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国外大学优秀教材——材料科学与工程系列（影印版）

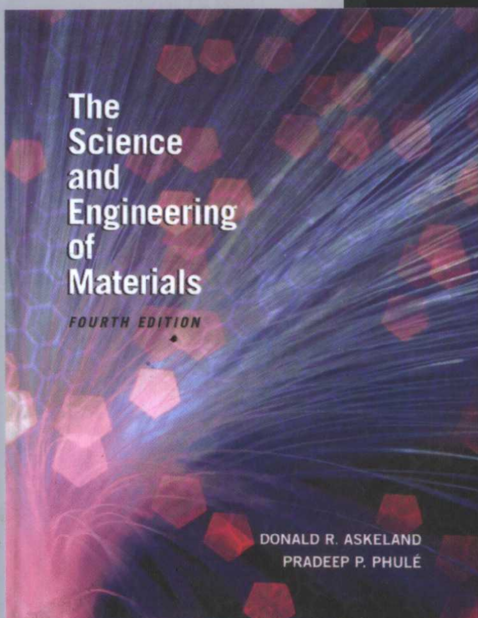
Donald R. Askeland, Pradeep P. Phulé

材料科学与工程（第4版）

The Science and Engineering of Materials

Fourth Edition

II



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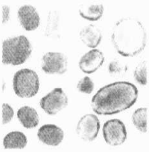

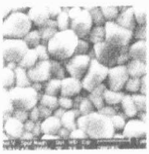

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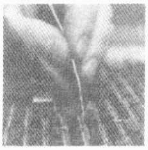

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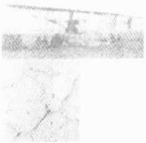

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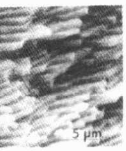

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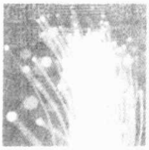

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PART 3

Engineering Materials

The mechanical properties of materials can be predicted and controlled by understanding the atomic bonding, atomic arrangement, and strengthening mechanisms discussed in the previous sections. This fact is particularly evident in Chapters 12 and 13, in which the ideas of solid solution strengthening, strain hardening, and dispersion strengthening are applied to the ferrous and nonferrous alloys.

The discussion of ceramics and polymers in Chapters 14 and 15 emphasizes the importance of atomic bonding and atomic arrangement. The mechanical properties of ceramics and polymers are explained in these chapters by mechanisms that do not involve dislocation movement.

Composite materials are even more difficult to categorize because of the many types and intended uses of the materials, as pointed out in Chapter 16. Many composites, are designed to provide special characteristics that go beyond conventional methods for controlling the structure-property relationship. Construction materials such as wood and concrete, described in Chapter 17, are special types of "composite" materials.

Frequently we find that complex parts and structures are composed of materials from several or even all of these groups. Each group has its own unique set of properties that best suit the individual application.

Chapter

Steels constitute the most widely used family of materials for structural, load-bearing applications. Most buildings, bridges, tools, automotives, and numerous other applications make use of ferrous alloys. With a range of heat treatments that can provide a wide assortment of microstructures and properties, steels are probably the most versatile family of engineered materials.

Gold is for the mistress—silver for the maid
Copper for the craftsman cunning at his trade.
"Good!" said the Baron, sitting in his hall,
"But Iron—Cold Iron—is master of them all!"

—Rudyard Kipling

(Courtesy of PhotoDisc/Getty Images.)

12

Ferrous Alloys

Have You Ever Wondered?

- *What is the most widely used engineered material?*
- *What makes stainless steels "stainless?"*
- *What is the difference between cast iron and steel?*
- *Are stainless steels magnetic?*
- *Is a tin can made out of tin?*
- *Is high-purity iron powder used as a supplement in breakfast cereals?*

Ferrous alloys, which are based on iron-carbon alloys, include plain-carbon steels, alloy and tool steels, stainless steels, and cast irons. These are the most widely used materials in the world. In the history of civilization, these materials made their mark by defining the *Iron Age*.[1] Steels typically are produced in two ways: by refining iron ore or by recycling scrap steel (Figure 12-1).

In producing primary steel, iron ore (processed to contain 50 to 70% iron oxide, Fe_2O_3 or Fe_3O_4) is heated in a *blast furnace* in the presence of coke (a form of carbon) and oxygen (Figure 12-1). Coke has a dual role: it is a fuel for

