Phase diagram

Introduction

The study of phase equilibria and phase transformations is central to nearly all branches of metallurgy and materials science. The understanding of phase diagrams for alloy systems is extremely important because there is a strong correlation between microstructure and mechanical properties, and the development of microstructure of an alloy is related to the characteristics of its phase diagram. In addition, phase diagrams **provide valuable information about melting, casting, crystallization, and other phenomena.**

Phase diagram: is a graphical representation of all the equilibrium phases as a function of temperature, pressure, and composition.

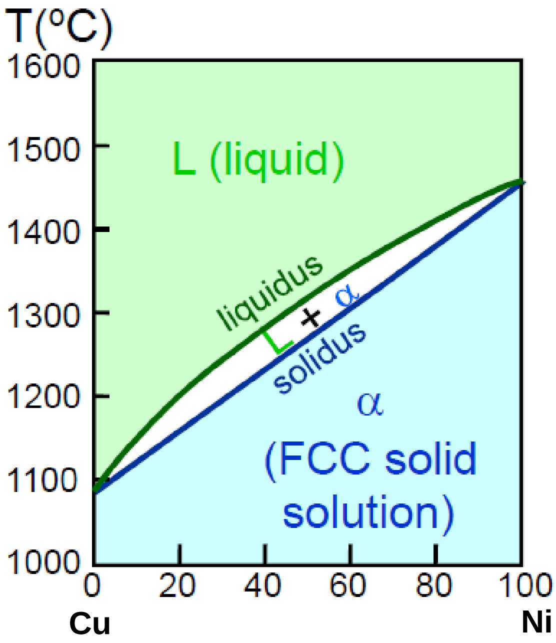
Solubility

Few metals are used in their pure state –they nearly always have other elements added to them which turn them into alloys and give them better mechanical properties. The alloying elements will always dissolve in the basic metal to form solid solutions, although the solubility can vary between <0.01% and 100% depending on the combinations of elements in system. As examples, the iron in a carbon steel can only dissolve 0.007% carbon at room temperature. There are three types of Solubility.

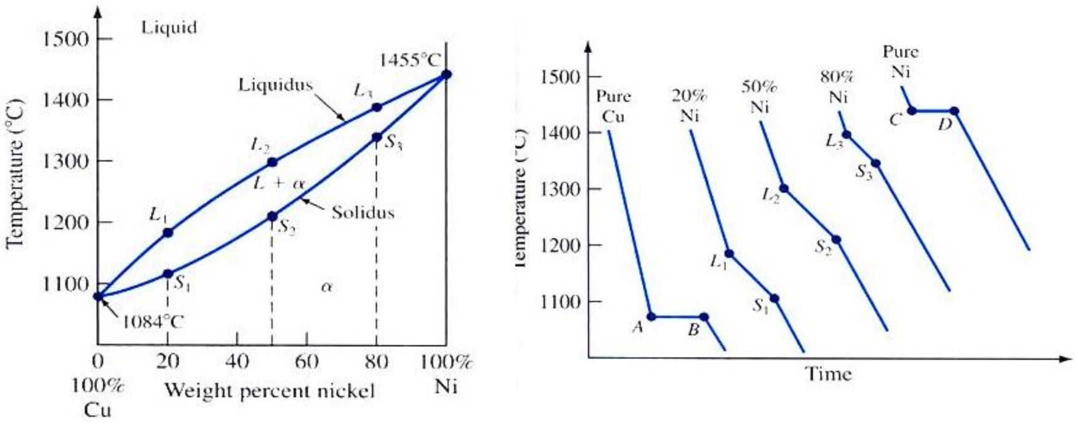
1- Unlimited Solubility

For two substances to have unlimited solubility, any amount of either substance must be able to dissolve completely into any amount of the other substance. A common application of unlimited solubility is alcohol and water. In this example it is very important to remember that after the solution is thoroughly mixed, only one phase is produced.

Copper and nickel are good examples of metals that display unlimited solubility. A solid solution of Cu and Ni forms only one solid phase below the individual melting points of each metal. However, at temperatures between their melting points, both a solid and a liquid phase will coexist. The solid phase in this temperature range is still the same phase as the solid below the melting points.



