Materials Science
The Iron- Iron Carbide Phase Equilibrium Diagram
(Part 3) (Weeks 11), Presented by Professor Ali Hussein Ataiwi

Hypereutectoid Alloys

hypereutectoid alloy

Analogous transformations and microstructures result for **hypereutectoid alloys**—those containing between 0.76 and 2.14 wt% C—that are cooled from temperatures within the γ-phase field. Consider an alloy of composition C_1 in Figure 9.32 that, upon cooling, moves down the line zz'. At point g, only the γ phase is present with a composition of C_1; the microstructure appears as shown, having only γ grains. Upon cooling into the $\gamma + Fe_3C$ phase field—say, to point h—the cementite phase begins to form along the initial γ grain boundaries, similar to the α phase in Figure 9.29, point d. This cementite is called **proeutectoid cementite**—that which forms before the eutectoid reaction. The cementite composition remains constant (6.70 wt% C) as the temperature changes. However, the composition of the austenite phase moves along line PO toward the eutectoid. As the temperature is lowered through the eutectoid to point i, all remaining austenite of eutectoid composition is converted into pearlite; thus, the resulting microstructure consists of pearlite and proeutectoid cementite as microconstituents (Figure 9.32). In the photomicrograph of a 1.4-wt%

proeutectoid cementite

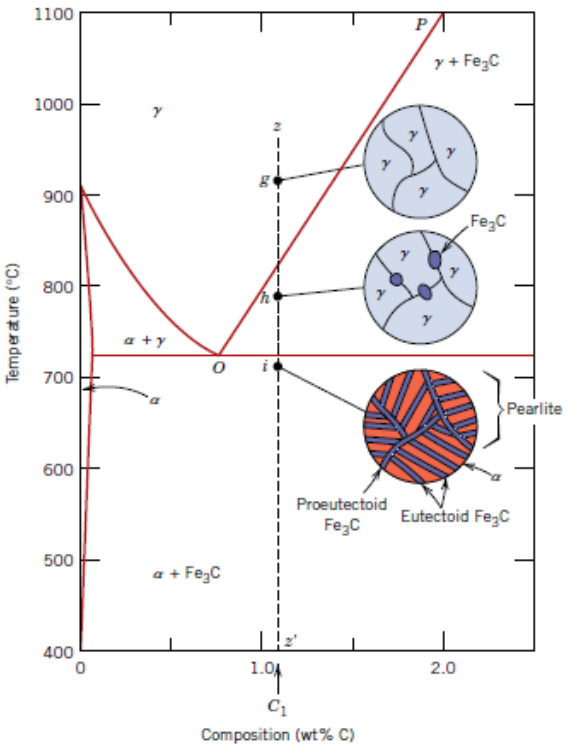


Figure 9.32 Schematic representations of the microstructures for an iron–carbon alloy of hypereutectoid composition C_1 (containing between 0.76 and 2.14 wt% C) as it is cooled from within the austenite-phase region to below the eutectoid temperature.

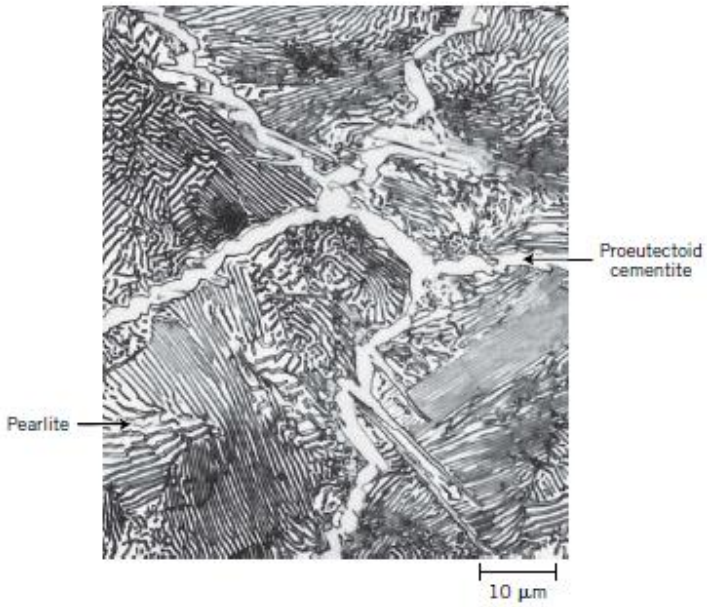


Figure 9.33 Photomicrograph of a 1.4 wt% C steel having a microstructure consisting of a white proeutectoid cementite network surrounding the pearlite colonies. 1000×. (Copyright 1971 by United States Steel Corporation.)

