Materials Science
The Iron- Iron Carbide Phase Equilibrium Diagram (Part 1)

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What is alloy and examples?

A metal alloy is a substance that combines more than one metal or mixes a metal with other non-metallic elements. The properties exhibited by alloys are often quite different from the properties of their individual components. Here are some of the most popular alloys and their applications.

Stainless Steel Alloys. Stainless steel is a corrosion-resistant alloy of Fe, Cr and, in some cases, Ni and other metals.

Copper Alloys like Cu- Zn, Cu-Sn, Cu-Be.

Nickel Alloys like Ni-Cu, Ni-Cr

Magnesium Alloys like Mg-Zn, Mg –Al

What do you mean by phases?

In the physical sciences, a phase is a region of space, throughout which all physical properties of a material are essentially uniform. The most familiar examples of phases are solids, liquids, and gases.

What is the simple meaning of chemical equilibrium?

Condition in the course of a reversible chemical reaction in which no net change in the amounts of reactants and products occurs. A reversible chemical reaction is one in which the products, as soon as they are formed, react to produce the original reactants.

What is equilibrium in a phase diagram?

The phase equilibrium diagram is a useful tool to visualize phase behaviour. Phase equilibrium is a theoretical condition where the liquids and vapours have reached certain pressure and temperature co

What is phase diagram in alloy system?

Phase diagrams are graphical representations of the phases present in a particular alloy being held at a particular temperature. Phase diagrams can be used to predict the phase changes that have occurred in an alloy that has been exposed to a particular heat treatment process.nditions at which they can separate.

9.18 THE IRON–IRON CARBIDE (Fe–Fe3C) PHASE DIAGRAM

A portion of the iron–carbon phase diagram is presented in Figure 9.24. Pure iron, upon heating, experiences two changes in crystal structure before it melts. At room temperature, the stable form, called ferrite, or α-iron, has a BCC crystal structure. Ferrite experiences a polymorphic (allotropic) transformation to FCC austenite, or γ-iron, at 912°C (1674°F). Austenite persists to 1394°C (2541°F), at which temperature the FCC austenite reverts back to a BCC phase known as δ-ferrite, which finally melts at 1538°C (2800°F). All these changes are apparent along the left vertical axis of the phase diagram.

