# Part IV : Solid-Solid Phase Transformations I
# Module 3. Eutectoid transformations

## 3 Eutectoid transformations

### 3.1 Motivation

What are the different microstructural features due to the eutectoid transformation in a 0.8 wt% C steel (Fe-C system)? Why and how do they form?

### 3.2 Pearlitic and bainitic transformations in eutectoid steel

Iron with 0.8 wt%C undergoes an eutectoid transformation at 727°C (see Fig. 23); the corresponding TTT diagram is as shown in Fig. 24.

The eutectoid transformation reaction in Fe-C system is as follows:

$$\gamma \;\; (\text{fcc, austenite}) \rightarrow \alpha \;\; (\text{bcc, ferrite}) + Fe_3C \;\; (\text{orthorhombic, cementite}) \tag{6}$$

### 3.3 Nucleation of pearlite

Pearlite typically forms on the grain boundaries of the austenite phase by the nucleation of either the ferrite or cementite; the exact phase that nucleates is decided both by the composition and the structure of the grain boundary.

The nucleation is such that the barrier for nucleation is the lowest; in other words, the nuclei has a orientation relationship with one of the grains such that the interfacial free energy is minimized. Suppose the first phase to nucleate is cementite; this leads to a depletion of the carbon surrounding this region leading to ferrite nucleation. Ferrite nucleation is also such that the interfacial free energy is minimized; thus, it also has an orientation relationship with the cementite. This process is repeated with the entire grain boundary coated with alternating cementite and ferrite nuclei. This is shown schematically in Fig. 25.

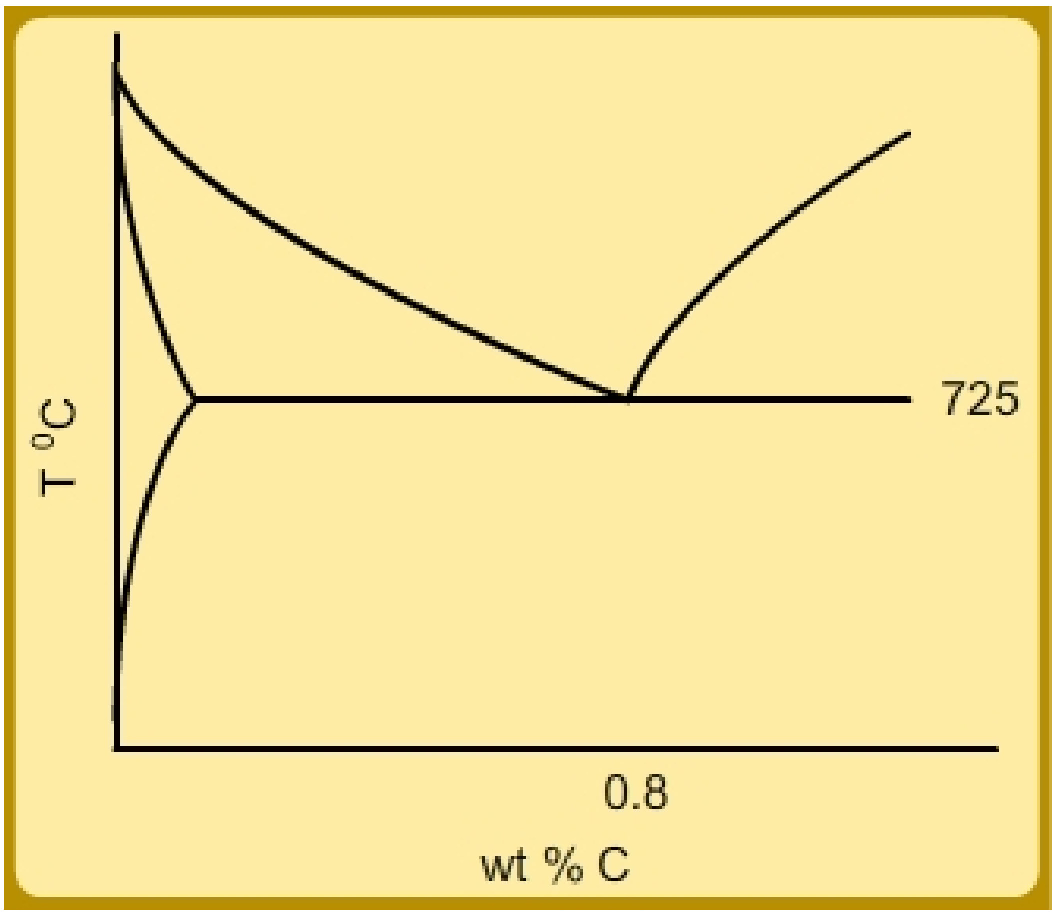


Figure 23: Phase diagram of the Fe-C system: eutectoid transformation.

