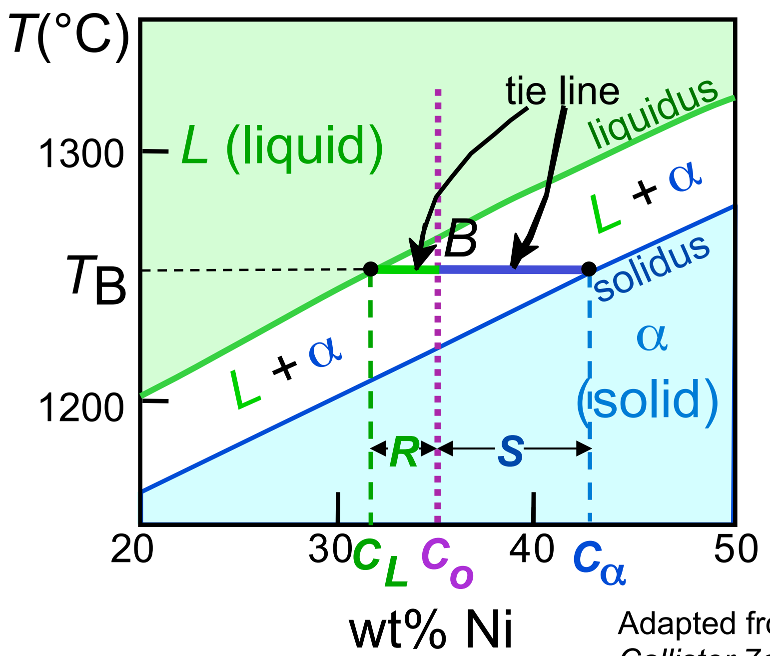
Chapter 9: Fe-C system

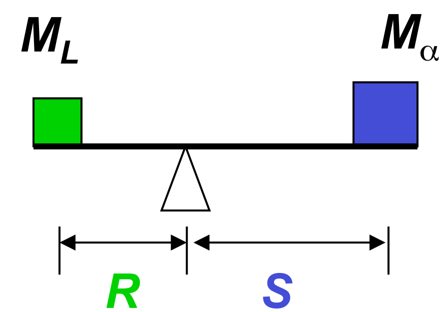
The Lever Rule

- Tie line – connects the phases in equilibrium with each other - essentially an isotherm



Adapted from Fig. 9.3(b), *Callister 7e.*

How much of each phase?
Think of it as a lever (teeter-totter)



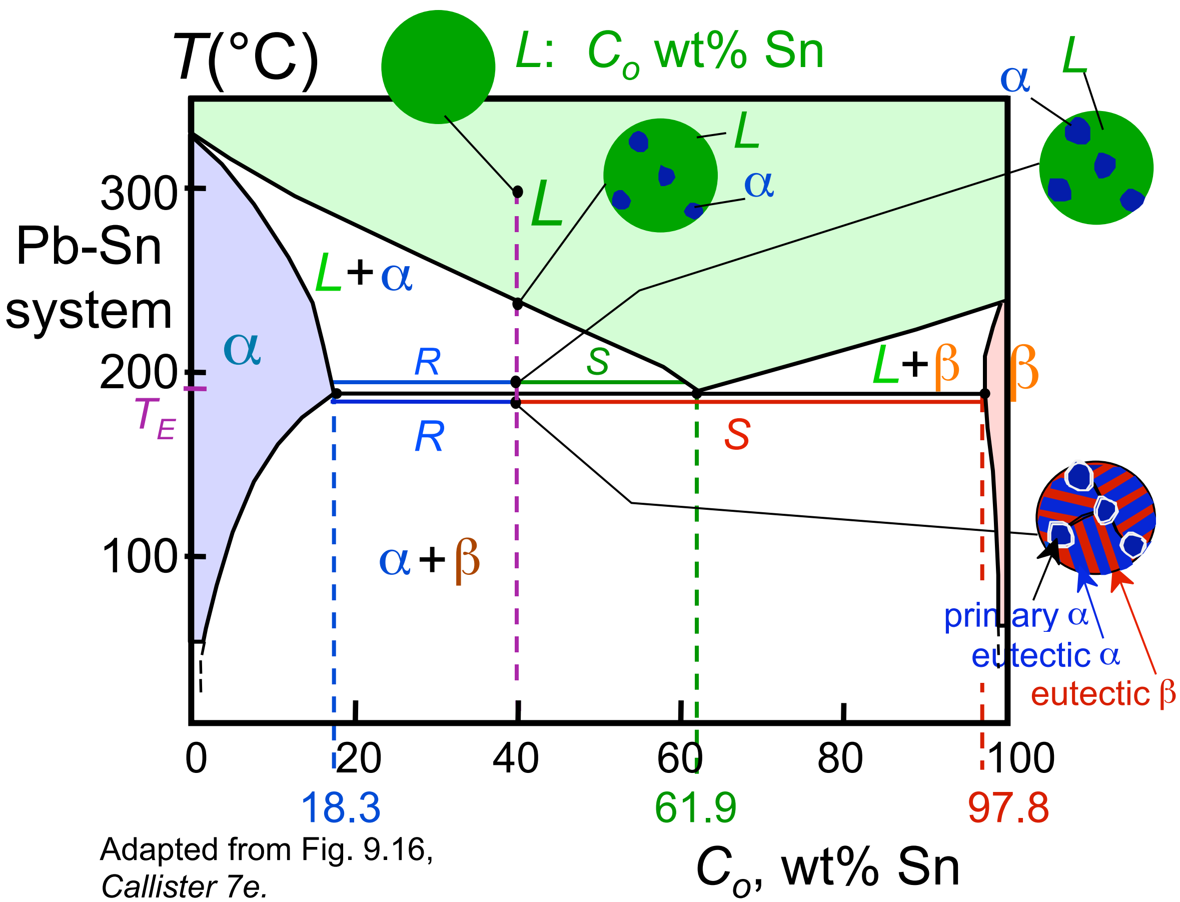
$$M_\alpha \cdot S = M_L \cdot R$$

$$W_L = \frac{M_L}{M_L + M_\alpha} = \frac{S}{R+S} = \frac{C_\alpha - C_0}{C_\alpha - C_L}$$

$$W_\alpha = \frac{R}{R+S} = \frac{C_0 - C_L}{C_\alpha - C_L}$$

Microstructures in Eutectic Systems

- 18.3 wt% Sn < C_o < 61.9 wt% Sn
- Result: α crystals and a eutectic microstructure