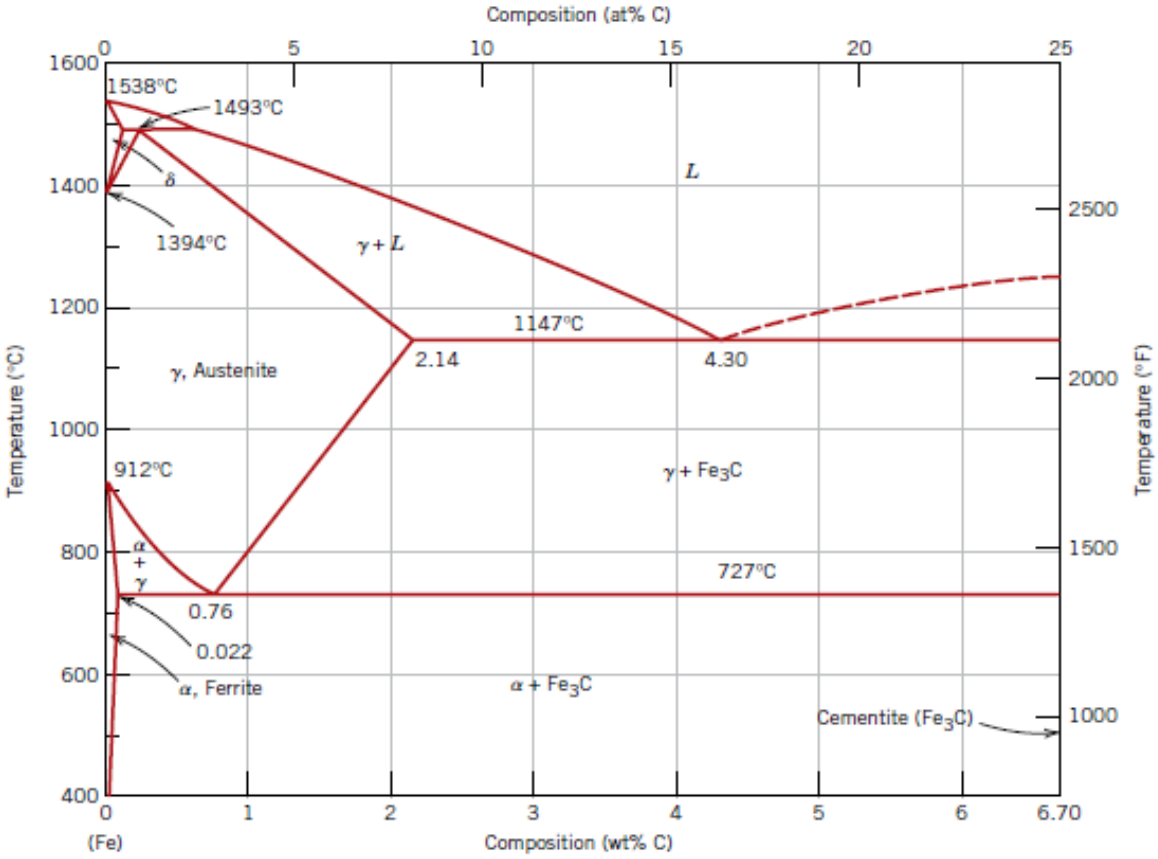


Figure 9.24 The iron–iron carbide phase diagram.

The composition axis in Figure 9.24 extends only to 6.70 wt% C; at this concentration the intermediate compound iron carbide, or cementite (Fe3C), is formed, which is represented by a vertical line on the phase diagram. Thus, the iron–carbon system may be divided into two parts: an iron-rich portion, as in Figure 9.24, and the other (not shown) for compositions between 6.70 and 100 wt% C (pure graphite). In practice, all steels and cast irons have carbon contents less than 6.70 wt% C; therefore, we consider only the iron–iron carbide system. Figure 9.24 would be more appropriately labelled the Fe–Fe3C phase diagram because Fe3C is now considered to be a component. Convention and convenience dictate that composition still be expressed in “wt% C” rather than “wt% Fe3C”; 6.70 wt% C corresponds to 100 wt% Fe3C.

The austenite, or γ phase, of iron, when alloyed with carbon alone, is not stable below 727°C (1341°F), as indicated in Figure 9.24. The maximum solubility of carbon in austenite, 2.14 wt%, occurs at 1147°C. This solubility is approximately 100 times greater than the maximum for BCC ferrite because the FCC octahedral sites are larger than the BCC tetrahedral sites, and, therefore, the strains imposed on the surrounding iron atoms are much lower. As the discussions that follow demonstrate, phase transformations involving austenite are very important in the heat treating of steels. In passing, it should be mentioned that austenite is nonmagnetic.

The δ-ferrite is virtually the same as α-ferrite, except for the range of temperatures over which each exists.

Cementite (Fe_3C) forms when the solubility limit of carbon in α-ferrite is exceeded below 727°C (1341°F) (for compositions within the $\alpha + Fe_3C$ phase region). As indicated in Figure 9.24, Fe_3C also coexists with the γ phase between 727°C and 1147°C (1341°F and 2097°F). Mechanically, cementite is very hard and brittle; the strength of some steels is greatly enhanced by its presence.

Strictly speaking, cementite is only metastable; that is, it remains as a compound indefinitely at room temperature. However, if heated to between 650°C and 700°C (1200°F and 1300°F) for several years, it gradually changes or transforms into α-iron and carbon, in the form of graphite, which remains upon subsequent cooling to room temperature. Thus, the phase diagram in Figure 9.24 is not a true equilibrium one because cementite is not an equilibrium compound. However, because the decomposition rate of cementite is extremely sluggish, virtually all the carbon in steel is as Fe_3C instead of graphite, and the iron–iron carbide phase diagram is, for all practical purposes, valid.

The two-phase regions are labeled in Figure 9.24. It may be noted that one eutectic exists for the iron–iron carbide system, at 4.30 wt% C and 1147°C (2097°F); for this eutectic reaction,

$$L \underset{\text{heating}}{\overset{\text{cooling}}{\rightleftharpoons}} \gamma + Fe_3C \qquad (9.18)$$

the liquid solidifies to form austenite and cementite phases. Subsequent cooling to room temperature promotes additional phase changes.