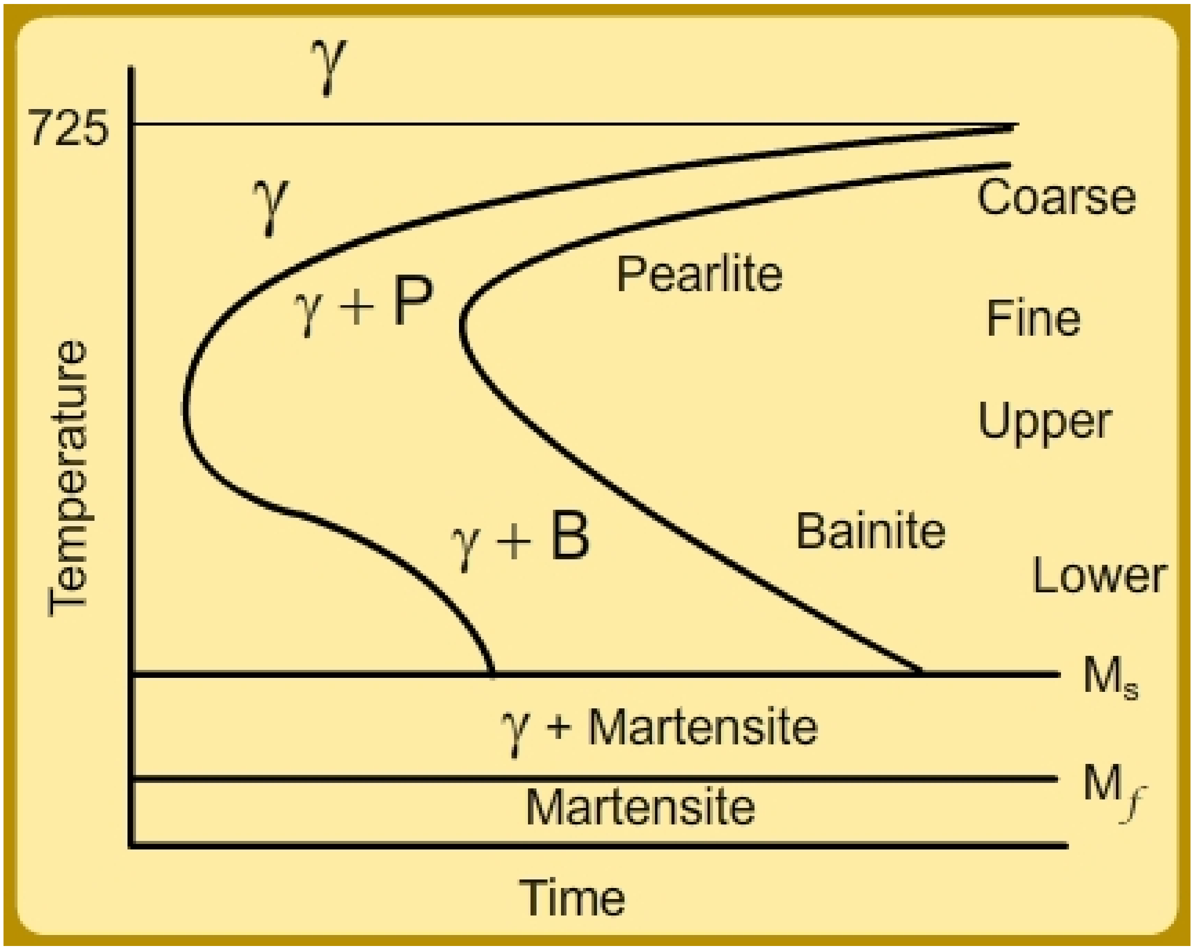


Figure 24: TTT diagram for Fe-0.8 wt%C system.

