# AMERICAN UNIVERSITY OF BEIRUT

## ENGINEERING MATERIALS-MECH 340

## QUIZ II-DEGREE FROM 100

**WARNING:** This is a very busy exam. Do not waste your time on irrelevancies and verbose statements. Wherever applicable, go straight to the point (s).

Student Name:

ID:

**Question 1- 20 Marks- 2 Marks/question**

- **What is the main difference between a *phase* and a *component* in alloy systems?**
  **Answer: See textbook**

- **What is the MAJOR difference between an *edge dislocation* and a *screw dislocation*?**
- **Answer: See textbook**

- The maximum solubility of carbon in a-iron is _0.022_____wt% and it occurs at _727_____°C.
- The maximum solubility of carbon in a-iron at room temperature is _____0___wt%
- The maximum solubility of carbon in g-iron is _____2.14_____wt%
- An iron-carbon alloy contains 0.4 wt% of carbon. The solute in this system is:_____carbon___

- **Which of the following statements is TRUE?**

The *solidus* line in a phase diagram is:
A. The temperature below which only solid phase(s) exist.
B. The phase boundary below which only solid phase(s) exist.
C. The temperature above which only liquid phase(s) exist.

- **Which of the following statements is TRUE?**

The *liquidus* line in a phase diagram is:
A. The temperature below which only liquid phase(s) exist.
**B.** The phase boundary above which liquid begins to form.
C. The temperature above which only liquid phase(s) exist.

- **What is the difference between the proeutectoid ferrite and the eutectoid ferrite?**
  **Answer: See textbook**

- **Under what cooling condition can proeutectoid cementite form in a FE-C alloy containing 0.35 wt % C?**

