Part VI. Heat treatment
Module 2 : Formation and evolution of microstructures

2 Formation and evolution of microstructures

2.1 Motivation

Shown below is the Pb-Sn phase diagram (Fig. 1). Consider the three alloys of the given compositions marked in the phase diagram, all of which are cooled from T_1 to T_2. How different would the three microstructures be?

2.2 Phase diagrams and microstructures

Let us consider the Ph-Sn phase diagram shown in Fig. 1. There are three compositions that are considered. These three compositions correspond to eutectic, hypo-eutectic and hyper-eutectic systems. In the case of eutectic system, the microstructure is as shown in Fig. 2: it consists of a fine mixture of the two phases, namely, α and β, the tin-rich and tin-poor phases. In the case of hypo- and hyper-eutectic systems, on the other hand, the microstructures are as shown Fig. 3. These type of microstructures arise, as shown schematically in Fig. 4, due to the formation of the pro-eutectic β (or α)) phase first making the composition of the remaining liquid shift towards the eutectic composition; the liquid that remains on achieving the eutectic point in terms of composition and temperature, then, phase separates into the eutectic mixture. Thus, from this exercise, it is very clear that the phase diagrams give us some indication of the microstructures that can result. However, phase diagrams assume equilibrium and hence gives an idea of microstructure that can form due to very slow cooling (small values of cooling rate). If we want to understand the formation of microstructures, taking into account the cooling rates, we need to peruse TTT or CCT diagrams.

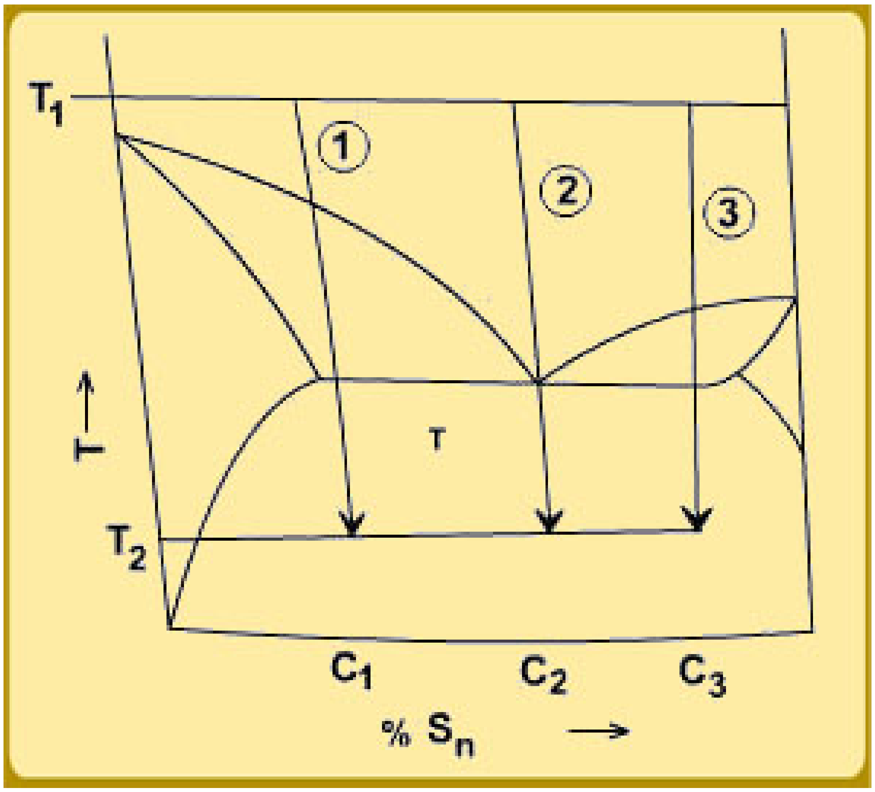

Figure 1: Pb-Sn phase diagram.