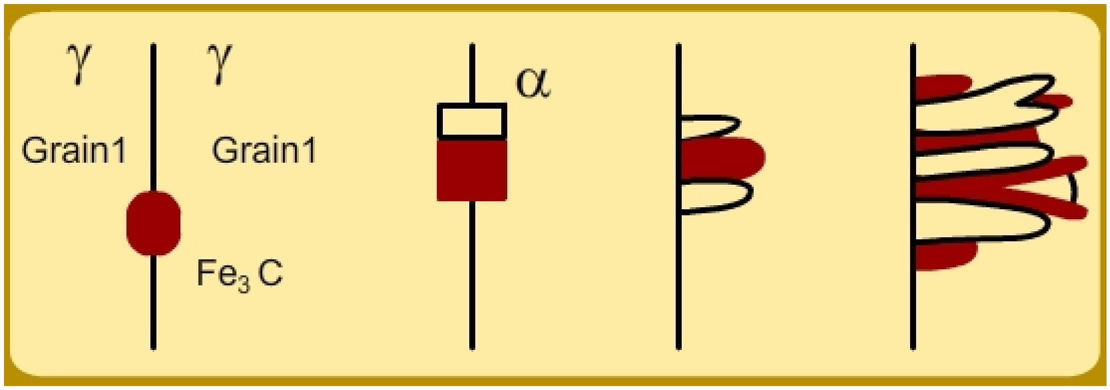


Figure 25: Nucleation of the eutectoid phases in a system with eutectoid composition.

If the composition of the steel is not the eutectoid composition, then, it is possible that proeutectoid ferrite or cementite is nucleated at the grain boundary. The other phase, be it cementite or ferrite, then forms on the incoherent boundary of this proeutectoid phase. This process is shown schematically in Fig. 26.

With sufficient undercooling, there is site saturation: that is, all the grain boundaries and other heterogeneous nucleation sites are covered with the ferrite and cementite nuclei. The resultant microstructure is shown schematically in Fig. 27.

Note that the nucleation process described here is one in which two phases have to nucleate in a cooperative manner; hence, it takes time for this process to take place. Thus, with increasing time, the nucleation of colonies also increase. If, for some reason such a cooperative nucleation does not take place, it leads to nonlamellar growth of ferrite and cementite leading to what is known as degenerate pearlite.

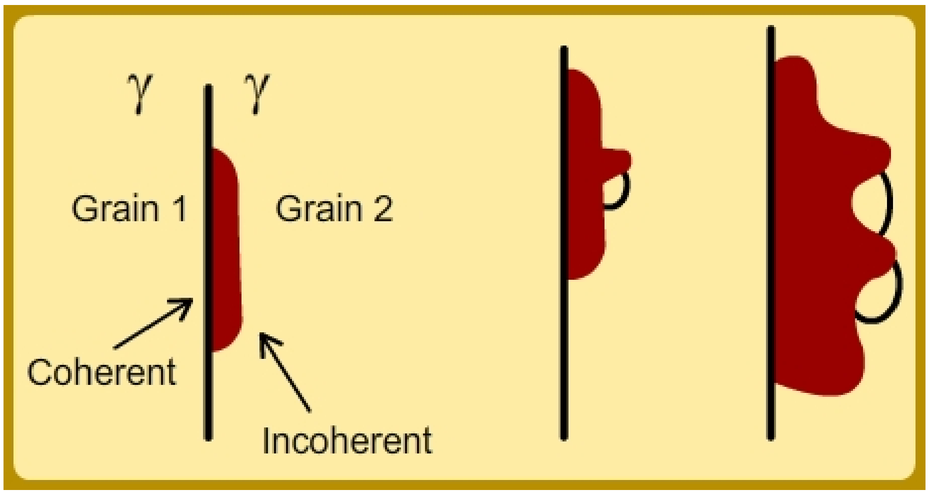


Figure 26: Nucleation of the eutectoid phases in a system with off-eutectoid composition.

### 3.4 Growth of pearlite

The pearlite colony grows into the grain with which it has no orientation relationship (and hence, shares an incoherent boundary). The carbon rejected by the growth of ferrite diffuses in through austenite phase ahead of the cementite phase. Thus, the late stage microstructure of the colony looks as shown in Fig. 28.