**Answer: It cannot form. You must have a wt% carbon >0.76 . Only α' and pearlite form at this composition.**

**Question 2-FE-C Phase Diagram-(20 Marks)**
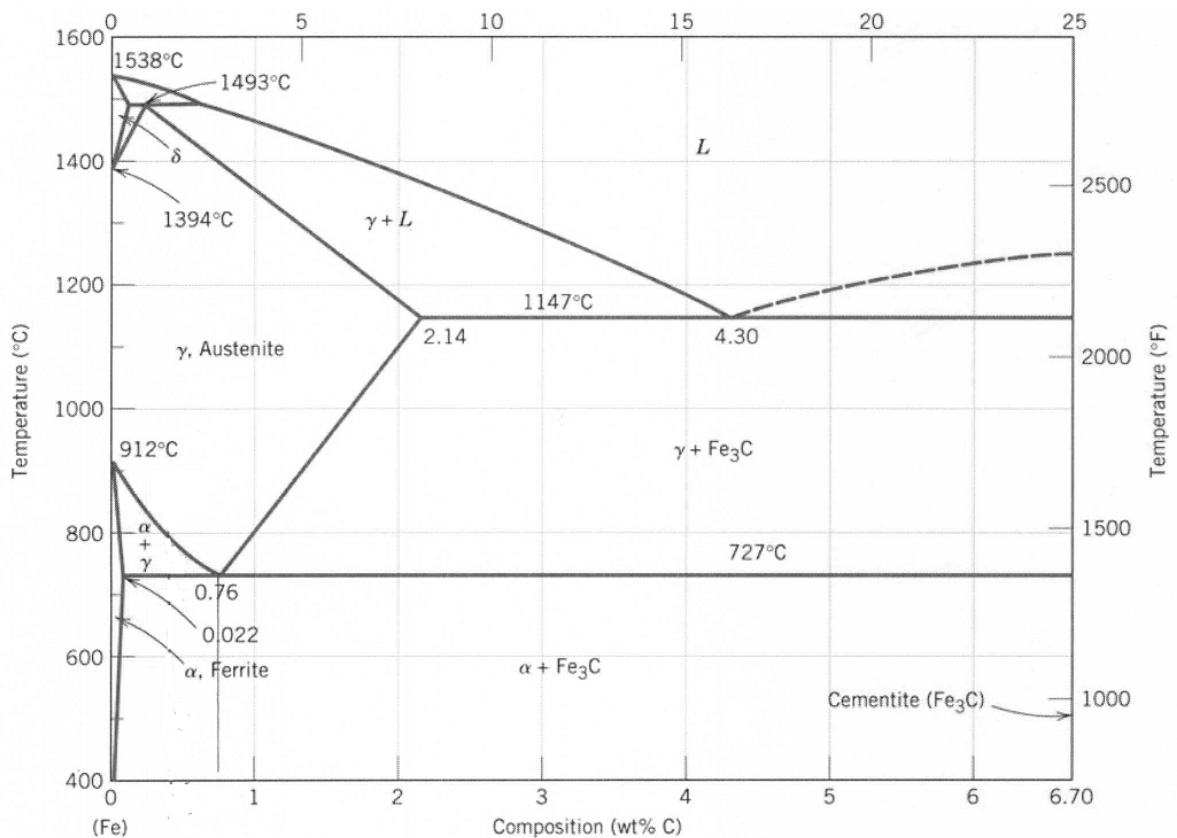


From the iron-iron carbide diagram shown above:

i. Explain why the solubility of carbon in α, ferrite (α) is so small compared to the solubility of carbon in austenite (γ)

2

*the Crystal Structures. α is BCC and γ is FCC. The BCC structure is closer packed not leaving as much room for interstitial carbon. The FCC is less packed. More room = more carbon solubility.*

**ii-With the aid of suitable sketches, describe the microstructural transformations that occur when a Fe-C alloy containing 0.55 wt. C undergoes equilibrium cooling from 950°C to room temperature (4 Marks)**
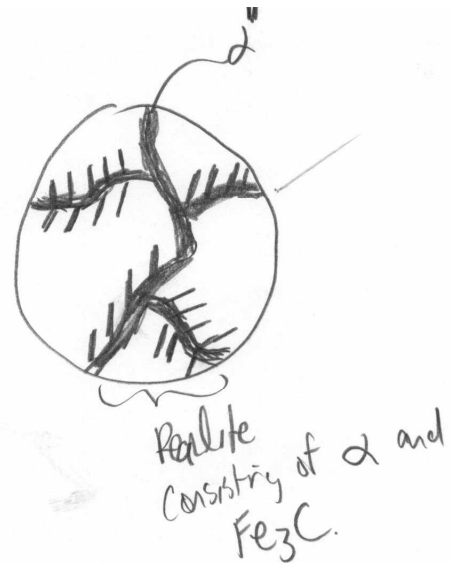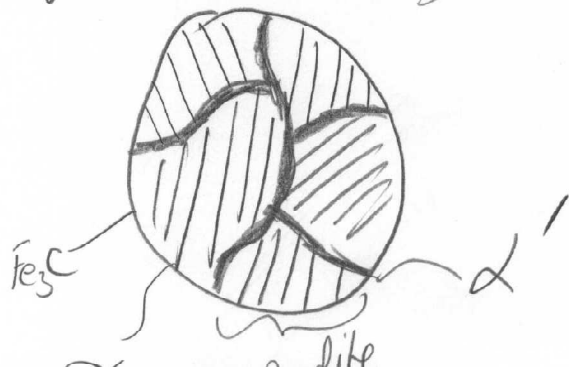
*A) the entire structure is γ*

*B) Proeutectoid ferrite formes at the grain boundaries*

*austinite*

*α'*
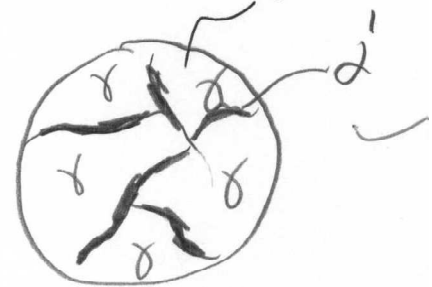
c) the remaining $\gamma$ begins to transform to pearlite. carbon atoms move around in the $\gamma$ to form low C $\alpha$ and higher C in $Fe_3C$



Pearlite consisting of $\alpha$ and $Fe_3C$.

d) the pearlite has completely formed. the microstructure is now stable.