It may be noted that a eutectoid invariant point exists at a composition of 0.76 wt% C and a temperature of 727°C (1341°F). This eutectoid reaction may be represented by

$$\gamma(0.76\ \text{wt\% C}) \underset{\text{heating}}{\overset{\text{cooling}}{\rightleftharpoons}} \alpha(0.022\ \text{wt\% C}) + Fe_3C(6.7\ \text{wt\% C}) \qquad (9.19)$$

or, upon cooling, the solid γ phase is transformed into α-iron and cementite. The eutectoid phase changes described by Equation 9.19 are very important, being fundamental to the heat treatment of steels.

Definitions

Austenite: **solid solution of carbon and other constituents in γ(gamma) iron**. This is a face-centred cubic structure formed when iron is heated above 910° C (1,670° F); gamma iron becomes unstable at temperatures above 1,390° C (2,530° F).
The alpha phase is called ferrite.. It is a solid solution of carbon and other constituents in a particular form of iron known as α (alpha) iron Ferrite is a common constituent in steels and has a Body Centred Cubic (BCC) structure [which is less densely packed than FCC].
Cementite: Fe3C is called cementite
Pearlite is the "eutectic like" mixture of alpha+ cementite

Eutectoid reactions take place where a solid phase freezes into a mixture of two solid phases

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eutectic reactions take place where a liquid phase freezes into a mixture of two solid phases

Ferrous alloys are those in which iron is the prime component, but carbon as well as other alloying elements may be present. In the classification scheme of ferrous alloys based on carbon content, there are three types: iron, steel, and cast iron. Commercially pure iron contains less than 0.008 wt% C and, from the phase diagram, is composed almost exclusively of the ferrite phase at room temperature. The iron–carbon alloys that contain between 0.008 and 2.14 wt% C are classified as steels. In most steels, the microstructure consists of both α and Fe_3C phases. Upon cooling to room temperature, an alloy within this composition range must pass through at least a portion of the γ-phase field; distinctive microstructures are subsequently produced, as discussed shortly. Although a steel alloy may contain as much as 2.14 wt% C, in practice, carbon concentrations rarely exceed 1.0 wt%. Cast irons are classified as ferrous alloys that contain between 2.14 and 6.70 wt% C. However, commercial cast irons normally contain less than 4.5 wt% C.

DEVELOPMENT OF MICROSTRUCTURE IN IRON–CARBON ALLOYS

Several of the various microstructures that may be produced in steel alloys and their relationships to the iron–iron carbon phase diagram are now discussed, and it is shown that the microstructure that develops depends on both the carbon content and heat treatment. This discussion is confined to very slow cooling of steel alloys, in which equilibrium is continuously maintained. Phase changes that occur upon passing from the γ region into the $\alpha + Fe_3C$ phase field (Figure 9.24) are relatively complex
Consider, for example, an alloy of eutectoid composition (0.76 wt% C) as it is cooled from a temperature within the γ-phase region, say, 800°C—that is, beginning at point *a* in Figure 9.26 and moving down the vertical line *xx'*. Initially, the alloy is composed entirely of the austenite phase having a composition of 0.76 wt% C and corresponding microstructure, also indicated in Figure 9.26. As the alloy is cooled, no changes occur until the eutectoid temperature (727°C) is reached. Upon crossing this temperature to point *b*, the austenite transforms according to Equation 9.1[illegible].