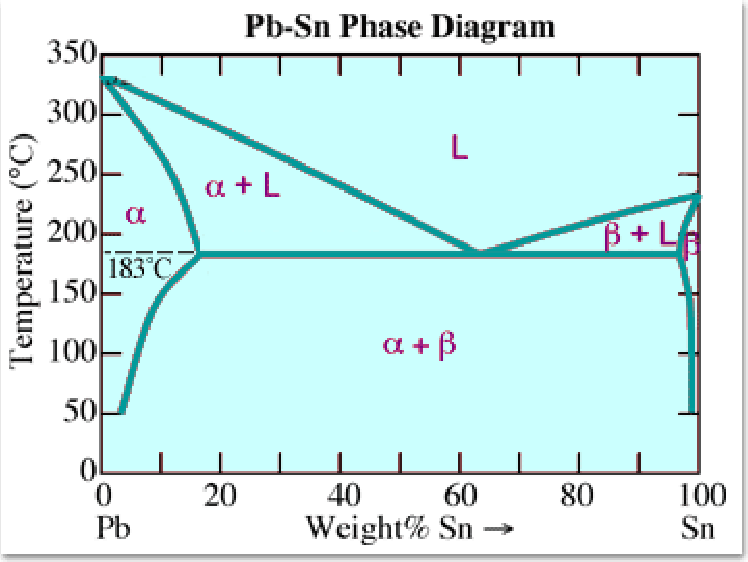
Phase diagram for Cu-Ni

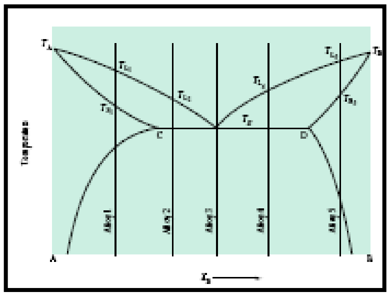


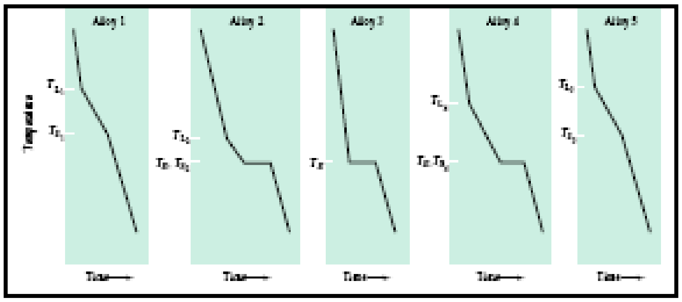
Cooling curves of Cu-Ni

2- Limited Solubility

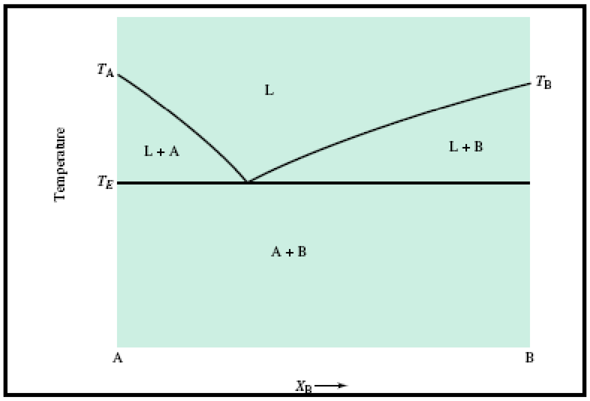
For limited solubility , only a certain amount of one substance may completely dissolve into the other substance. If this level of solubility is surpassed one of the original components will remain. At this time, two phases exist: the solution and the excess substance that was unable to mix. A simple example is sugar and water. Sugar will dissolve in water but only to a certain point (which depends on temperature). After this point, the excess sugar will sink to the bottom of the container. Many materials behave this way. Lead (Pb) and Tin (Sn) are two metals that display limited solubility.