Adapted from Fig. 9.16, *Callister 7e.*

- Just above T_E :

C_α = 18.3 wt% Sn

C_L = 61.9 wt% Sn

$$W_\alpha = \frac{S}{R+S} = 50 \text{ wt\%}$$

$W_L = (1 - W_\alpha) = 50$ wt%

- Just below T_E :

C_α = 18.3 wt% Sn

C_β = 97.8 wt% Sn

$$W_\alpha = \frac{S}{R+S} = 73 \text{ wt\%}$$

W_β = 27 wt%

Eutectoid & Peritectic

- Eutectic - liquid in equilibrium with two solids

$$L \underset{\text{heat}}{\overset{\text{cool}}{\rightleftharpoons}} \alpha + \beta$$

- Eutectoid - solid phase in equation with two solid phases

$$S_2 \rightleftharpoons S_1 + S_3$$

intermetallic compound - cementite

$$\gamma \underset{\text{heat}}{\overset{\text{cool}}{\rightleftharpoons}} \alpha + Fe_3C \qquad (727^{o}C)$$

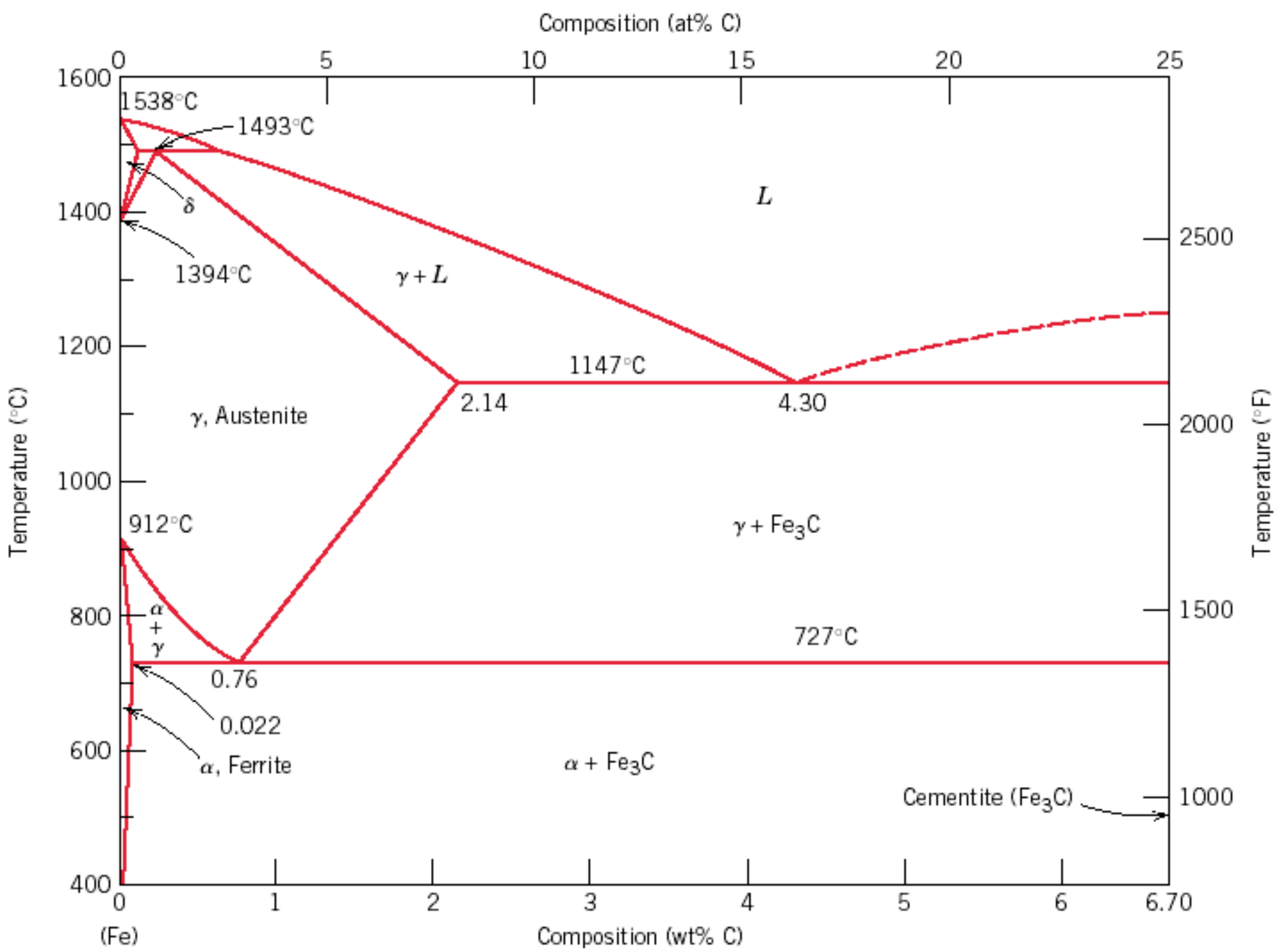
- Peritectic - liquid + solid 1 → solid 2 (Fig 9.21)

