Part IV : Solid-Solid Phase Transformations I
Module 2 : Cellular precipitation

2. Cellular precipitation

2.1 Motivation

Consider the microstructure (schematic) shown in Fig. 18. This is a typical microstructure found in Mg-9 at% Al alloy for example. Why and how do such structures form?

Figure 18: Cellular precipitation.

2.2 Discontinuous precipitation

In the last section, we discussed the effect of grain boundaries on the nucleation of precipitates with specific reference to ferrite (α) on austenite (γ).

We saw that there exist two morphologies, namely, grain boundary allotriomorphs and Widmanstatten side plates. In some cases, the precipitates that are nucleated at the grain boundary, when they grow, also carry the grain boundary along with them. This process is shown schematically in Fig. 19. Such a process leads to a cellular microstructure as shown. This kind of process is known as cellular precipitation.

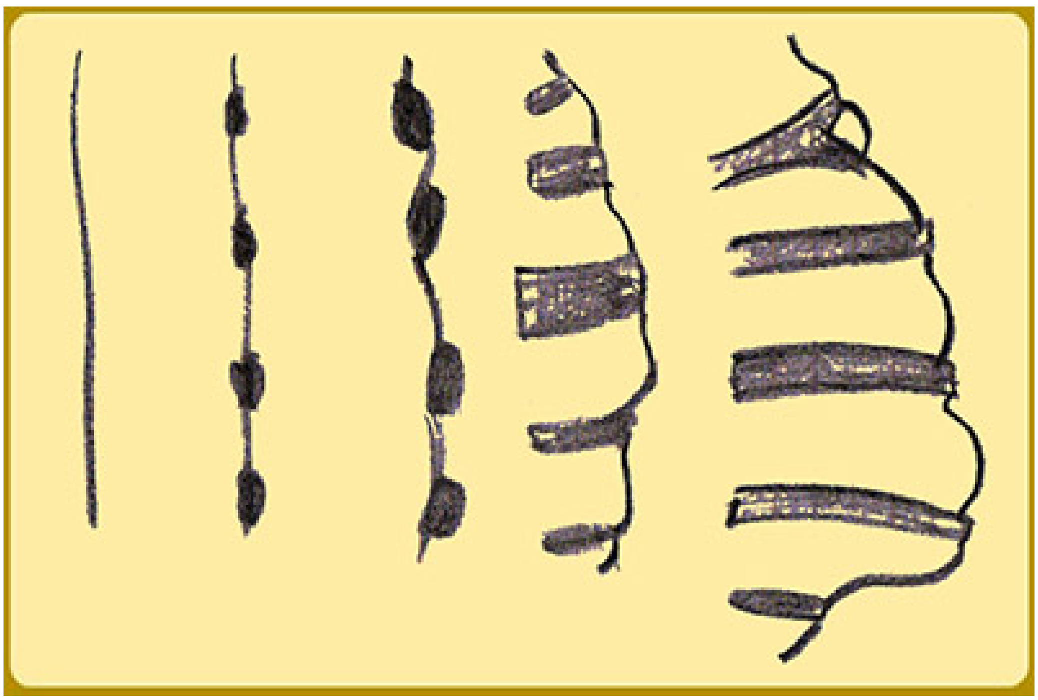

Figure 19: Mechanism of formation of cellular precipitates.

Cellular precipitation is also known discontinuous precipitation because of the sudden change in composition across the moving grain boundary as shown below; on the other hand, non-cellular precipitation is known as continuous because the composition of the matrix phase decreases continuously at any point. In general, continuous precipitation leads to much better mechanical properties (due to the more uniform distribution of precipitates, which nucleate throughout the matrix (on dislocations for example) and hence, much smaller size distribution) as opposed to discontinuous precipitation.

Cellular precipitation leads to microstructures that are very similar to eutectoid transformations (to be discussed in the next module). In fact, the only difference between cellular precipitation and eutectoid transformation is that while in eutectoid transformation both the phases that form are different from the original phase, in cellular precipitation one of the phases remains the same as the original phase (albeit with a different composition):

$\alpha' \rightarrow \alpha + \beta$

α' is the supersaturated matrix, and α is the matrix phase with a composition closer to equilibrium composition and β is the precipitate phase.