3- No Solubility

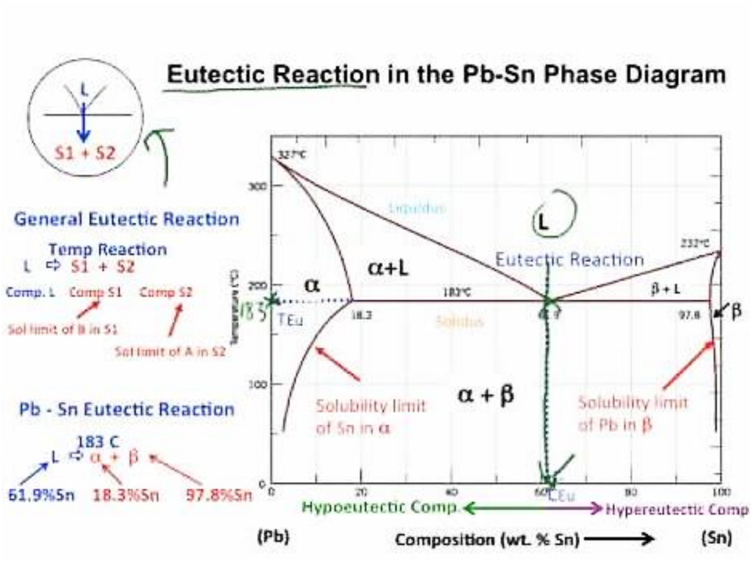


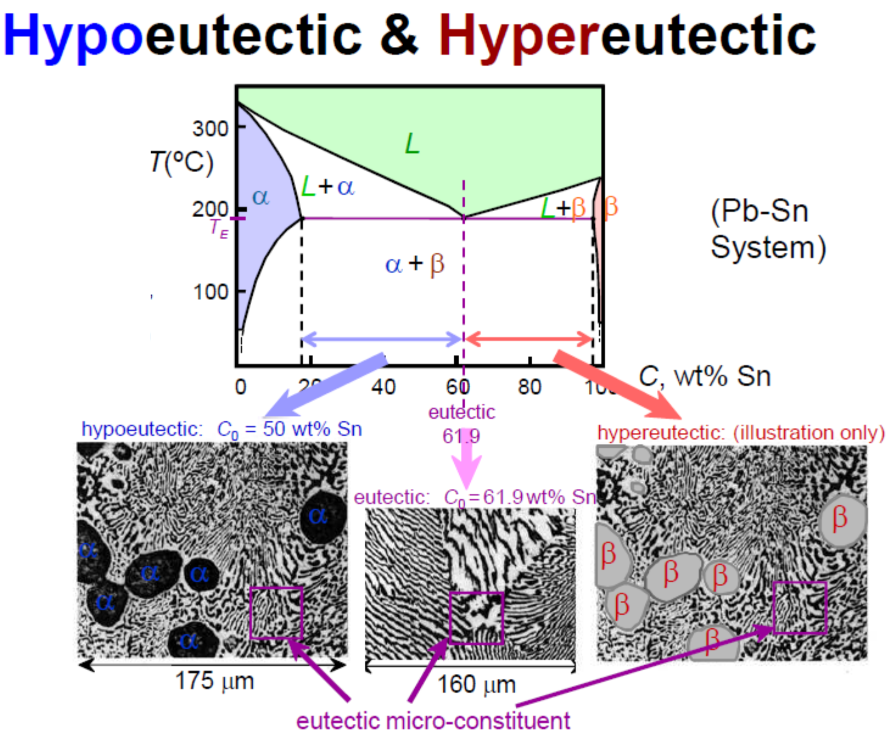
When two substances are insoluble, almost none of either substance will dissolve in the other. Oil and water are a good example of insolubility . Most materials will dissolve at least a tiny amount of another component, but when the maximum amount is small, this is often described as insoluble. For instance, lead and copper are considered insoluble.

Eutectic Binary Systems

It is commonly found that many materials are highly miscible in the liquid state, but have very limited mutual miscibility in the solid state. Thus much of the phase diagram at low temperatures is dominated by a 2-phase field of two different solid structures-one that is highly enriched in component A (the α phase) and one that is highly enriched in component B (the β phase). These binary systems, with unlimited liquid state miscibility and low or negligible solid state miscibility are referred to as **eutectic system**.

A eutectic reaction is a three-phase reaction, by which, on cooling, a liquid transforms into two solid phases at the same time. It is a phase reaction, but a special one. For example: liquid alloy becomes a solid mixture of alpha and beta at a specific temperature.


Eutectic Reaction in the Pb-Sn Phase Diagram
L
S1 + S2
General Eutectic Reaction
Temp Reaction
L ⇨ S1 + S2
Comp. L
Comp S1
Comp S2
Sol limit of B in S1
Sol limit of A in S2
Pb - Sn Eutectic Reaction
183 C
L ⇨ α + β
61.9%Sn
18.3%Sn
97.8%Sn
327°C
300
200
100
0
Temperature (°C)
183
TEu
Liquidus
L
Eutectic Reaction
232°C
α
α+L
183°C
β + L
18.3
61.9
97.8
β
Solidus
α + β
Solubility limit of Sn in α
Solubility limit of Pb in β
20
40
60
80
100
CEu
Hypoeutectic Comp.
Hypereutectic Comp
(Pb)
Composition (wt. % Sn)
(Sn)


Hypoeutectic & Hypereutectic
300
T(°C)
200
TE
100
L
L+α
α
L+β
β
α + β
(Pb-Sn System)
0
20
40
60
80
100
C, wt% Sn
eutectic
61.9
hypoeutectic: C0 = 50 wt% Sn
hypereutectic: (illustration only)
eutectic: C0 = 61.9 wt% Sn
α
β
175 μm
160 μm
eutectic micro-constituent

Determination of phase weight fractions

EXAMPLE 7.4–1

Figure 7.4–5 shows a hypothetical binary eutectic phase diagram on which we indicate an alloy of