$$S_1 + L \rightleftharpoons S_2$$

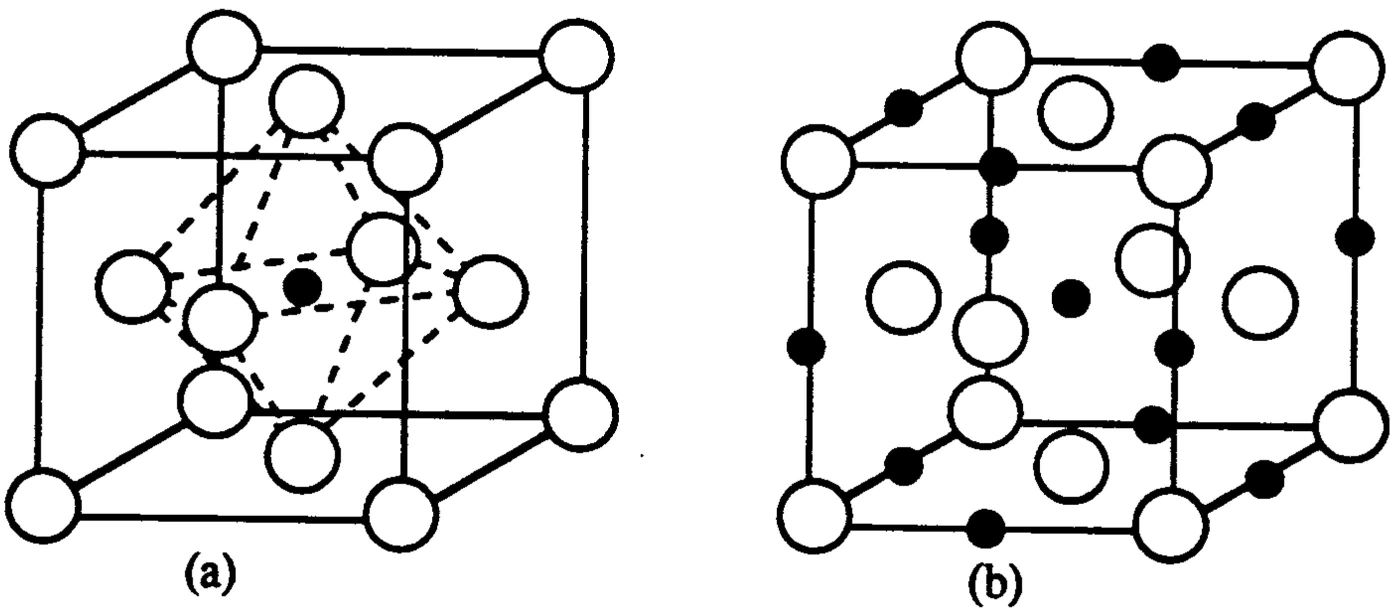
$$\delta + L \underset{\text{heat}}{\overset{\text{cool}}{\rightleftharpoons}} \gamma \qquad (1493^{o}C)$$

The iron-iron carbide ($Fe-Fe_3C$) phase diagram

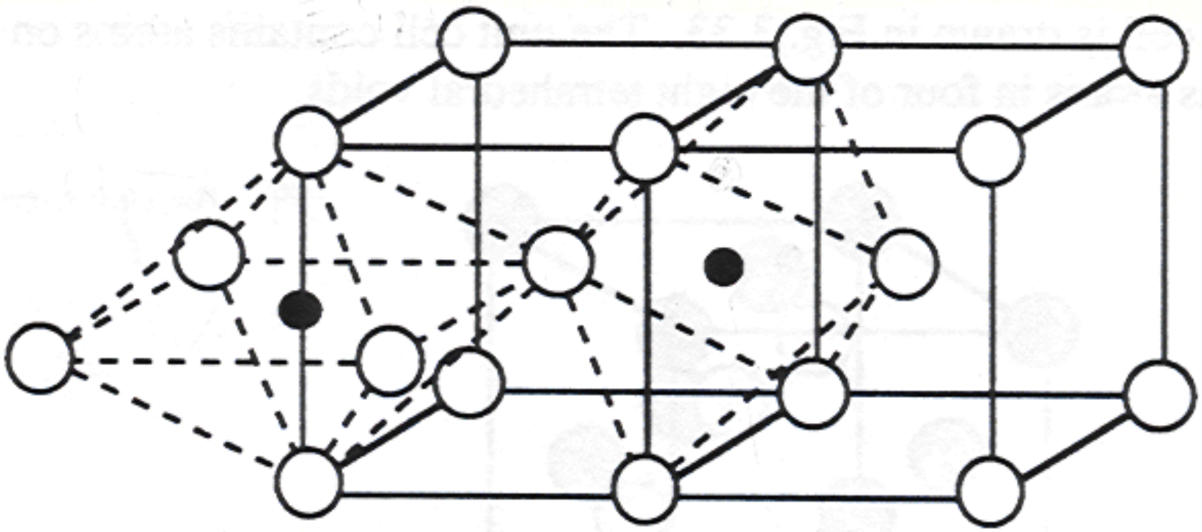
- **Ferrite-α -BCC, low C solubility(0.022%wt), magnetic**
- **Austenite-γ-FCC, high C solubility(2.14%wt), nonmagnetic**
- **Ferrite-δ-BCC**
- **Cementite (Fe_3C)**
- **Eutectic, peritectic, eutectoid**
- **Iron, ferrite (C<0.008wt%)**
- **Stainless steel, α +Fe_3C (0.008-2.14wt %)**