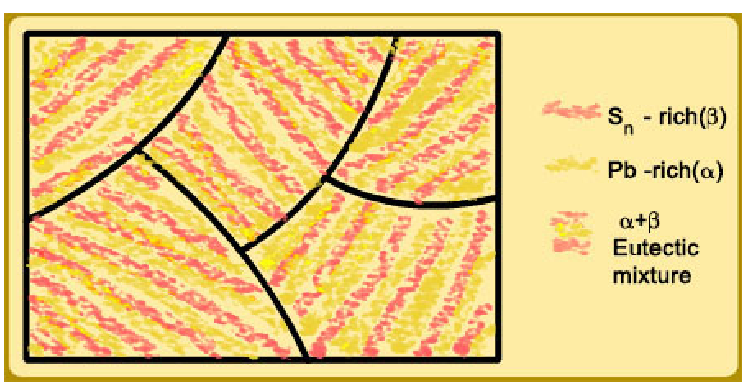

Figure 2: Eutectic microstructure.

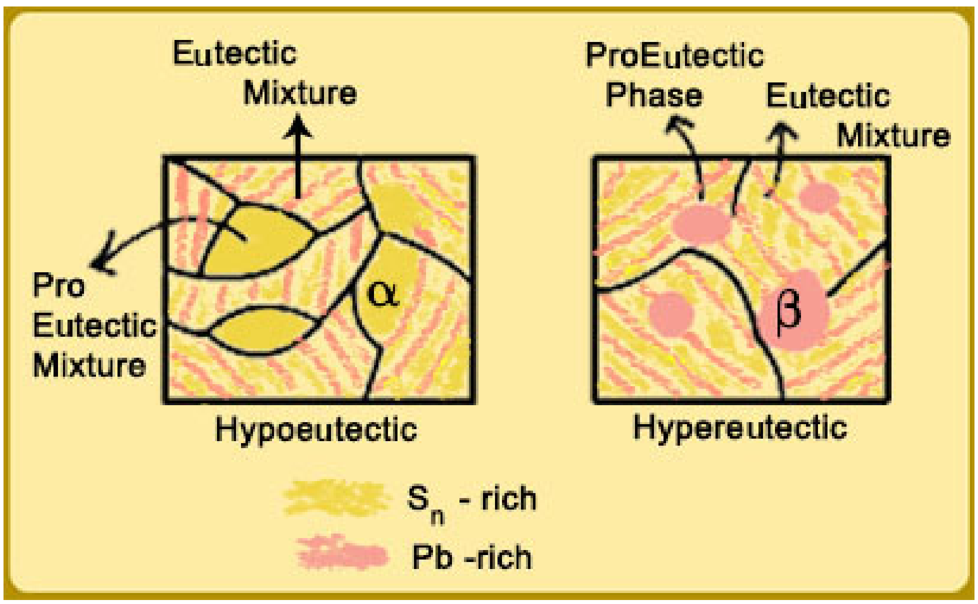

Figure 3: Hypo- and hyper-eutectic microstructures.