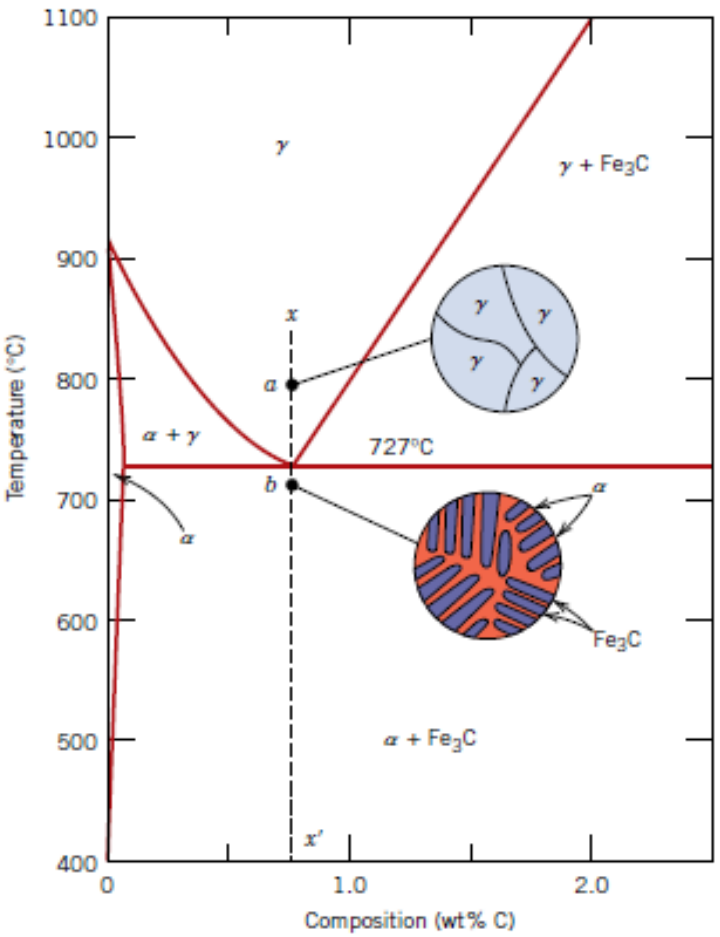


Figure 9.26 Schematic representations of the microstructures for an iron–carbon alloy of eutectoid composition (0.76 wt% C) above and below the eutectoid temperature.

The microstructure for this eutectoid steel that is slowly cooled through the eutectoid temperature consists of alternating layers or lamellae of the two phases (α and Fe_3C) that form simultaneously during the transformation. In this case, the relative layer thickness is approximately 8 to 1. This microstructure, represented schematically in Figure 9.26, point *b*, is called pearlite because it has the appearance of mother-of-pearl when viewed under the microscope at low magnifications. Figure 9.27 is a photomicrograph of a eutectoid steel showing the pearlite. The pearlite exists as grains, often termed colonies; within each colony the layers are oriented in essentially the same direction, which varies from one colony to another. The thick light layers are the ferrite phase, and the cementite phase appears as thin lamellae, most of which appear dark. Many cementite layers are so thin that adjacent phase boundaries are so close together that they are indistinguishable at this magnification and, therefore, appear dark. Mechanically, pearlite has properties intermediate between those of the soft, ductile ferrite and the hard, brittle cementite.

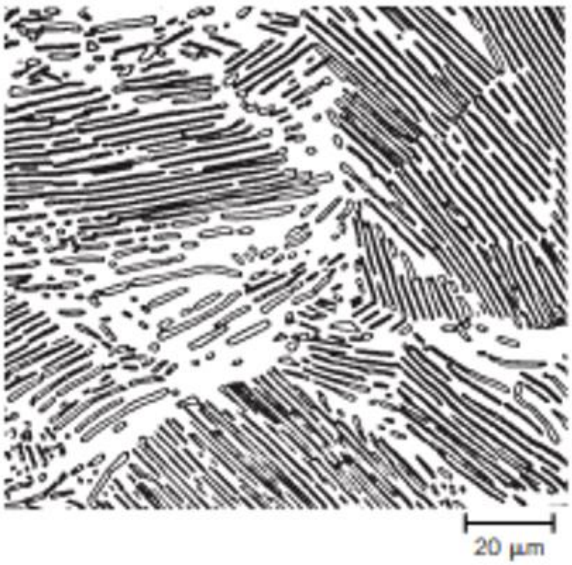


Figure 9.27 Photomicrograph of a eutectoid steel showing the pearlite microstructure consisting of alternating layers of α-ferrite (the light phase) and Fe_3C (thin layers most of which appear dark). 470×. (From *Metals Handbook*, Vol. 9, 9th edition, *Metallography and Microstructures*, 1985. Reproduced by permission of ASM International, Materials Park, OH.)

The composition of the parent phase [in this case, austenite (0.76 wt% C)]is different from that of either of the product phases [ferrite (0.022 wt% C) and cementite (6.70 wt% C)], and the phase transformation requires that there be a redistribution of the carbon by diffusion. Figure 9.28 illustrates microstructural changes that accompany this eutectoid reaction; here, the directions of carbon diffusion are indicated by arrows. Carbon atoms diffuse away from the 0.022-wt% ferrite regions and to the 6.70-wt% cementite layers, as the pearlite extends from the grain boundary into the unreacted austenite grain. The layered pearlite forms because carbon atoms need diffuse only minimal distances with the formation of this structure.

Subsequent cooling of the pearlite from point *b* in Figure 9.26 produces relatively insignificant microstructural changes.

Figure 9.28 Schematic representation of the formation of pearlite from austenite; direction of carbon diffusion indicated by arrows.