### 3.5 Bainite transformation

At relatively larger supersaturations (austenite cooled below the nose of the pearlite transformaton), there is another eutectoid product that develops known as bainite; bainite is also a mixture of ferrite and cementite; however, it is microstructurally quite distinct. In the next two subsections, we discuss these microstructural features.

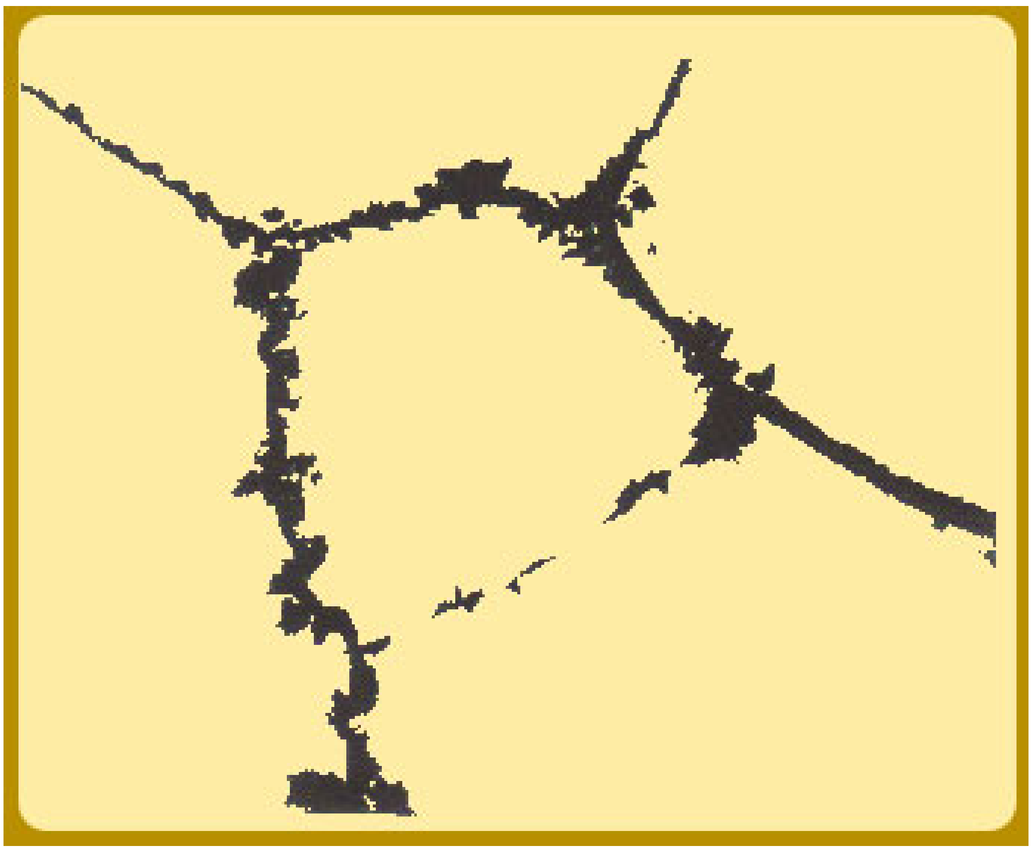

Figure 27: Site saturation in sufficiently undercooled system.

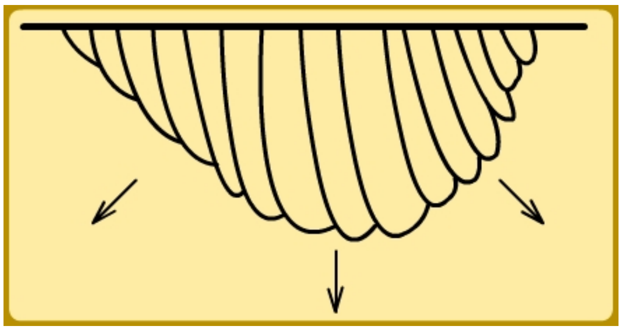

Figure 28: Late stage microstructure in an eutectoid colony.

### 3.5.1 Upper bainite

At the higher end of the temperatures (350-550°C), the microstructure consists of needles of laths of ferrite nucleated at the grain boundary and grown into one of the grains with cemetite precipitates between the ferrites; see Fig. 29. The ferrite formed is Widmanstatten; it has a Kurdjumov-Sachs orientation relationship with the austenite grain into which it is growing; it is in this respect, namely the orientation relationship between the ferrite/cementite and the austeinite grain in which they grow, that the the bainite differs from pearlite.