$Fe_3C$        $\alpha'$

pearlite

**i-**    Consider 10 kg of austenite containing 0.55 wt% cooled under equilibrium condition from austenite phase region to just below 727°C. At this temperature:

**a- How many kilograms of each total ferrite and cementite form? (4 Marks)**

**b- How many kilograms each of pearlite and proeutectoid phase form? (4 Marks)**

c- **How many kilograms of eutectoid ferrite form? (4 Marks)**

$$\text{total ferrite} = \frac{6.7 - .55}{6.7 - .022} (10kg) = 9.21 Kg$$

$$\text{total cementite} = \frac{.55 - .022}{6.7 - .022} (10kg) = .79 Kg$$

$$\text{pearlite} = \frac{.55 - .022}{.76 - .022} (10kg) = 7.15 kg$$

$$\alpha' = \frac{.76 - .55}{.76 - .022} (10kg) = 2.85 kg \ \alpha'$$

$$\text{eutectoid } \alpha = \text{total ferrite} - \alpha'$$
$$= 9.21 - 2.85 = 6.36 \ kg$$

**Question 3- 20 Marks -5 marks/quetsion**

Use the Mg-Pb phase diagram below to answer the following questions:

a) What phases are in equilibrium for an alloy of 20 wt%Pb at a temperature of 400°C?

b) Is it possible to have a hypo-eutectic Mg-Pb alloy with a mass fraction of the $Mg_2Pb$ phase of 40% at 400°C? If so, what is the composition of the alloy? If not, why not?

c) At a temperature just below the eutectic temperature, the mass fraction of ALPHA-phase is 15%. What is the proeutectic phase?

d) Of the solid phases on the phase diagram, which phases are capable of being precipitation hardened and why?
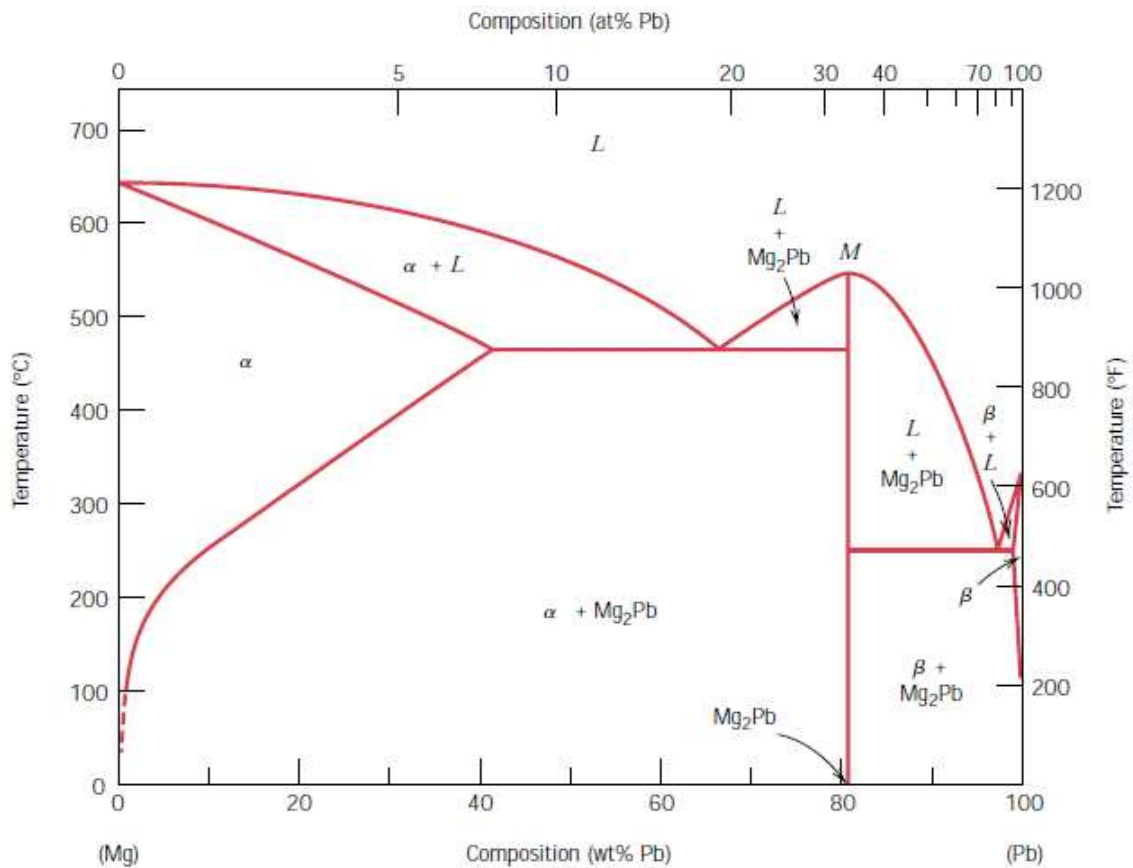
# Solution:

3a) For the alloy of 20 wt%Pb at a temperature of 400 degrees C the point (a) is in a single phase region, so that the only stable phase is **ALPHA**.

b) At 400 C, the compositions that are in equilibrium are shown by the isotherm (b) as ALPHA of about 31w%Pb, and the intermetallic Mg2Pb of about 81w% Pb. fraction of Mg2Pb:

$$M_{Mg2Pb} = \frac{C_{alloy} - C_\alpha}{C_{Mg2Pb} - C_\alpha} \Rightarrow C_{alloy} = \left(M_{Mg2Pb}\right)\left(C_{Mg2Pb} - C_\alpha\right) + C_\alpha$$

$$C_{alloy} = (0.40)(0.81 - 0.31) + 0.31 = 0.51 = 51w\%Pb.$$

c) Again we can use the lever rule to determine the overall composition of the alloy that gives 15% mass fraction of ALPHA-phase just below the eutectic temperatur

$$M_\alpha = \frac{C_{Mg2Pb} - C_{Alloy}}{C_{Mg2Pb} - C_\alpha} \Rightarrow C_{Alloy} = C_{Mg2Pb} - \left(M_\alpha\right)\left(C_{Mg2Pb} - C_\alpha\right)$$

$$C_{Alloy} = 0.81 - (0.15)(0.81 - 0.40) = 0.75 = 75w\%Pb.$$

The vertical blue line shows the alloy composition. For this composition, above the eutectic temperature the alloy will be in the Liquid + Mg2Pb phase, so the pro-eutectic phase will be **Mg2Pb**.

d) Both the ALPHA and the BETA phases are capable of being precipitation hardened. This is because both exhibit a decrease in the solubility of the second element as the composition is reduced.

**Question 4 (20 Marks)**

**a. Give two limitations of phase equilibrium diagrams-(5 Marks)**

**1-No info about time required to transform (2) the occurrence of phase changes or transformations at temperatures other than those predicted by phase boundary lines on the phase diagram, and (3) the existence at room temperature of non-equilibrium phases that**
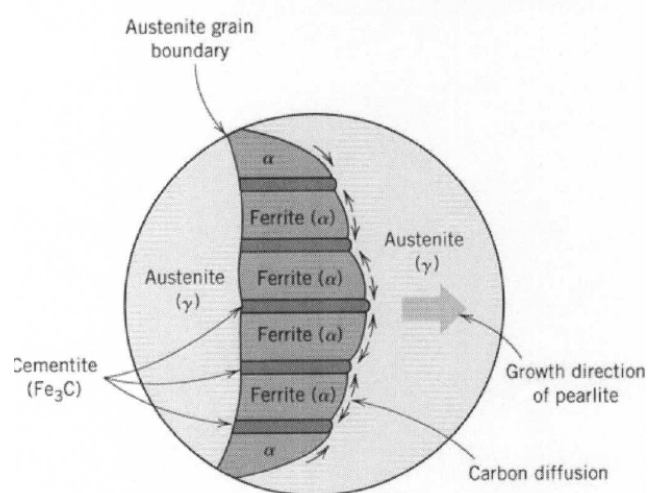
**do not appear on the phase diagram**

**b. What is phase transformation? Mention two stages of phase transformations. (5 Marks)**

**Answer: see textbook**

c. Figure 2 shows a schematic representation of the formation of pearlite from austenite. **Why does the pearlite nucleate preferentially at austenite grain boundary as shown is this diagram? (5 Marks)**

**Answer:**

**See textbook.**

**d-Which is stronger, fine parlite or coarse pearlite? Give reason for your answer (5 Marks)**

**Answer: Fine pearlite. It has more grain boundaries serving as dislocations barriers.**

**Question 5 (20 Marks).**

(a) A steel alloy was fractured under a tensile stress of 250 MPa when a surface crack length is 10 mm. The yield strength of the steel is 850 MPa. Assume a geometric factor of 1.2.

