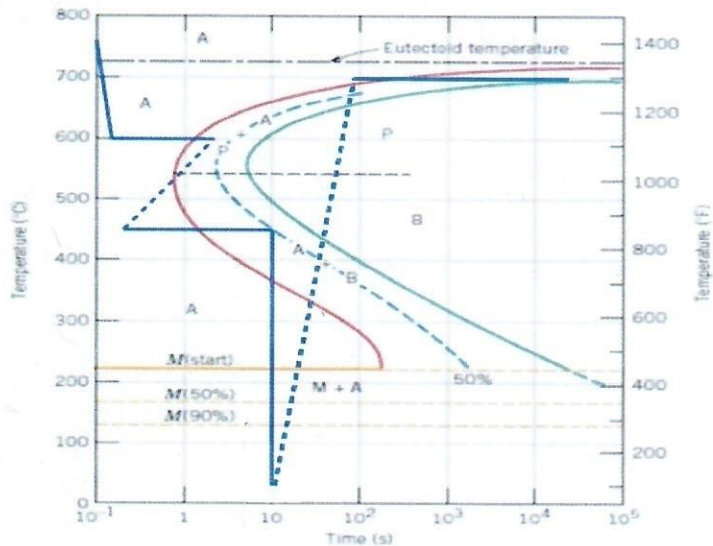


After cooling to 600°C and holding for 4s 50% pearlite is formed. After that the remaining sample is rapid cooled to 450°C and held for 10s, we will begin time from zero time, 50% of the remaining sample (or 25% of original sample) will transform to bainite. After that the sample is quenched to room temperature, therefore, the remaining 25% of the original specimen will transform to martensite.

Therefore, the microstructure formed is

50% pearlite, 25% bainite and 25% martensite

d)

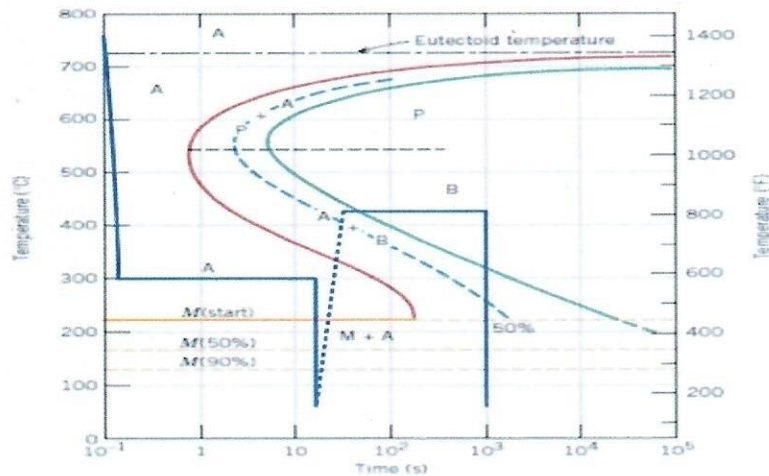


100% spheroidite is formed when the specimen reheats in part c to the temperature 700°C for 20 hours. This can be seen from the transformation diagram.

Therefore, the microstructure formed is

100% Spheroidite

e)

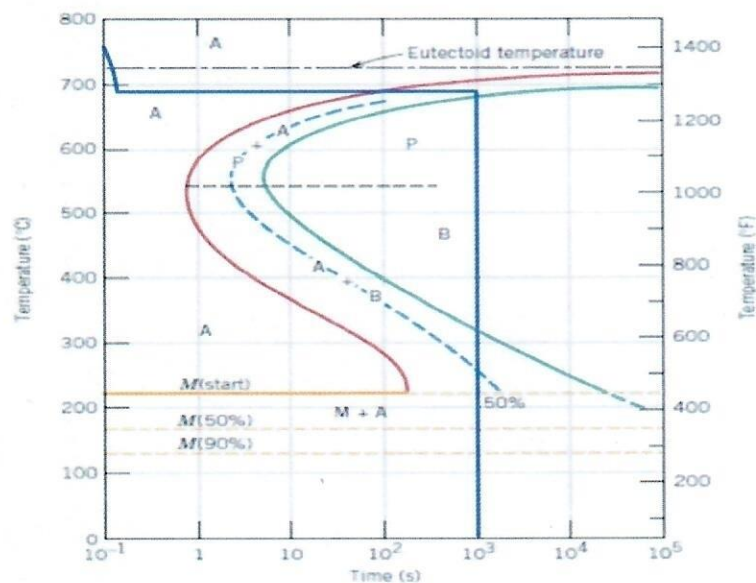


100% tempered martensite is formed when the specimen is cooled rapidly to 300°C from 760°C and held for 20s and quenched to room temperature and again heated to 425°C and then held for 10³s and then slowly cooled to room temperature. This can be seen from the transformation diagram.