Consider the phase diagram of the Al-Mg system as shown in Fig. 20. The β phase is the $Mg_{17}Al_{12}$ phase and the α phase is the solid solution of Mg and Al. Consider an alloy of 9 at % Al, which is solution treated (at, say 410°C) and aged for an hour at 220°C. The cellular precipitation that takes place during the aging treatment leads to microstructures as shown schematically in Fig. 18. The composition profiles across the boundary as well as parallel to the boundary are as shown in Fig. 21. The discontinuous nature of the composition in the α phase across the moving boundary indicates that the mechanism of diffusion which leads to the formation of cellular structures is the diffusion of solutes through the moving grain boundary (since, if the diffusion took place through the matrix on either side of the boundary, it would have led to composition gradients). The composition of the α in the profile parallel to the moving boundary indicates that α composition is still not equilibrated after the precipitation of β.

2.3 Tutorial problems and questions

1. Explain the microstructure that forms due to cellular precipitation if the material is aged at two different temperatures before quenched.

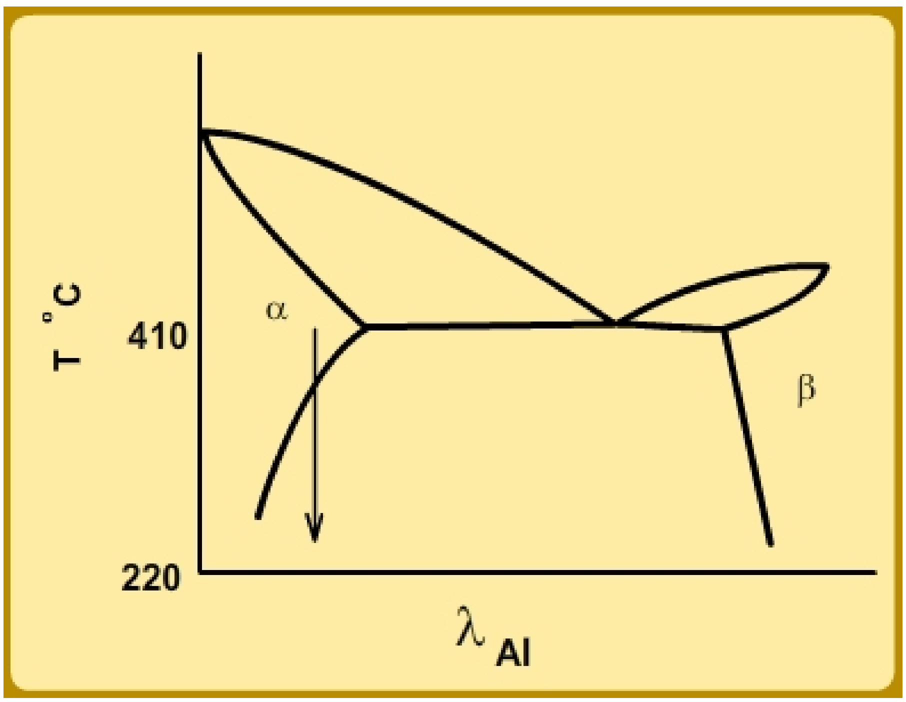

Figure 20: Al-Mg phase diagram.