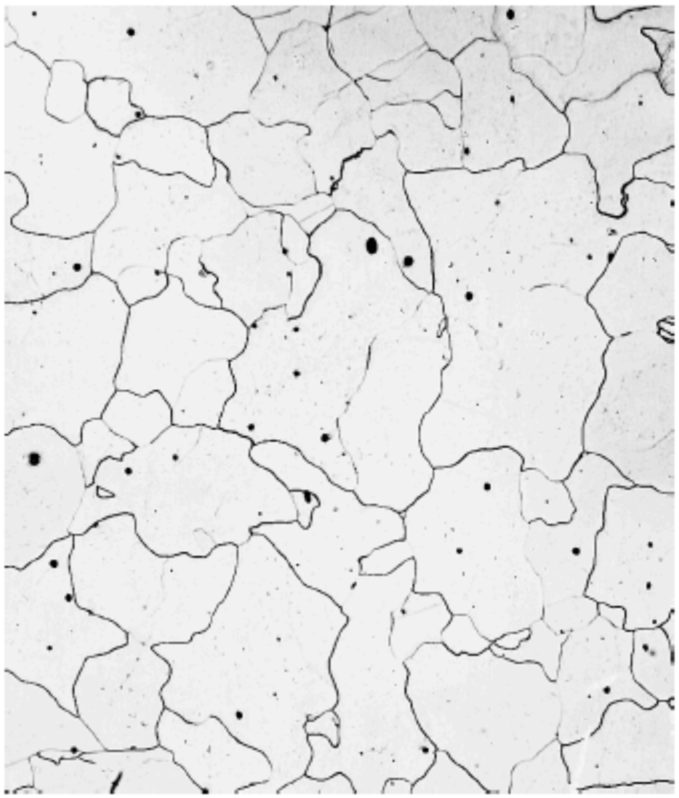
Interstitial sites of FCC



Interstitial sites of BCC

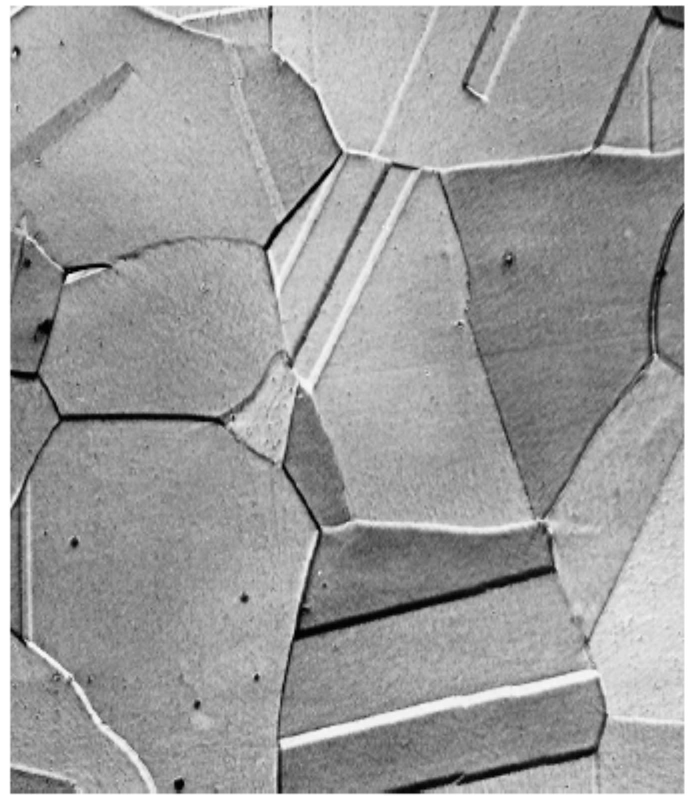


Microstructures of iron



(a)

α- ferrite



(b)

austenite

Iron-Carbon (Fe-C) Phase Diagram

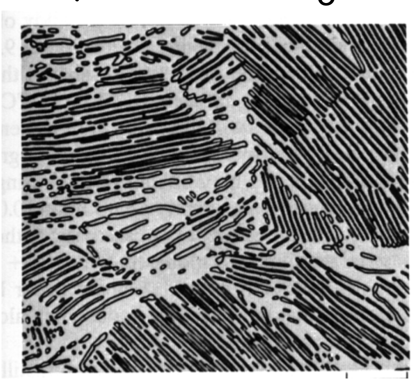
- 2 important points

-Eutectic (*A*):

$L \Rightarrow \gamma + Fe_3C$

-Eutectoid (*B*):