C steel (Figure 9.33), note that the proeutectoid cementite appears light. Because it has much the same appearance as proeutectoid ferrite (Figure 9.30), there is some difficulty in distinguishing between hypoeutectoid and hypereutectoid steels on the basis of microstructure.

Relative amounts of both pearlite and proeutectoid Fe_3C microconstituents may be computed for hypereutectoid steel alloys in a manner analogous to that for hypoeutectoid materials; the appropriate tie line extends between 0.76 and 6.70 wt% C. Thus, for an alloy having composition C_1' in Figure 9.31, fractions of pearlite W_p and proeutectoid cementite $W_{Fe_3C'}$ are determined from the following lever rule expressions:

$$W_p = \frac{X}{V + X} = \frac{6.70 - C_1'}{6.70 - 0.76} = \frac{6.70 - C_1'}{5.94} \tag{9.22}$$

and

$$W_{Fe_3C'} = \frac{V}{V + X} = \frac{C_1' - 0.76}{6.70 - 0.76} = \frac{C_1' - 0.76}{5.94} \tag{9.23}$$

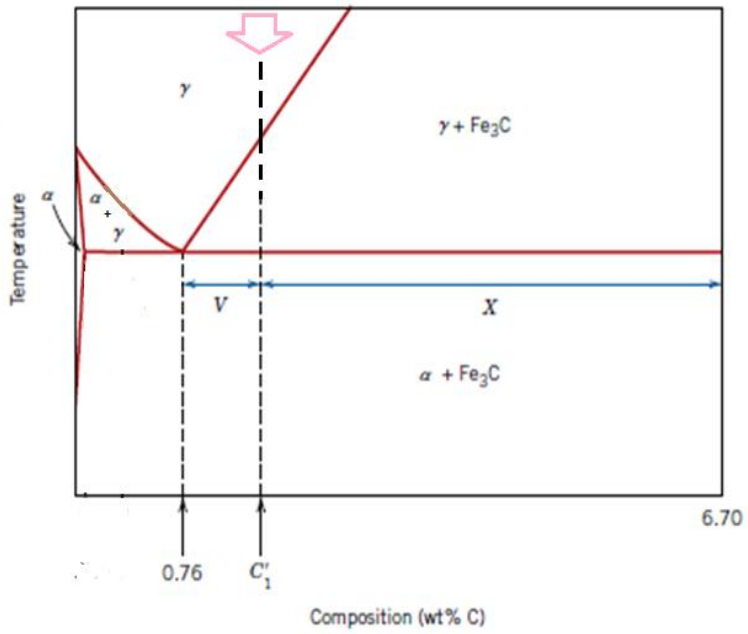


Figure 9.31 A portion of the Fe–Fe_3C phase diagram used in computing the relative amounts of proeutectoid and pearlite microconstituents for hypereutectoid C_1' composition .

Nonequilibrium Cooling

In this discussion of the microstructural development of iron–carbon alloys, it has been assumed that, upon cooling, conditions of metastable equilibrium[3] have been continuously maintained; that is, sufficient time has been allowed at each new temperature for any necessary adjustment in phase compositions and relative amounts as predicted from the Fe–Fe_3C phase diagram. In most situations these cooling rates are impractically slow and unnecessary; in fact, on many occasions nonequilibrium conditions are desirable. Two nonequilibrium effects of practical importance are (1) the occurrence of phase changes or transformations at temperatures other than those predicted by phase boundary lines on the phase diagram, and (2) the existence at room temperature of nonequilibrium phases that do not appear on the phase diagram.

9.20 THE INFLUENCE OF OTHER ALLOYING ELEMENTS

Additions of other alloying elements (Cr, Ni, Ti, etc.) bring about rather dramatic changes in the binary iron–iron carbide phase diagram, Figure 9.24. The extent of these alterations of the positions of phase boundaries and the shapes of the phase fields depends on the particular alloying element and its concentration. One of the important changes is the shift in position of the eutectoid with respect to temperature and carbon concentration. These effects are illustrated in Figures 9.34 and 9.35, which plot the eutectoid temperature and eutectoid composition (in wt% C), respectively, as a function of concentration for several other alloying elements. Thus, other alloy additions alter not only the temperature of the eutectoid reaction, but also the relative fractions of pearlite and the proeutectoid phase that form. Steels are normally alloyed for other reasons, however—usually either to improve their corrosion resistance or to render them amenable to heat treatment.