Therefore, the microstructure formed is

100% tempered martensite

f)

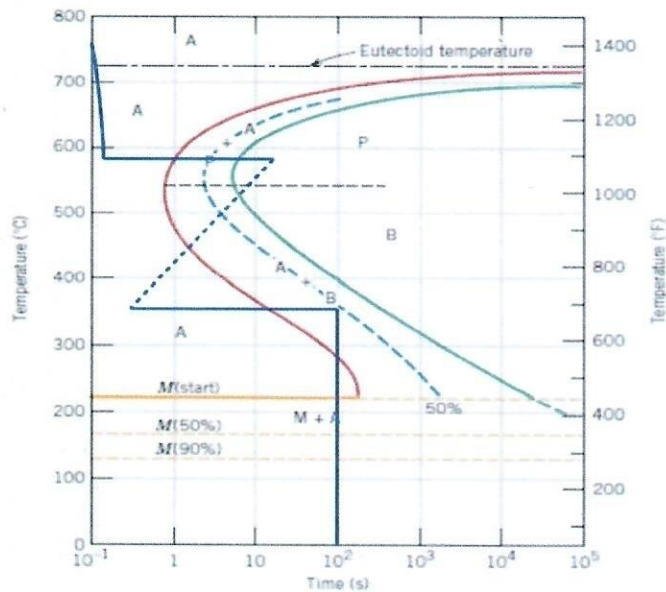


100% coarse pearlite is formed when the specimen is cooled rapidly to 575°C from 760°C and held for 20s and rapidly cooled to 350°C and held for 100s and then quenched to room temperature. This can be seen from the transformation diagram.

Therefore, the microstructure formed is

100% coarse pearlite

g)

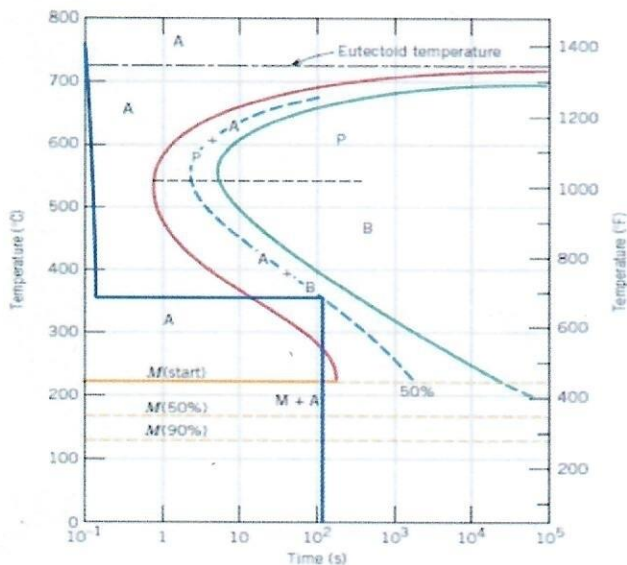


100% fine pearlite is formed when the specimen is cooled rapidly to 665°C from 760°C and held for 10^3 s and quenched to room temperature. This can be seen from the transformation diagram.

Therefore, the microstructure formed is

100% fine pearlite

h)

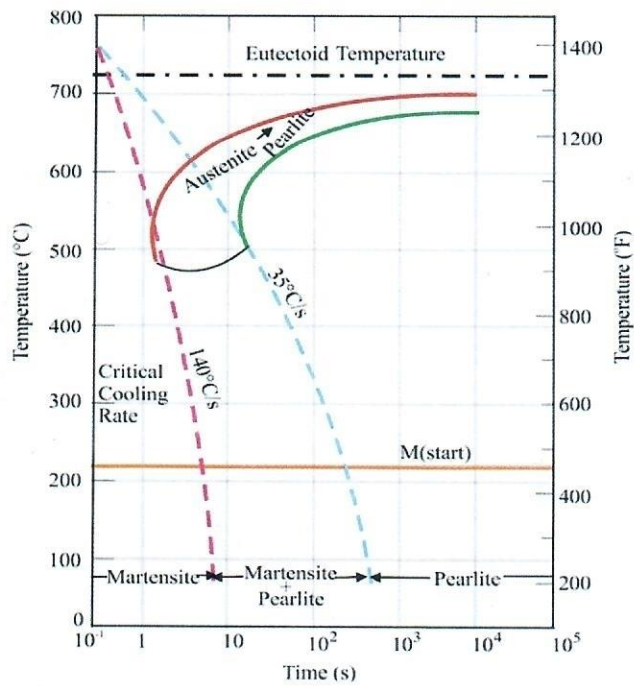


50% bainite and 50% martensite is formed when the specimen is rapidly cooled to 350°C from 760°C and held for 150s and quenched to room temperature. This can be seen from the transformation diagram.