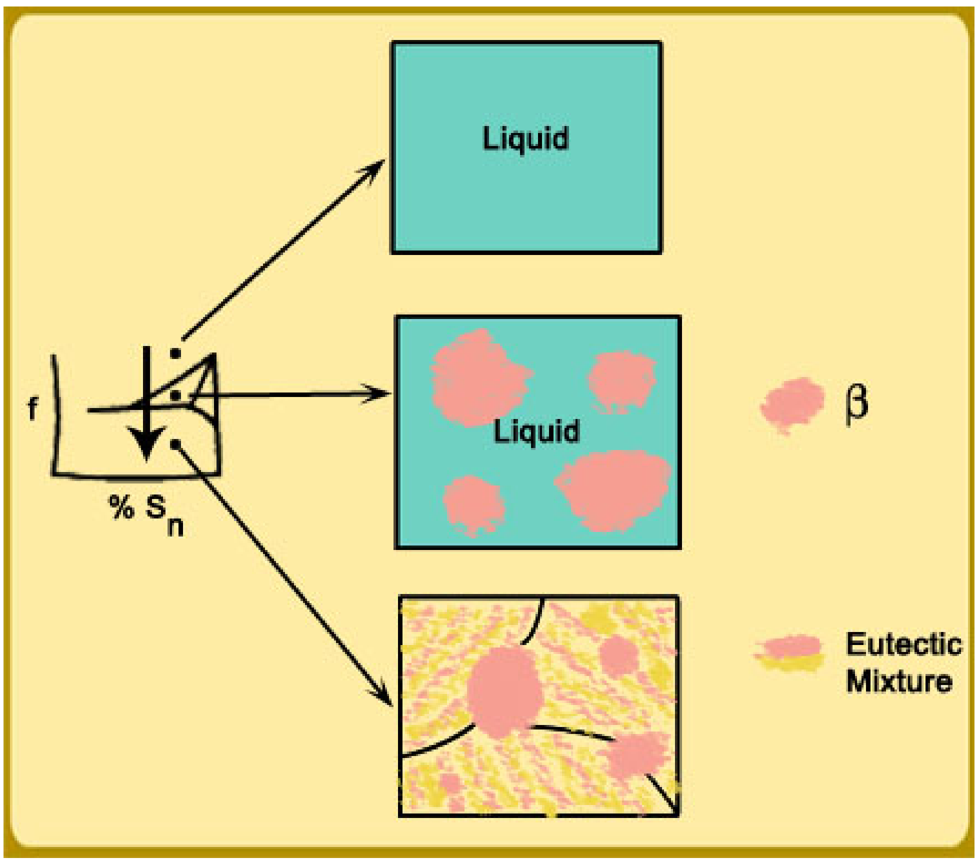

Figure 4: Formation of microstructure in an off-eutectic alloy.

2.3 TTT diagrams and heat treatment

As seen in Part III, the overall transformation kinetics (in systems that undergo nucleation and growth) is represented using the TTT diagram. It is the TTT diagrams that are helpful in planning heat treatments.

For example, consider a typical TTT phase diagram shown in Fig. 5. If this system is cooled at a rate smaller than $(T_1 - T_2)/(t - t_0)$, then, the second phase will form; however, if the quench is fast enough that the rate is greater than that given by $(T_1 - T_2)/(t - t_0)$, then, one can suppress the second phase formation completely.

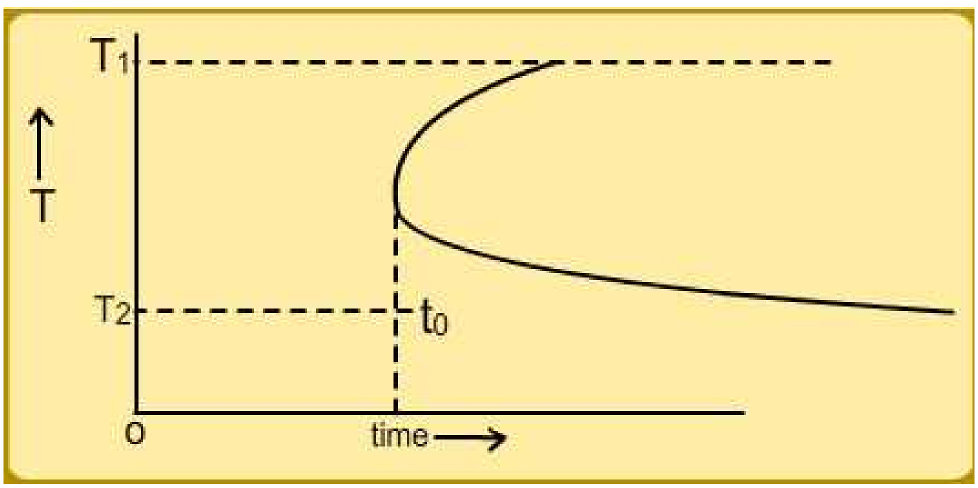

Figure 5: Fast quench for the suppression of second phase formation.