    (i)      Calculate the fracture toughness of the steel (3 marks).

    (ii)     Calculate the fracture strength of the steel due to the presence of a central crack of 12 mm long. (3 Marks)

    (iii)    If a tensile stress of 500 MPa is applied to the materials, what is the maximum allowable length of cracks for the steel without brittle fracture? (3 Marks)

    (iv)    Calculate the maximum crack size required for the steel to yield rather than brittle fracture. (3 Marks)

(b) A laboratory creep test was conducted at 1100 °C on an alloy under constant stress conditions. A steady-state creep rate $\dot{\epsilon}_S$ of 1 x $10^{-2}$% /h was produced. The activation energy for the creep is 100 kJ/mole. A component of 100 mm in length is made of the alloy and to be operated at a temperature of 700 °C. The maximum length change for the component is 1 mm. Calculate how many hours the component can be operated for, assuming the

component is to operate under the same constant stress condition as in the laboratory steady state creep test (6 Marks). (Gas constant R = 8.31 J/mol-K).

**Answer:**

Part 1-

## SOLUTION:

**(i)**

**Given:** applied stress = 250 Mpa

surface crack length $a$ = 10 mm

$Y$ = 1.2.

**Required:** Calculate the fracture toughness ($K_c$) of the steel.

**Solution:** Formula: $K_c = Y\sigma_c\sqrt{\pi a}$

$$K_c = 1.2 \times 250 \times \sqrt{\pi \times 10 \times 10^{-3}} = 53.1\, MPa\, m^{\frac{1}{2}}$$

**(ii)**

**Given:** $K_c$ = 53.1 MPa $\sqrt{m}$ , $Y$ = 1.2, and central crack length $2a$ = 12 mm

$a$ = 6 mm

**Required:** Calculate $\sigma_c$

**Solution:** Formula: $K_c = Y\sigma_c\sqrt{\pi a}$

$$\sigma_c = K_c /(Y\sqrt{\pi a}) = 322\, MPa$$

**Required:** Calculate $a$ .

**Solution:** $53.1 > 1.2 \times 500 \times \sqrt{\pi a}$

$$\therefore\ \pi a < \left(\frac{53.1}{1.2 \times 500}\right)^2 \quad \Rightarrow a < \frac{1}{\pi}\left(\frac{53.1}{1.2 \times 500}\right)^2 = 0.00249 m\ = 2.49\ mm$$

(i.e. surface crack).

For surface crack, it would be 2.49 mm, for internal crack, it would be 5 mm for the component to have brittle fracture. Thus the maximum crack length is less 2.49 mm in order to avoid brittle fracture.

**(iv)**
**Given:** $K_c$ = 53.1 MPa$\sqrt{m}$ , $Y$ = 1.2, yield stress= 850MPa

Required: calculate the minimum crack length for the steel to yield first, that means the yield stress should be smaller than the critical stress to cause rapid crack extension (brittle fracture).