Therefore, the microstructure formed is

50% bainite and 50% martensite

10.24



a) 200°C/s

Martensite forms. The martensite will exist for quenching rates greater than the critical

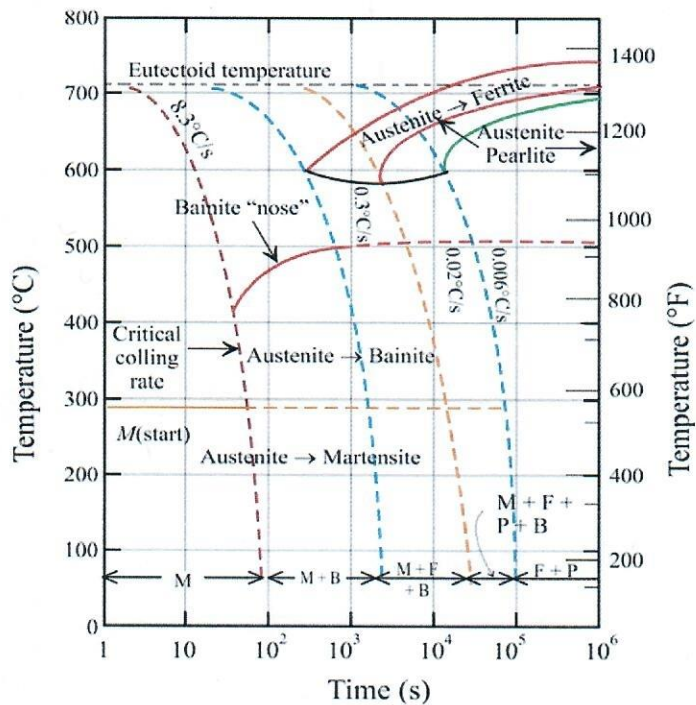
b) 100°C/s

Pearlite and martensite forms. There will be range of rates over which both pearlite and martensite

c) 20°C/s

Fine pearlite forms.

10.28



In order to solve this problem, consider figure. Continuous cooling transformation diagram for an alloy steel type 4340 and several superimposed cooling curves demonstrating dependence of the final microstructure of this alloy on the transformation that occurs during cooling

- At a cooling rate of 10°C/s , only martensite forms.
- At a cooling rate of 1°C/s , both martensite and bainite form.
- At a cooling rate of 0.1°C/s , martensite, proeutectoid ferrite, and bainite forms.
- At a cooling rate of 0.01°C/s , martensite, proeutectoid ferrite, pearlite, and bainite form.

AVERAGE

MCEG 2023 Materials Science and Engineering

Student Name (Print): Lira Anette

Last name **First name**

Homework Requirements:

- 1) Draw a **box** around the final answer. Correct units, where applicable, must be displayed on the final answer for each homework problem. Incorrect or the omission of units on the final answer may be penalized, particularly when units are not carried throughout calculations that support the final answer.
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- 4) Put this cover sheet on **top** of your homework. Print your **name** clearly on page 1.
- 5) All homework will follow the above requirements.

Very neat

10.1

Nucleation - This is the formation of very particles or nuclei new phase, like embryo, from the parent phase. It exists in two types, the first type is the homogeneous nucleation, which forms from the inside of the parent phase. The second type is the heterogeneous nucleation, which forms at nonhomogeneous structures, such as container surfaces, insoluble impurities, grain boundaries and so on.

Growth - This is the growing stage of the nuclei after it becomes a stable nucleus and occurs when the embryo size becomes larger than the critical size This process will form new. Phase particles inside the parent phase. The growth step doesn't stop the nucleation stage. The two processes occur at the same time to form more particles of the new phase until the parent phase has been completely changed into the new phase.

10.15

- a) Superheating is heating above phase transition temperature without the occurrence of the transformation whereas super cooling corresponds to cooling below phase transition temperature
- b) At the phase transition temperature, the driving force is not enough to occur transformation. By superheating or super cooling driving force can be obtained.

10.17

PEARLITE - 1. Two phase lamellar structure composed of alternating layers of ferrite (87.5 wt%) and cementite (12.5 wt%) that occurs in some steels and cast irons. 2. It is hard and strong but not tough. 3. Wear resistant because of strong lamellar network of ferrite and cementite.

BAINITE -. 1. Bainite is plate like microstructure that forms in steels at temperature of 130-550°C fine non lamellar structure, bainite commonly consist of cementite and dislocation rich ferrite. 2. Bainite is harder and stronger than pearlite and speroidite. 3. Bainite consists of very fine and parallel needles of ferrite that are separated by elongated particles of cementite.

SPHEROIDITE - 1. Spherical shaped cementite particles in an alpha ferrite matrix. 2.It is most ductile and softest than pearlite and bainite. 3. Spheroidite microstructure are more stable than pearlite.