### 3.5.2 Lower bainite

At low enough temperatures, the bainitic microstructure changes to that of plates of ferrite and very finely dispersed carbides; since the diffusion of carbon is very low at these temperatures (especially in the austenite phase as compared to ferrite), the carbides precipitate in ferrite (and, with an orientation relationship). These carbides that precipitate could be the equilibrium cementite or metastable carbides (such as, $\epsilon$-carbide, for example). A schematic of lower bainite plate that is formed is shown in Fig. 30.

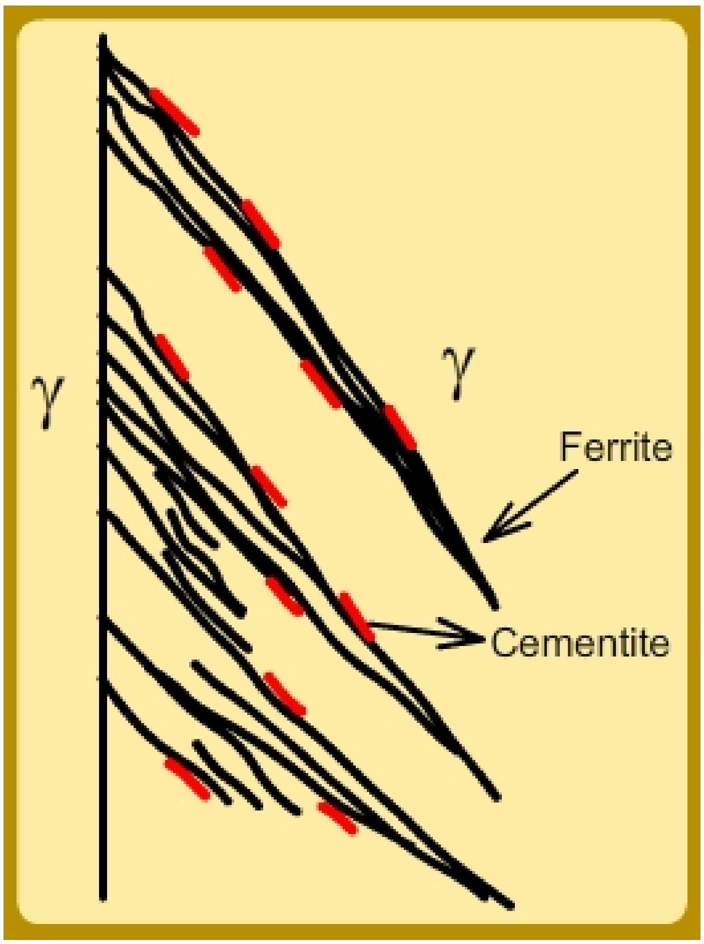


Figure 29: Upper bainite.

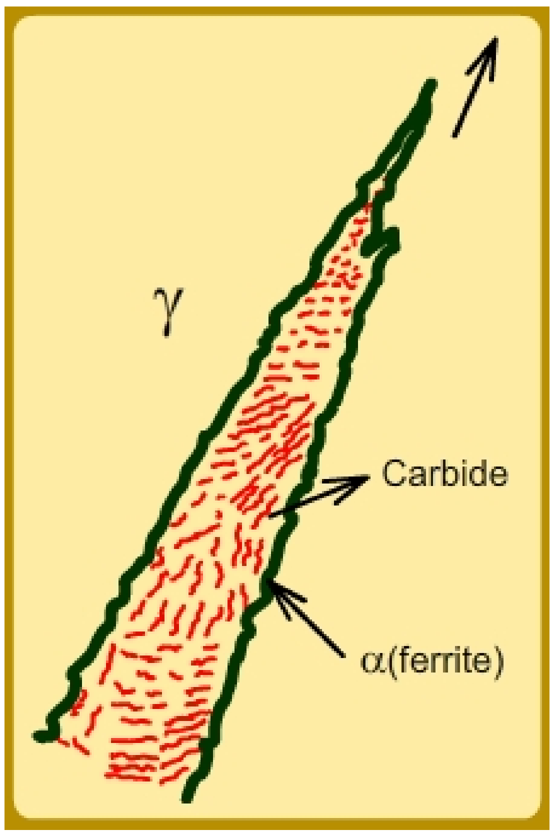


Figure 30: Lower bainite.