**Solution:**

$\sigma_c = K_c / (Y \sqrt{\pi a})$ > yield stress = 850 MPa

Then $\pi a < \left( \dfrac{53.1}{1.2 \times 850} \right)^2 \Rightarrow a < \dfrac{1}{\pi} \left( \dfrac{53.1}{1.2 \times 850} \right)^2 = 0.00086 m = 0.86$ mm
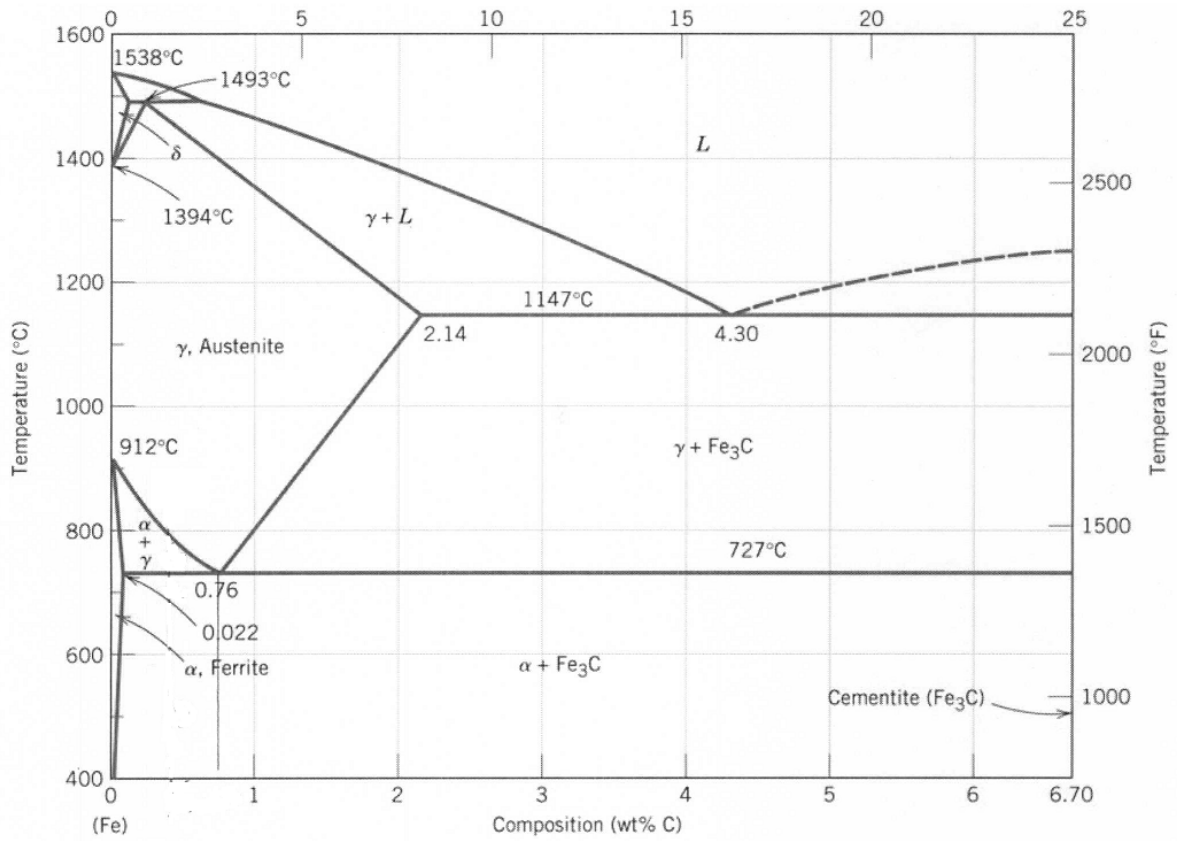
For the surface crack, the crack length should be smaller than 0.86 mm, for the internal crack, the crack length should be smaller than 1.72 mm in order for the steel to yield rather than brittle fracture. The maximum crack length should be 0.866 mm in order to for the steel to yield rather than brittle fracture.
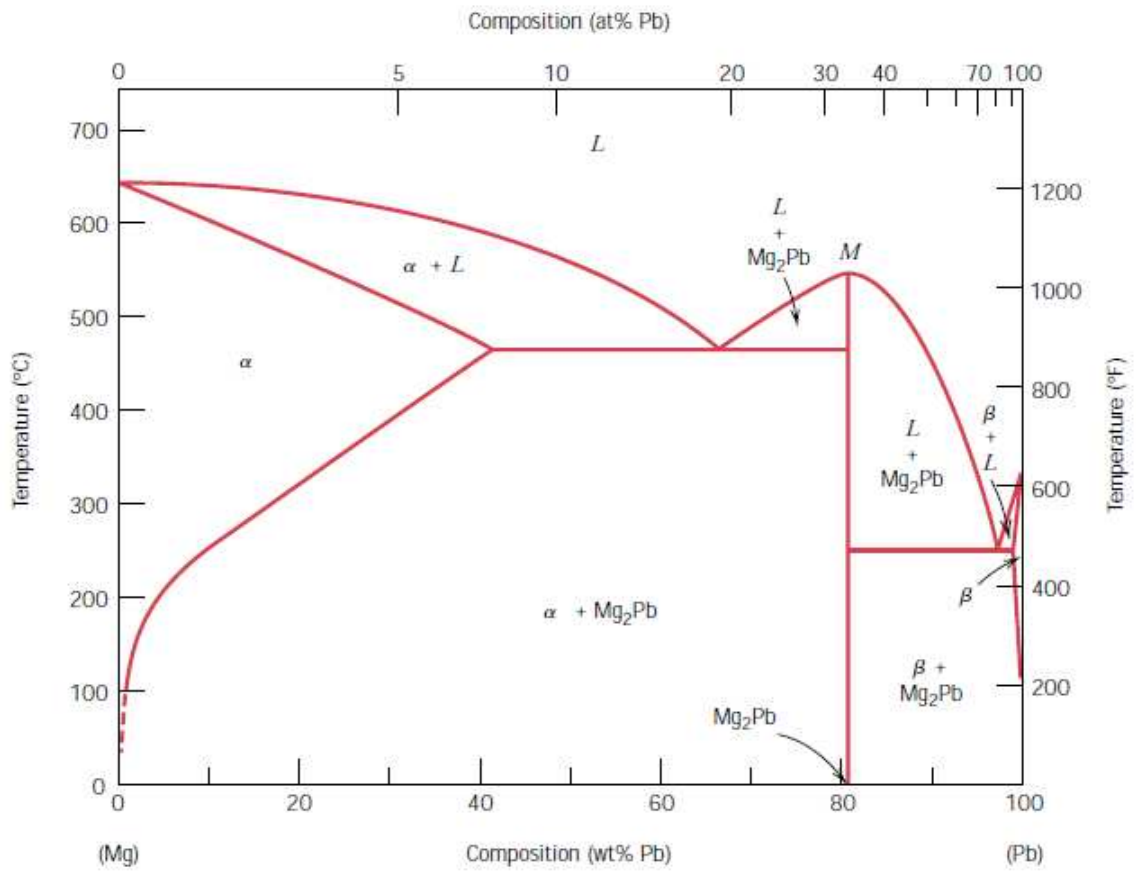