10.9

- A) After cooling and holding at 700 degrees * C for 10^4 approximately 50% of the specimen has transformed to coarse pearlite. Upon cooling to room temperature, the remaining 50% transforms to martensite. Hence the final microstructure consists of about 50% coarse pearlite and 50% martensite.
- B) Heating to 700 degrees * C for 20 h the specimen in part (a) will transform the coarse pearlite and martensite to spheroidite .
- C) After cooling to and holding at 600 degrees * C for 4 approximately 50% of the specimen transformed to pearlite (medium). During the rapid cooling to 450 degrees * C no transformations occur. At 450 degrees * C we start timing again at zero time while holding at 450°C for 10 s, approximately 50 percent of the remaining unreacted 50% (or 25% of the original specimen) will transform to bainite .And upon cooling to room temperature, the remaining 25% of the original specimen transforms to martensite. Hence, the final microstructure consists of about 50% pearlite (medium)25% bainite, and 25% martensite.
- D) After cooling to and holding at 400 degrees * C for 2 , no of the transformation begin lines have been crossed, and therefore, the specimen is 100% austenite. Upon cooling rapidly to room temperature, all of the specimen transforms to martensite, such that the final microstructure is 100% martensite.
- E) After cooling and holding at 400 degrees * C for 20 s, approximately 40% of the specimen has transformed to bainite. Upon cooling to room temperature, the remaining 60% transforms to martensite. Hence, the final microstructure consists of about 40% bainite and 60% martensite.
- F) After cooling and holding 408 degrees * C for entire specimen has transformed to Therefore, during the cooling to room temperature no additional transformations occur. Hence, the final microstructure consists of 100% bainite.
- G) After cooling and holding at 250 degrees for 100 s , nor transformation will have occurred-at this point , the entire specimen is still austenite. Upon rapidly cooling to room temperature in water , the specimen will completely transform to martensite. The second heat treatment (at 315 degrees for 1 h) not shown on the above plot will transform the material to tempered martensite. Hence , the final microstructure is 100% tempered martensite.

10.24

a) 200 degrees /s:

Martensite forms. The martensite will exist for quenching rates greater than critical

b) 100 degrees /s:

Pearlite and martensite forms. There will be range of rates over which both pearlite and martensite.

c) 20 degrees/s: Fine pearlite forms.

10.28

a) At a cooling rate of 10 degrees /s , only martensite forms.

b) At a cooling rate of 1 degree/s , both martensite and bainite form.

c) At a cooling rate of 0.1 degree/s , martensite , proeutectoid ferrite , bainite form.

d) At a cooling rate of 0.01 degree/s martensite , proeutectoid ferrite , bainite form.

BELOW AVERAGE

MCEG 2023 Materials Science and Engineering

Student Name (Print): Garay Gabriela
 Last name **First name**

Homework Requirements:

- 1) Draw a **box** around the final answer. Correct units, where applicable, must be displayed on the final answer for each homework problem. Incorrect or the omission of units on the final answer may be penalized, particularly when units are not carried throughout calculations that support the final answer.
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- 5) All homework will follow the above requirements.

Gabriela Garay

Homework 15

10.1 - Name the two stages involved in the formation of particles of a new phase. Briefly describe each.

Growth & Nucleation.

Growth is the growing stage for the nuclei.

Nucleation is the parent phase, which has two types heterogeneous & homogeneous.

10.15 - (a) Briefly describe the phenomena of superheating & supercooling.
(b) Why do these phenomena occur?

(a) answer:

- superheating is the heating above the phase transition temp.
- supercooling is below the phase transition temp.

(b) answer:

- These phenomena occur b/c the phase transition temp. isn't enough to make a transformation.

10.17 - Briefly cite the differences between pearlite, bainite, & spheroidite relative to microstructure & mechanical properties.

answer:

- Pearlite is a two phase microstructure.
- Bainite is a austenitic transformation product.
- Spheroidite is sphere shape cementite particles, formed with heat.

10.24 - Name the microstructural products of eutectoid iron-carbon alloy (0.76 wt% C) specimens that are first completely transformed to austenite, then cooled to room temp. @ the following rates:

answers:

- (a) 200°C/s : Martensite
- (b) 100°C/s : Pearlite & Martensite
- (c) 20°C/s : Pearlite

10.28 - Name the microstructural products of 4340 alloy steel specimens that are 1st completely transformed to austenite, then cooled to room temp. @ the following rate.

answers:

- (a) 10°C/s : martensite
- (b) 1°C/s : bainite & martensite
- (c) 0.1°C/s : bainite, martensite & proeutectoid ferrite
- (d) 0.01°C/s : martensite, proeutectoid ferrite, bainite & pearlite.