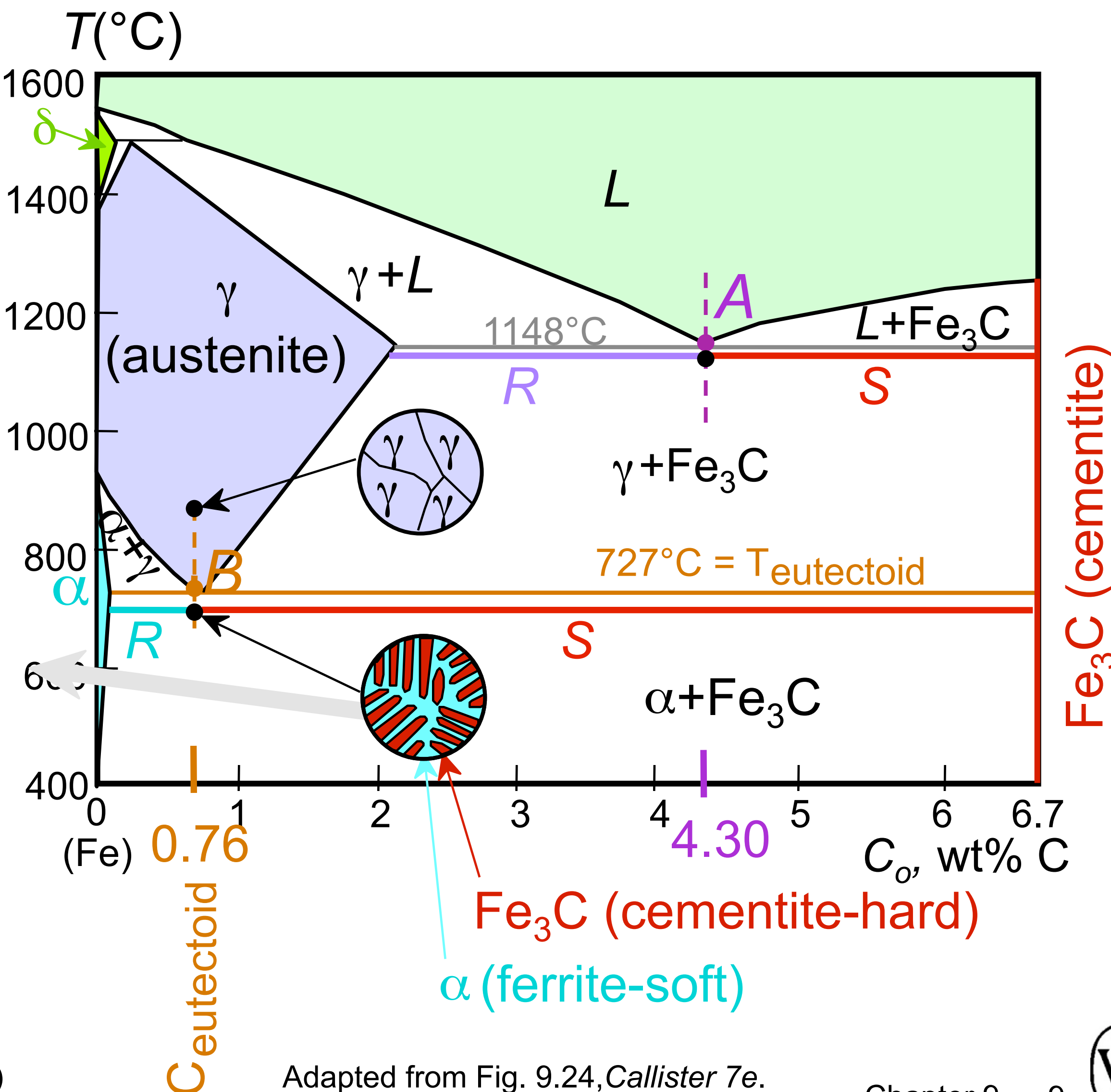
$\gamma \Rightarrow \alpha + Fe_3C$



120 μm

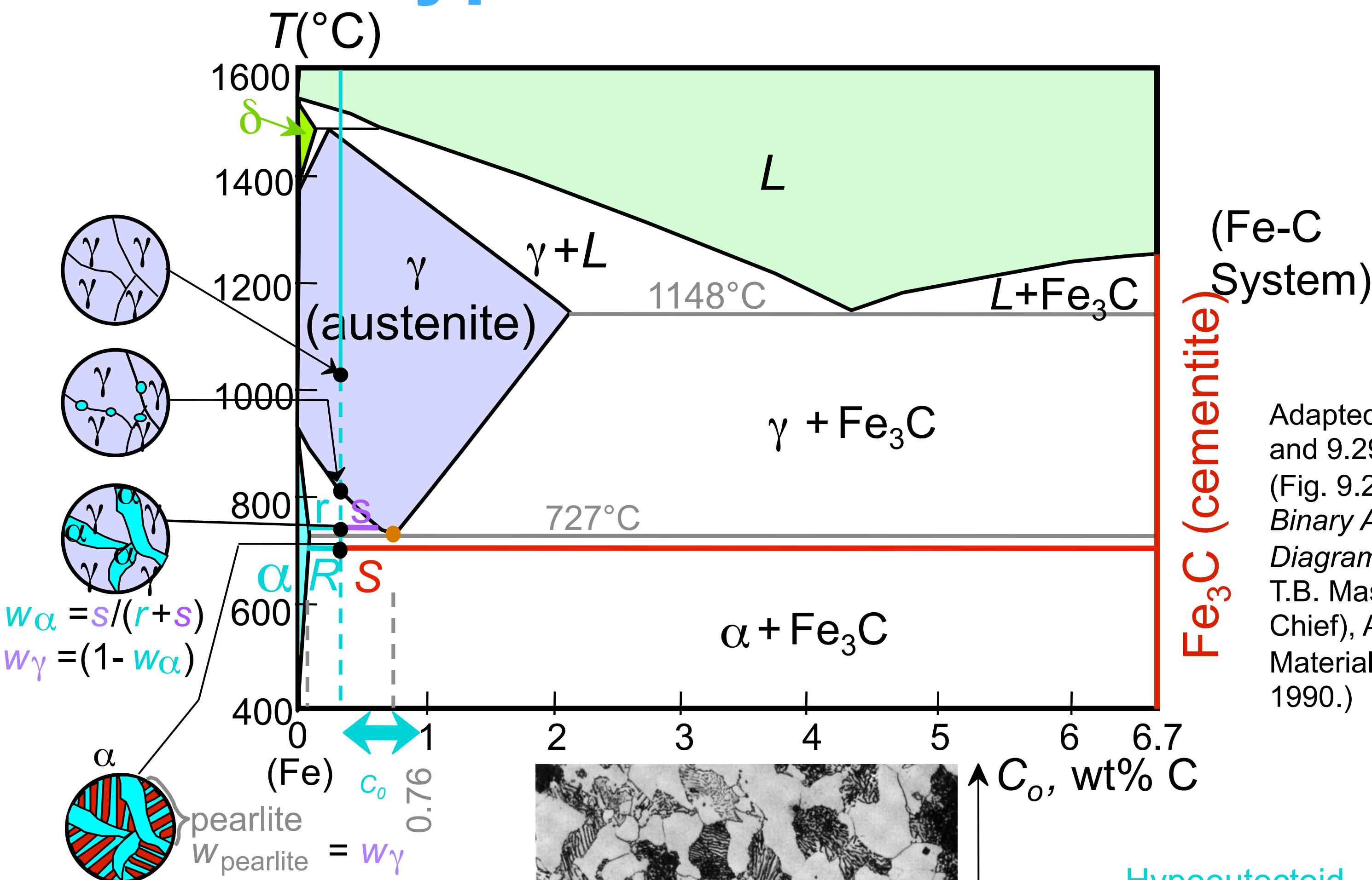
Result: Pearlite = alternating layers of α and Fe_3C phases