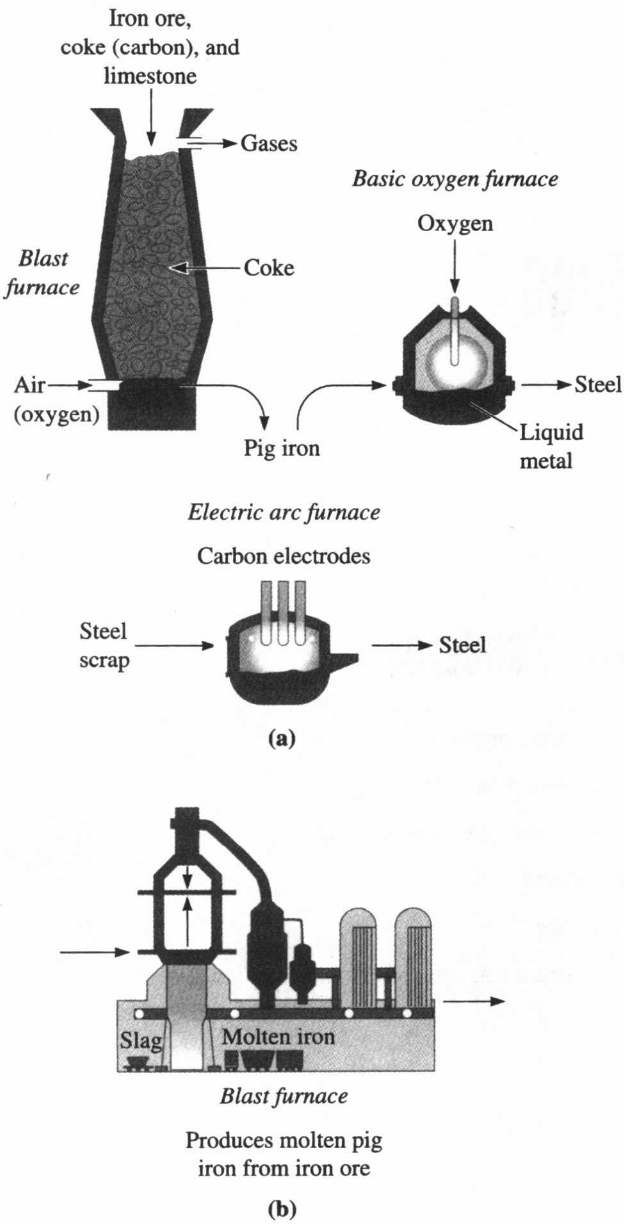

Figure 12-1 (a) In a blast furnace, iron ore is reduced using coke (carbon) and air to produce liquid pig iron. The high-carbon content in the pig iron is reduce by introducing oxygen into the basic oxygen furnace to produce liquid steel. An electric arc furnace can be used to produce liquid steel by melting scrap. (b) Schematic of a blast furnace operation. (*Source: www.steel.org. Used with permission of the American Iron and Steel Institute.*)

the blast furnace and it is also a reducing agent. The coke is burned using a blast of air (sometimes enriched with oxygen). The coke reduces the iron oxide into a crude molten iron known as **pig iron**. At about ~1600°C, this material contains about 95% iron; 4% carbon; 0.3 to 0.9% silicon; 0.5% Mn; and 0.025 to 0.05% of sulfur, phosphorus, and titanium. Carbon monoxide and carbon dioxide are produced as gaseous byproducts. Limestone ($CaCO_3$) is added as a fluxing agent to help remove impurities. The limestone decomposes and forms CaO. The calcium oxide forms eutectics with silica and other oxides contained as impurities in the ore concentrate, which help produce a molten **slag**. Slag is a byproduct of the blast furnace process. It contains silica, CaO, and other impurities in the form of a silicate melt.

Because the liquid pig iron contains a large amount of carbon, oxygen is blown into it in the *basic oxygen furnace* (BOF) to eliminate the excess carbon and produce liquid steel. Steel has a carbon content up to a maximum of ~2%. Steel processing occurs at a very large scale. About 300 tons of pig iron can be refined into molten steel in about 30 minutes! Steel is also produced by recycling steel scrap. The scrap is often melted in an **electric arc furnace** in which the heat of the arc melts the scrap. Many alloy and specialty steels, such as stainless steels, are produced using electric melting. Molten steels (including stainless steels) often undergo further refining using such processes as ladle refining, argon oxygen decarburization (AOD), and the like (Chapter 8). The goal here is to reduce the levels of impurities such as phosphorus, sulfur, etc. and to bring the carbon to a desired level. This basic process is used to oxidize impurities such as P, S, Si, Mn, etc. and eventually transfer them to the slag. The trick is not to oxidize the iron and other desirable alloying elements. For example, in stainless steel making, the goal is not to oxidize chromium and nickel, sending these expensive elements to slag. Thus, the oxidation of impurities has to be performed under controlled conditions. The steels refined this way are often described as *clean steels*.

Molten steel is poured into molds to produce finished steel castings; or cast continuously into shapes that are later processed through metal-forming techniques such as rolling or forging (Chapter 7). In the latter case, the steel is either poured into large ingot molds or is continuously cast into regular shapes.

All of the strengthening mechanisms discussed in the previous chapter apply to at least some of the ferrous alloys. In this chapter, we will discuss how to use the eutectoid reaction to control the structure and properties of steels through heat treatment and alloying. We will also examine two special classes of ferrous alloys: stainless steels and cast irons.

12-1 Designations and Classification of Steels

The dividing point between "steels" and "cast irons" is 2.11% C, where the eutectic reaction becomes possible. For steels, we concentrate on the eutectoid portion of the diagram (Figure 12-2) in which the solubility lines and the eutectoid isotherm are specially identified. The A_3 shows the temperature at which ferrite starts to form on cooling; the A_{cm} shows the temperature at which cementite starts to form; and the A_1 is the eutectoid temperature.