### 3.6 Fibrous and interphase precipitation in alloy steels

When strong carbide forming elements (such as Mo, W, V, Ti and Cr) are alloyed with steel, and when such steels are transformed at temperatures where the alloying element has low mobility, two morphologies of alloy carbide form. In Fig. 31 we show (schematically) the formation of fibrous morphology. In Fig. 32 we show (schematically) the formation of interphase precipitates; such interphase precipitates form at the flat surfaces of ledges of the $\alpha - \gamma$ as opposed to the incoherent step (which would otherwise be the favourable site); however, in this case these interfaces move very fast for nucleation to occur.

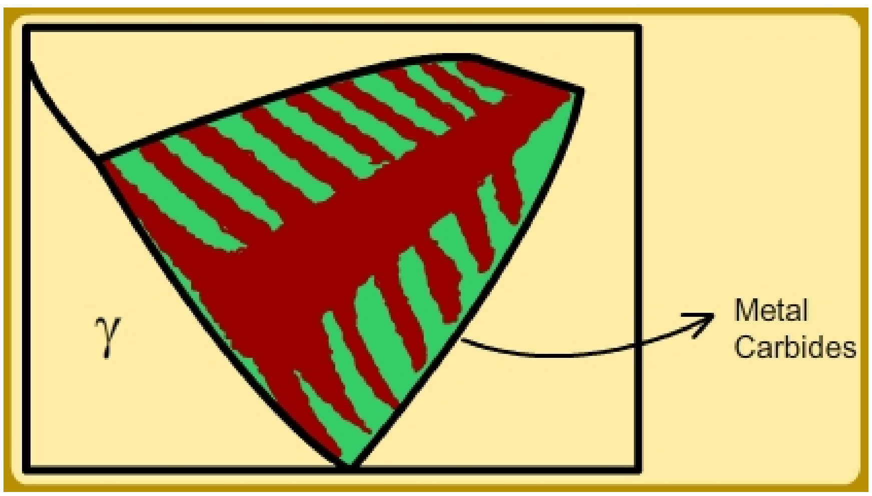


Figure 31: Fibrous precipitation.

### 3.7 Supplementary information

The mechanism of the growth of bainitic ferrite and the nature of the austenite-ferrite interface during the formation of bainite are not well understood. Please see [1] for a detailed discussion on some of these aspects.

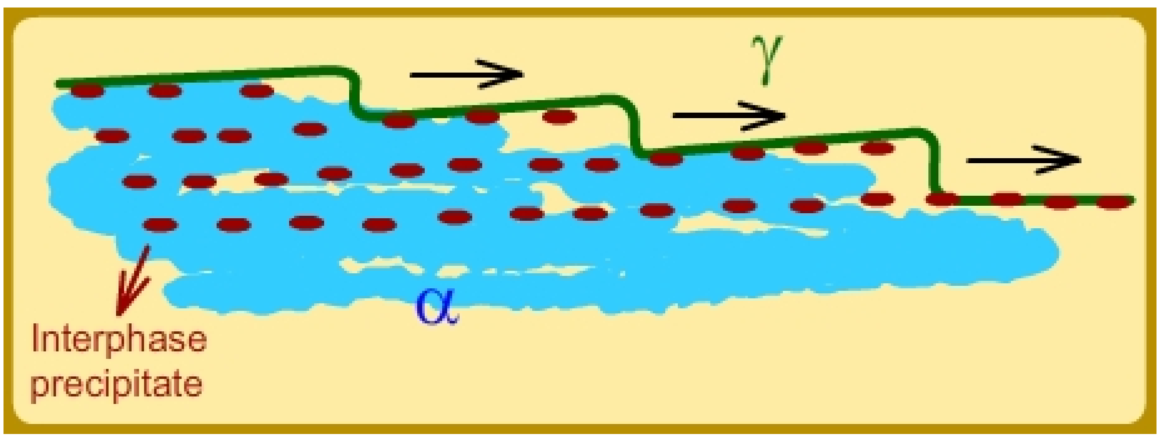


Figure 32: Interphase precipitation.