**Part II- Answer**


Then we have
$$(\dot{\varepsilon}_s)_{1100°c} = k_2 \sigma^n \exp\left(-\frac{Q_c}{RT_1}\right) \rightarrow k_2\sigma^n = (\dot{\varepsilon}_s)_{1100°c} \exp\left(\frac{Q_c}{RT_1}\right)$$

$$(\dot{\varepsilon}_s)_{700°c} = k_2\sigma^n \exp\left(-\frac{Q_c}{RT_2}\right) = (\dot{\varepsilon}_s)_{1100°c} \exp\left(\frac{Q_c}{RT_1} - \frac{Q_c}{RT_2}\right)$$

$$\rightarrow (\dot{\varepsilon}_s)_{700°c} = (\dot{\varepsilon}_s)_{1100°c} \exp\left[\frac{Q_c}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]$$

$T_1 = 1100 + 273 = 1373 k$
$T_2 = 700 + 273 = 973 k$

$\rightarrow (\dot{\varepsilon}_s)_{700 °C} = (\dot{\varepsilon}_s)_{1100 °C}$ x exp {Q/R(1/1373-1/973)} = 0.0001 x exp(-3.6) = 0.00000273

Then the life time:  t = $\varepsilon / \dot{\varepsilon}_s$ = 0.01/0.00000273 = 3663 hrs

Formula and diagrams sheet:

**Formulas:**

$$\dot{\varepsilon}_s = K_2 \sigma^n \exp\left(-\frac{Q_c}{RT}\right)$$

$$K_c = Y\sigma_c \sqrt{\pi a}$$

$$\gamma\,(0.76 \text{ wt\% C}) \underset{\text{heating}}{\overset{\text{cooling}}{\rightleftharpoons}} \alpha\,(0.022 \text{ wt\% C}) + Fe_3C\,(6.7 \text{ wt\% C})$$