(Adapted from Fig. 9.27, *Callister 7e*.)



Adapted from Fig. 9.24, *Callister 7e*.

Hypoeutectoid Steel



$w_\alpha = s/(r+s)$

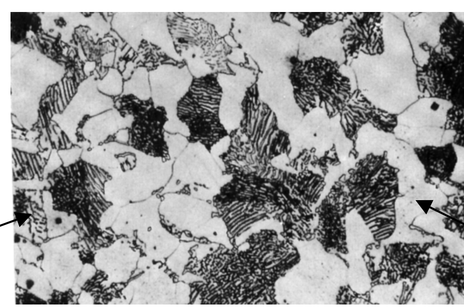
$w_\gamma = (1- w_\alpha)$

$w_{pearlite} = w_\gamma$

$w_\alpha = S/(R+S)$

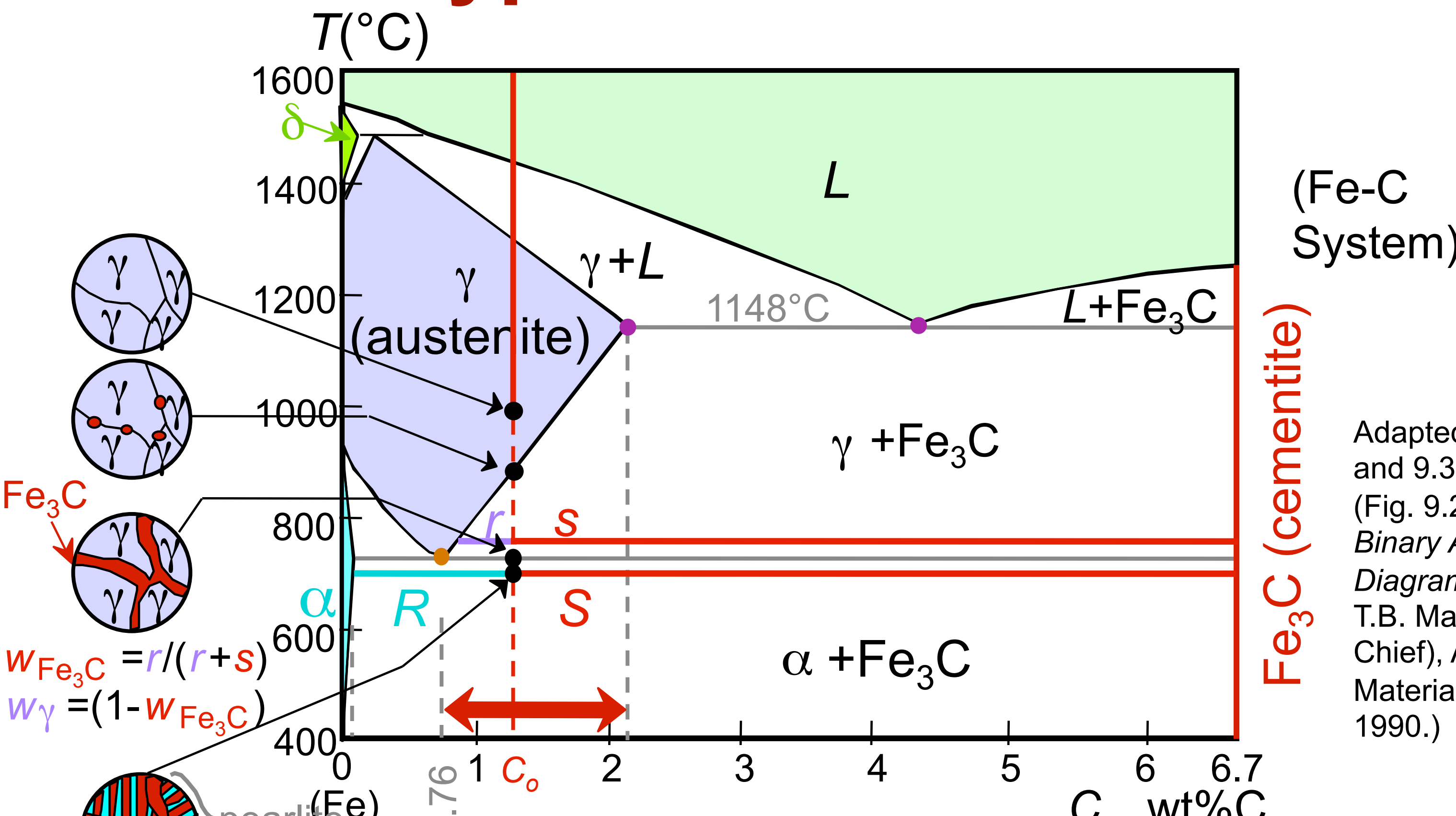
$w_{Fe_3C} = (1-w_\alpha)$

Adapted from Figs. 9.24 and 9.29, *Callister 7e*. (Fig. 9.24 adapted from *Binary Alloy Phase Diagrams*, 2nd ed., Vol. 1, T.B. Massalski (Ed.-in-Chief), ASM International, Materials Park, OH, 1990.)