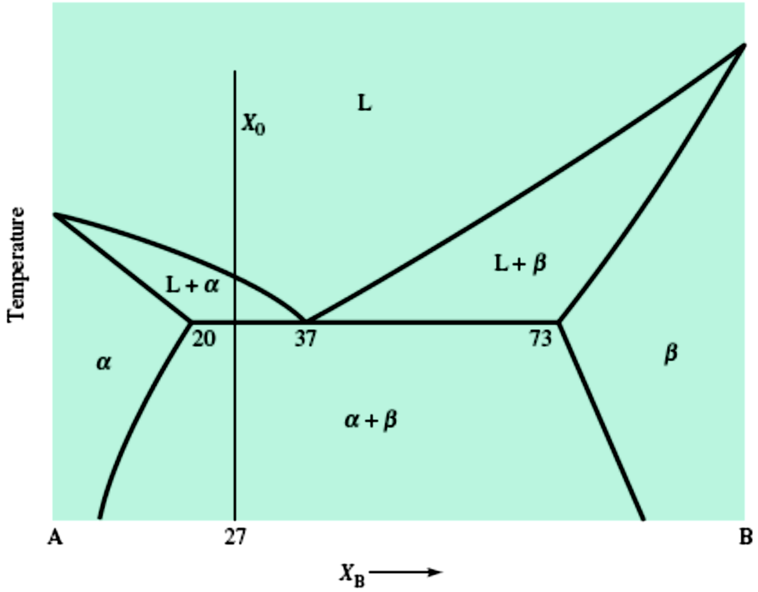


FIGURE 7.4–5 A hypothetical binary eutectic phase diagram indicating an alloy of composition 0.27 B.

composition 0.27 B. Calculate the following quantities:

a. The fraction of primary solid that forms under equilibrium cooling at the eutectic temperature.

b. The fraction of liquid with the eutectic composition that will transform to two solid phases below the eutectic isotherm.

c. The amount of α and β that will form from the liquid just below the eutectic isotherm.

d. The total amount of α phase in the alloy at a temperature just below the eutectic temperature.

Solution

a. The fraction of primary α, f_α^P, is determined by performing a lever rule calculation just above the eutectic temperature and using a composition corresponding to that of the alloy (i.e., $X_0 = 0.27$ B):

$$f_\alpha^P = \frac{X_L - X_0}{X_L - X_\alpha} = \frac{37 - 27}{37 - 20} = 0.588$$

b. Similarly, the fraction of liquid having the eutectic composition is:

$$f_L^{\text{eut}} = \frac{X_0 - X_\alpha}{X_L - X_\alpha} = \frac{27 - 20}{37 - 20} = 0.412$$

c. To determine the fraction of α that forms during solidification of the *eutectic liquid,* we must perform a lever rule calculation just below the eutectic temperature at a composition corresponding to that of the eutectic liquid. Therefore, the fraction of α in the eutectic constituent is:

$$f_\alpha = \frac{X_\beta - X_L^{\text{eut}}}{X_\beta - X_\alpha} = \frac{73 - 37}{73 - 20} = 0.679$$

Similarly, the fraction of β in the eutectic constituent is:

$$f_\beta = \frac{X_L^{\text{eut}} - X_\alpha}{X_\beta - X_\alpha} = \frac{37 - 20}{73 - 20} = 0.321$$

The fraction of alloy composed of eutectic α is obtained by multiplying the fraction of the alloy that was eutectic liquid ($f_L^{\text{eut}} = 0.412$) by the fraction of the eutectic liquid that becomes α ($f_\alpha = 0.679$). That is, the fraction of eutectic α, f_α^{eut}, is:

$$f_\alpha^{\text{eut}} = (f_L^{\text{eut}})(f_\alpha) = (0.412)(0.679) = 0.280$$

Similarly, the fraction of eutectic β is:

$$f_\beta^{\text{eut}} = (f_L^{\text{eut}})(f_\beta) = (0.412)(1.0 - 0.679) = 0.132$$

d. The total amount of α phase in the alloy can be calculated in several ways. The total fraction of α phase is just the sum of the fractions of primary α and eutectic α:

$$f_\alpha^{\text{total}} = f_\alpha^P + f_\alpha^{\text{eut}} = 0.588 + 0.280 = 0.868$$

Alternatively, since the microstructure is composed of just two phases, $\alpha + \beta$, the total fraction of α must be given by:

$$f_\alpha^{\text{total}} = 1 - f_\beta^{\text{eut}} = 1 - 0.132 = 0.868$$

Finally, the total amount of any phase at any temperature can be calculated directly by the lever rule evaluated at the corresponding state point. That is,

$$f_\alpha^{\text{total}} = \frac{X_\beta - X_0}{X_\beta - X_\alpha} = \frac{73 - 27}{73 - 20} = 0.868$$