Also, as one can see from the TTT diagram of eutectoid steel (Fig. 6), it can contain phases which are not there in the phase diagram (martensite, for example) as well as give more information on the microstructure that is formed: bainite, pearlite, etc.

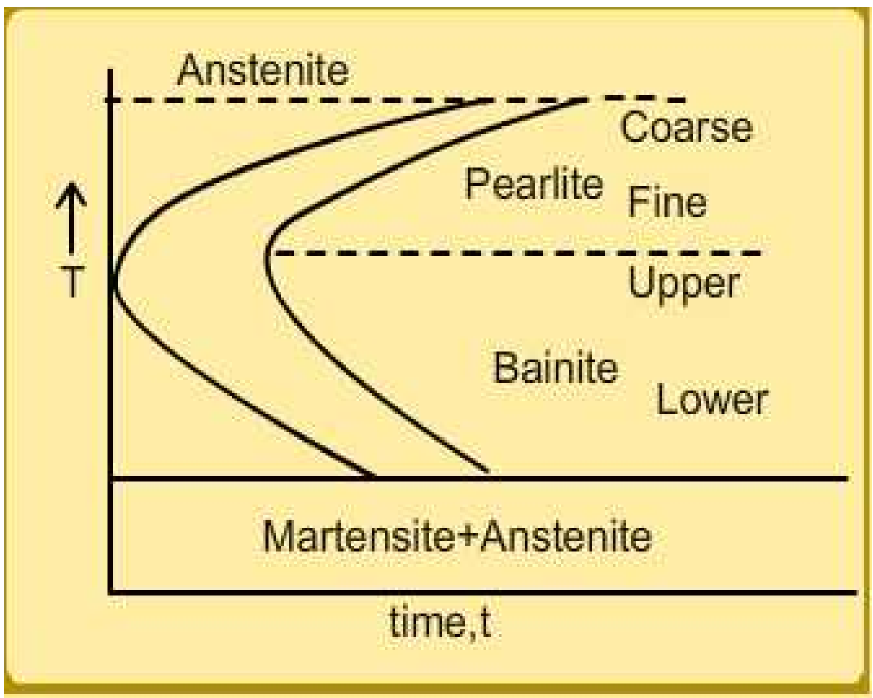

Figure 6: Schematic TTT diagram in eutectoid steel.

2.3.1 CCT and TTT diagrams and the rule of Scheil

Even though TTT diagrams are very useful for studying microstructures, in most of the cases of practical interest, the transformations take place not isothermally but during continuous cooling. Hence, the so-called Continuous Cooling Transformation diagrams (CCT diagrams are very important).

It is possible to go from TTT diagrams to CCT diagrams under certain circumstances, namely, if we assume that the kinetics of the transformation depends only one the fraction of the phases transformed and the temperature. In Fig. 7 we show how to calculate the CCT diagram from the isothermal transformation curve, schematically; the steps involved are as follows:

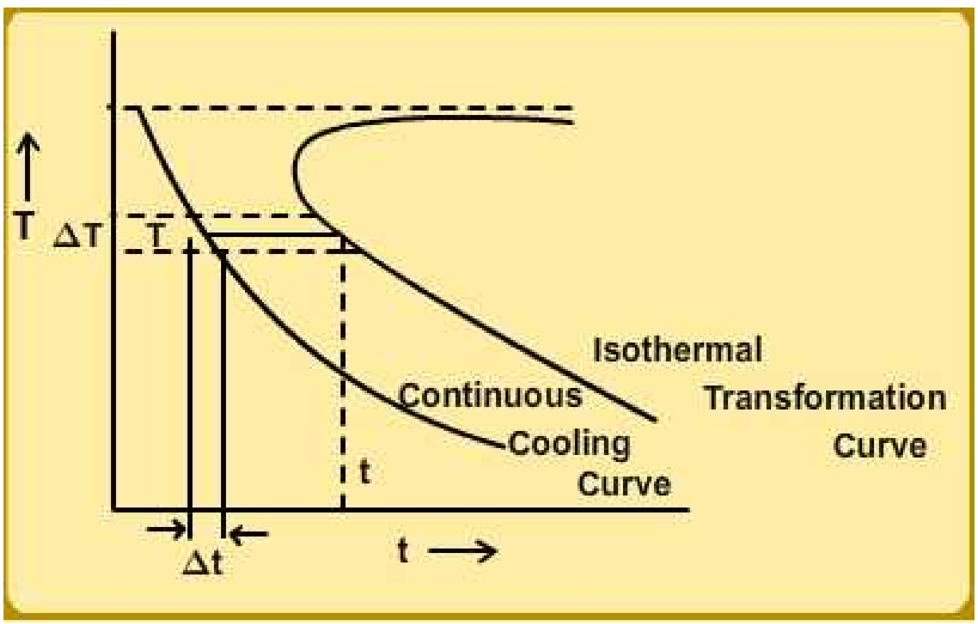

Figure 7: CCT and TTT diagrams.

1. Divide the temperature range into steps of size ΔT;

2. Calculate the time spent in each temperature range; this calculation is carried out by dividing the time step Δt by the time of the isothermal transformation t which corresponds to the average temperature T corresponding to the given Δt;

3. The cumulative phase fraction, then is given by

$$f = \sum_{T_e}^{T} \frac{\Delta t}{t} \tag{1}$$

4. The transformation begins when $f \approx 1$.

The Eq. 1 is known as the additive rule of Scheil.

2.4 Tutorial problems and questions

1. Consider the relevant portion of Pb-Sn phase diagram shown in Fig. 8. Calculate the amount of pro-eutectic β phase for an alloy of composition 70% Sn.

2.5 Solutions to the tutorial

1. Using the lever rule and substituting the information from the phase diagram, the amount of pro-eutectic β will be $\frac{70-62}{97-62} = 0.228$.

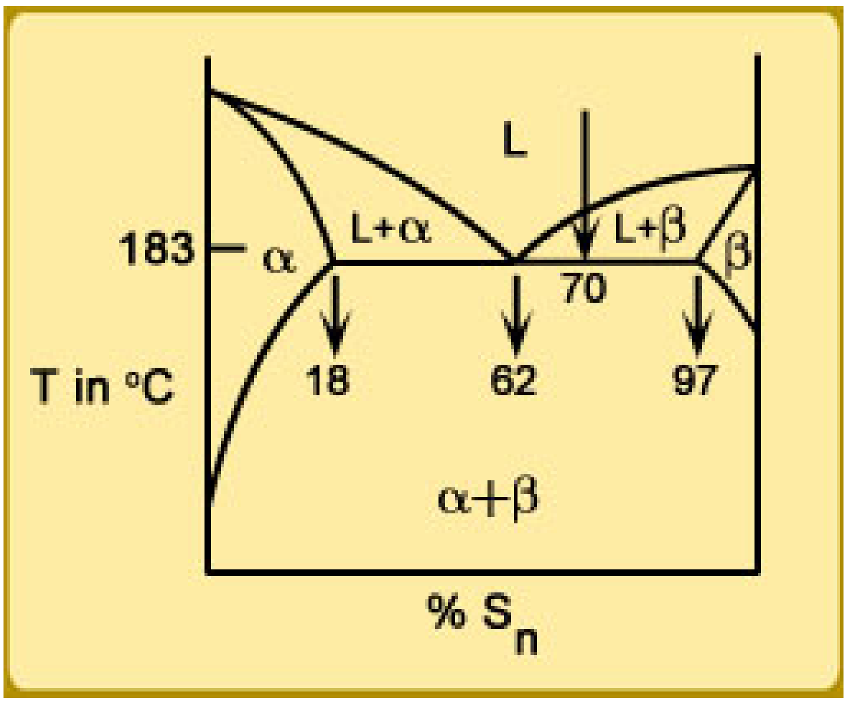

Figure 8: Pb-Sn phase diagram with equilibrium values for the eutectic line and point.