Adapted from Fig. 9.30, *Callister 7e*.

Hypereutectoid Steel



Adapted from Figs. 9.24 and 9.32, *Callister 7e*. (Fig. 9.24 adapted from *Binary Alloy Phase Diagrams*, 2nd ed., Vol. 1, T.B. Massalski (Ed.-in-Chief), ASM International, Materials Park, OH, 1990.)

Adapted from Fig. 9.33, *Callister 7e*.

Example: Phase Equilibria

For a 99.6 wt% Fe-0.40 wt% C at a temperature just below the eutectoid, determine the following

a) composition of Fe_3C and ferrite (α)

b) the amount of carbide (cementite) in grams that forms per 100 g of steel

c) the amount of pearlite and proeutectoid ferrite (α)

Chapter 9 – Phase Equilibria

Solution: a) composition of Fe_3C and ferrite (α)

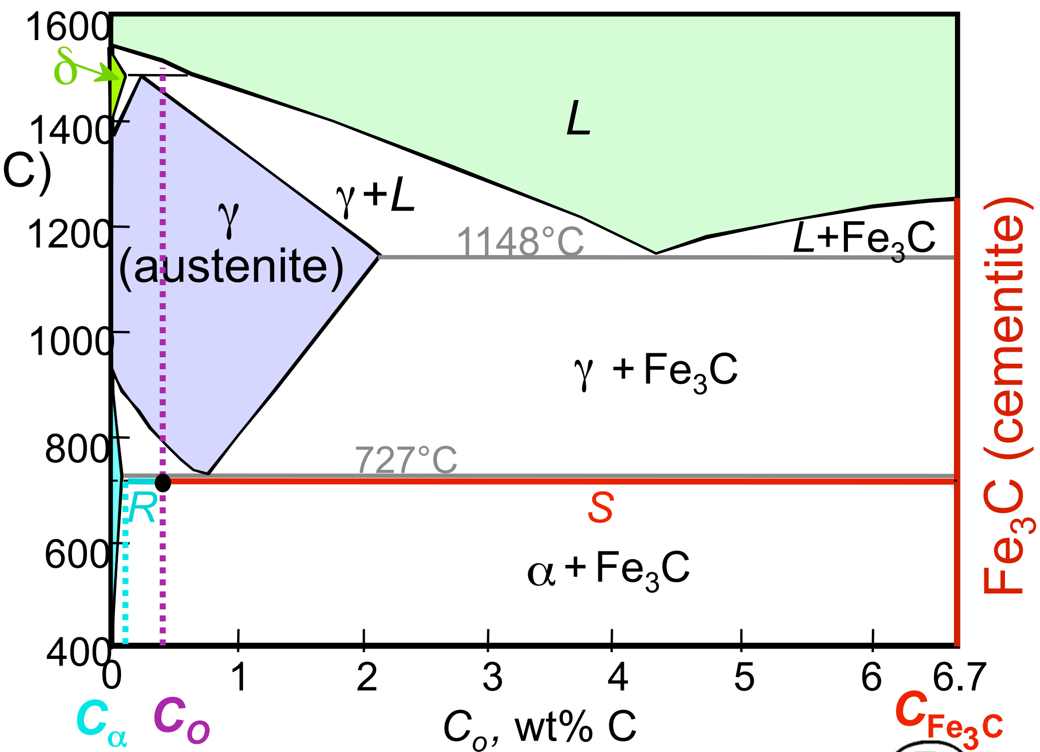
b) the amount of carbide (cementite) in grams that forms per 100 g of steel

C_O = 0.40 wt% C
C_α = 0.022 wt% C
C_{Fe_3C} = 6.70 wt% C

$$\frac{Fe_3C}{Fe_3C + \alpha} = \frac{C_o - C_\alpha}{C_{Fe_3C} - C_\alpha} \text{x}100$$

$$= \frac{0.4 - 0.022}{6.7 - 0.022} \, x\, 100 = 5.7\text{g}$$

$Fe_3C = 5.7$ g
$\alpha = 94.3$ g



Chapter 9 – Phase Equilibria

c. the amount of pearlite and proeutectoid ferrite (α)