FIGURE 10.33 A portion of the Fe–Fe$_3$C phase diagram used in computations for relative amounts of proeutectoid and pearlite microconstituents for hypoeutectoid ($C_0'$) and hypereutectoid ($C_1'$) compositions.
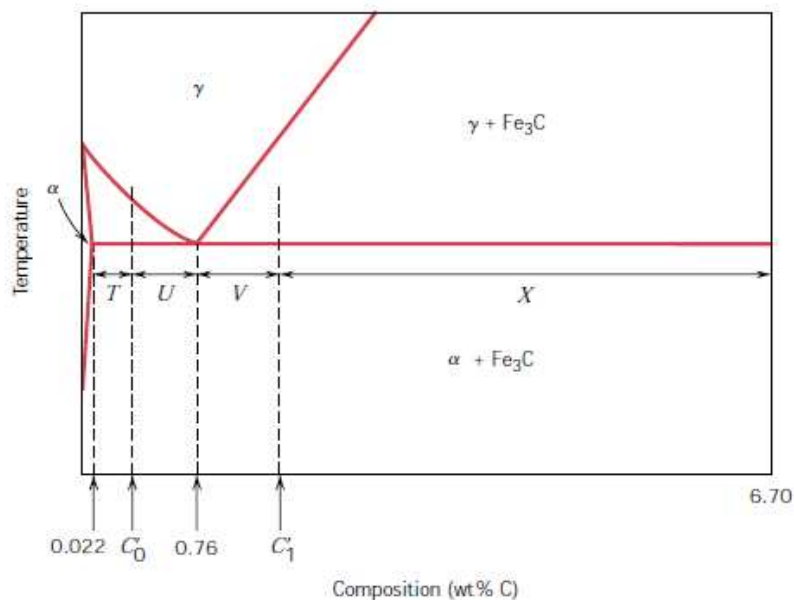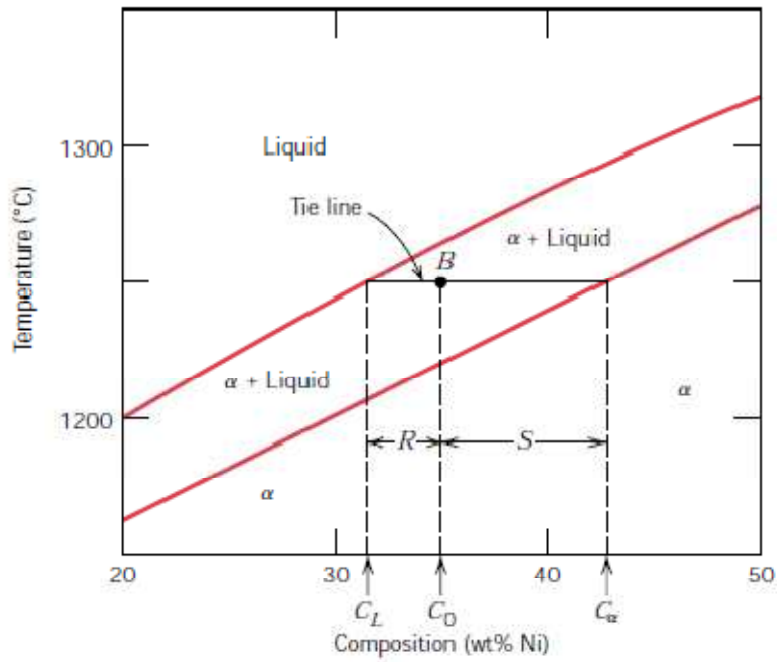
Hypoeutectoid alloys:

$$W_p = \frac{T}{T + U} \qquad W_{\alpha'} = \frac{U}{T + U}$$

Hypereutectoid alloys:

$$W_p = \frac{X}{V + X} \qquad W_{Fe_3C'} = \frac{V}{V + X}$$

Example to determine Lever rule:



$$W_L = \frac{S}{R + S}$$

$$W_L = \frac{C_\alpha - C_0}{C_\alpha - C_L}$$

$$W_\alpha = \frac{R}{R + S}$$

$$= \frac{C_0 - C_L}{C_\alpha - C_L}$$