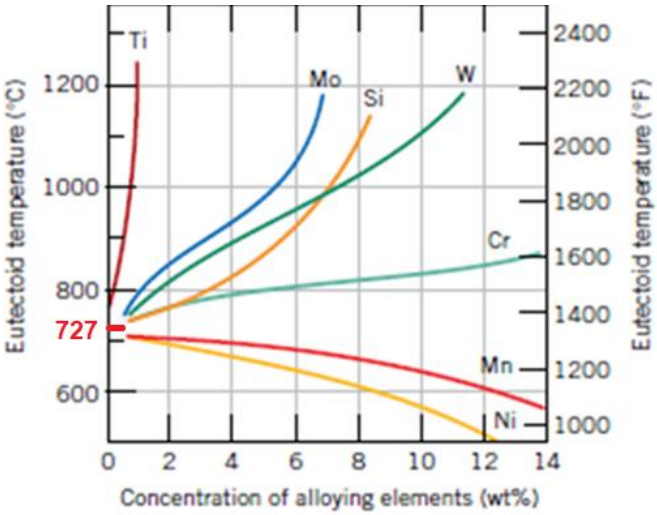


Figure 9.34 The dependence of eutectoid temperature on alloy concentration for several alloying elements in steel.

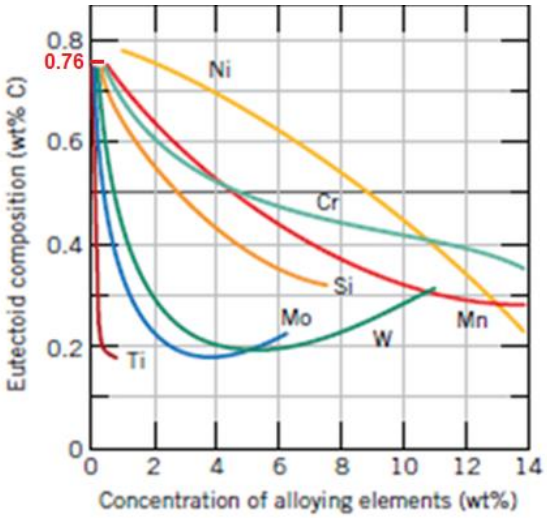


Figure 9.35 The dependence of eutectoid composition (wt% C) on alloy concentration for several alloying elements in steel.

EXAMPLE PROBLEM 9.4

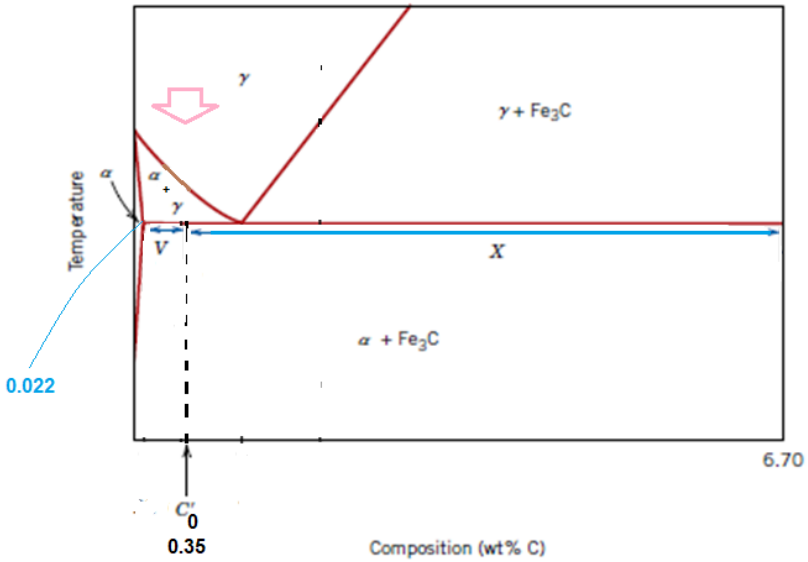
Determination of Relative Amounts of Ferrite, Cementite, and Pearlite Microconstituents

For a 99.65 wt% Fe–0.35 wt% C alloy at a temperature just below the eutectoid, determine the following:

(a) The fractions of total ferrite and cementite phases

(b) The fractions of the proeutectoid ferrite and pearlite

(c) The fraction of eutectoid ferrite



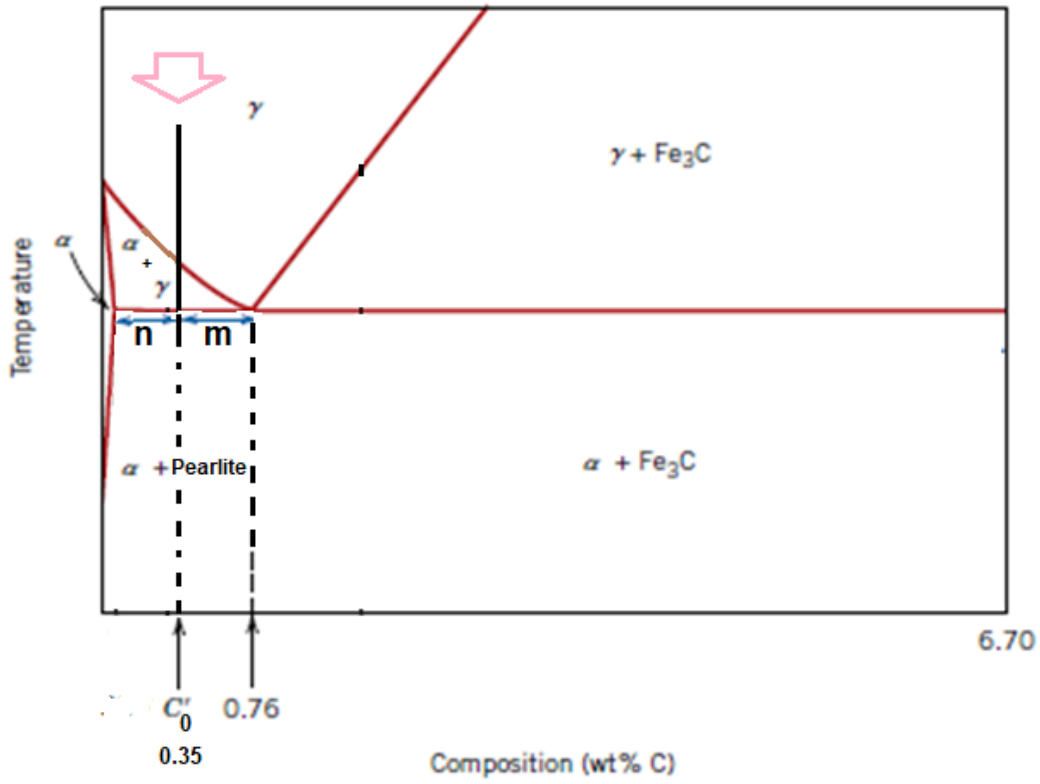
Solution

(a) This part of the problem is solved by applying the lever rule expressions using a tie line that extends all the way across the $\alpha + Fe_3C$ phase field. Thus, C_0' is 0.35 wt% C, and

x/v+x= $$W_\alpha = \frac{6.70 - 0.35}{6.70 - 0.022} = 0.95$$

and

v/v+x= $$W_{Fe_3C} = \frac{0.35 - 0.022}{6.70 - 0.022} = 0.05$$



(b) The fractions of proeutectoid ferrite and pearlite are determined by using the lever rule and a tie line that extends only to the eutectoid composition (i.e., Equations 9.20 and 9.21). We have

n/n+m= $$W_p = \frac{0.35 - 0.022}{0.76 - 0.022} = 0.44$$

and

m/n+m= $$W_{\alpha'} = \frac{0.76 - 0.35}{0.76 - 0.022} = 0.56$$

(c) All ferrite is either as proeutectoid ($W_{\alpha'}$) or eutectoid (in the pearlite) ($W_{\alpha e}$). Therefore, the sum of these two ferrite fractions equals the fraction of total ferrite; that is,

$$W_{\alpha'} + W_{\alpha e} = W_\alpha$$

where $W_{\alpha e}$ denotes the fraction of the total alloy that is eutectoid ferrite. Values for W_α and $W_{\alpha'}$ were determined in parts (a) and (b) as 0.95 and 0.56, respectively. Therefore,

$$W_{\alpha e} = W_\alpha - W_{\alpha'} = 0.95 - 0.56 = 0.39$$