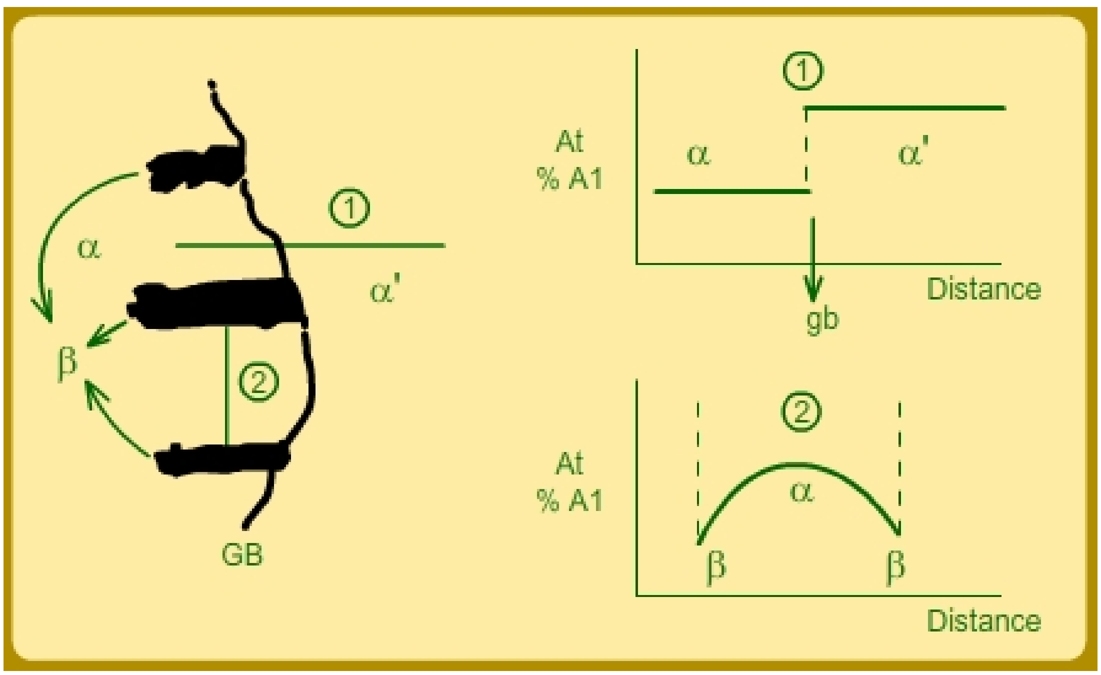

Figure 21: Composition profiles in a cellular precipitated microstructure.

2.4 Solutions to the tutorial

1. As noted, in the formation of cellular microstructures, the diffusion of solutes takes place in the moving grain boundary. Hence, if the system is aged at two different temperatures, the diffusion distances at these two temperatures along the grain boundary will be different: it would be higher at higher temperatures and lower at lower temperatures. Thus, the resultant microstructure is as shown below in Fig. 22.

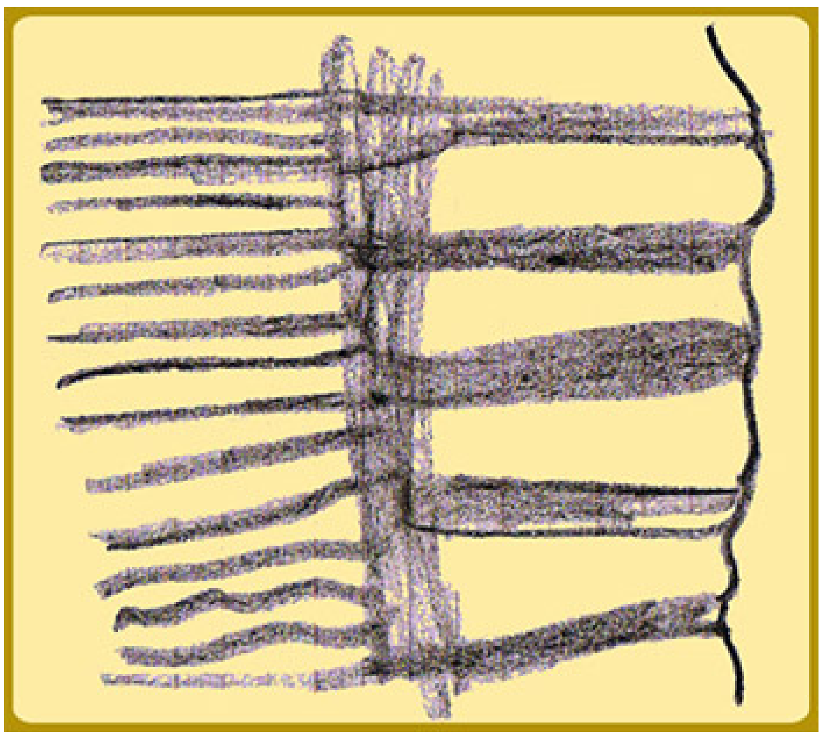

Figure 22: Effect of two stage cooling on cellular precipitated microstructure: the intercell spacings change.

2.5 Supplementary information

In this module, we discussed the cellular or discontinuous precipitation. When the mechanism of phase transformation changes from nucleation and growth to spinodal decomposition (to be discussed in the next part), it is possible for discontinuous spinodal to take place; in such cases, phase separation starts near the grain boundary and the boundary moves with the phase separation (reaction) front.