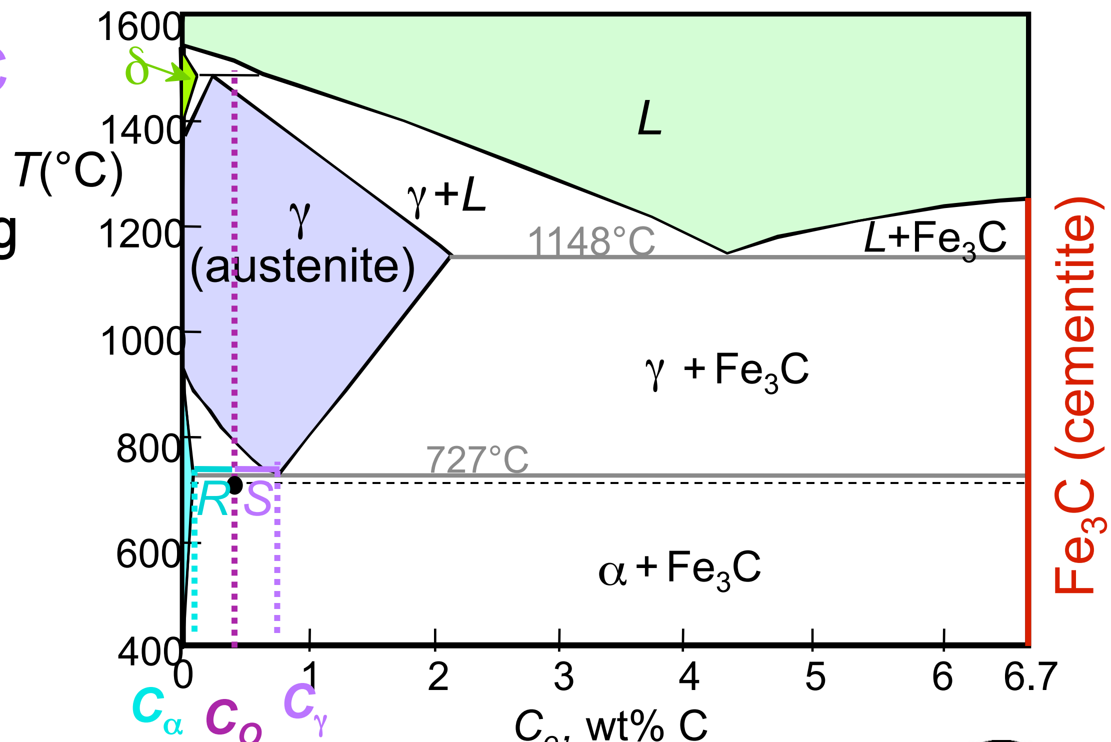
note: amount of pearlite = amount of γ just above T_E

C_o = 0.40 wt% C

C_α = 0.022 wt% C

$C_{pearlite} = C_\gamma$ = 0.76 wt% C

$$\frac{\gamma}{\gamma+\alpha} = \frac{C_o - C_\alpha}{C_\gamma - C_\alpha} \times 100 = 51.2 \text{ g}$$

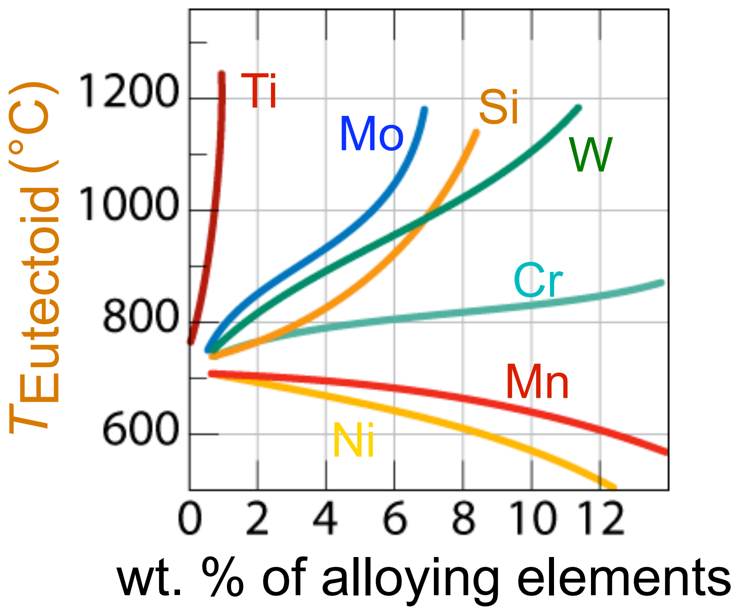


pearlite = 51.2 g

proeutectoid α = 48.8 g

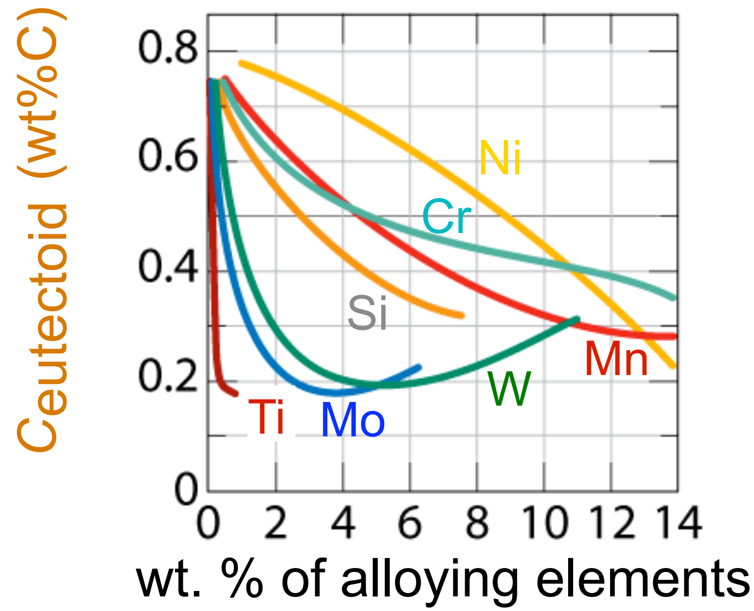
Alloying Steel with More Elements

- $T_{eutectoid}$ changes:



Adapted from Fig. 9.34,*Callister 7e*. (Fig. 9.34 from Edgar C. Bain, *Functions of the Alloying Elements in Steel*, American Society for Metals, 1939, p. 127.)

- $C_{eutectoid}$ changes:



Adapted from Fig. 9.35,*Callister 7e*. (Fig. 9.35 from Edgar C. Bain, *Functions of the Alloying Elements in Steel*, American Society for Metals, 1939, p. 127.)

Summary

- Phase diagrams are useful tools to determine:

  --the number and types of phases,

  --the wt% of each phase,

  --and the composition of each phase

  for a given *T* and composition of the system.

- Alloying to produce a solid solution usually

  --increases the tensile strength (*TS*)

  --decreases the ductility.

- Binary eutectics and binary eutectoids allow for a range of microstructures.