CHAPTER 4

WELDING METALLURGY

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CHAPTER 4

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INTRODUCTION

The various metallurgical phenomena involved in welding—melting, freezing, diffusion, precipitation, solid-state transformations, thermal strains, and shrinkage stresses—can cause many practical concerns. These problems can be addressed by applying the appropriate metallurgical principles to the welding process. Welding metallurgy differs from conventional metallurgy in certain important respects. However, a broad knowledge of physical metallurgy is necessary in order to understand welding metallurgy. For this reason, the topic of physical metallurgy is addressed first in this chapter. This discussion is followed by an examination of the specifics of welding metallurgy.

PHYSICAL METALLURGY

The field of physical metallurgy relates not only to the study of the structure of metals and their properties but also to the science and technology of the extraction of metals from their ores, their refining, and preparation for use (alloying, rolling, heat treating, and so forth). Considering that the field is so broad, the survey of physical metallurgy that follows is by no means exhaustive. Those who wish to increase their knowledge of the discipline or who are interested in specific subject matter or specialty materials are therefore directed to the resources cited in the Bibliography and Supplementary Reading List at the conclusion of this chapter and to other volumes of the *Welding Handbook*.

STRUCTURE OF METALS

Solid metals have a crystalline structure. The atoms composing each crystal are arranged in a specific geometric pattern. This orderly arrangement of the atoms, termed a *lattice*, is responsible for many properties of metals. The most common crystalline structures in metals are the face-centered cubic, body-centered cubic, and hexagonal close-packed lattices. The most common lattice structures found in metals are listed in Table 4.1. Their atomic arrangements are illustrated in Figure 4.1.

In the liquid state, the atoms composing metals have no orderly arrangement. The atoms are amorphous like water or glass. As the liquid metal approaches the solidification temperature, solid particles known as *nuclei* begin to form at preferred sites, as shown in Figure 4.2(A).

As shown in Figure 4.2(B), solidification proceeds as the individual nuclei grow into larger, solid particles called *grains*. As the amount of solid metal increases,

Table 4.1
Crystalline Structures of Common Metals

Face-Centered Cubic [see Figure 4.1(A)]	
Aluminum	Iron†
Cobalt*	Lead
Copper	Nickel
Gold	Silver
Body-Centered Cubic [see Figure 4.1(B)]	
Chromium	Titanium‡
Iron†	Tungsten
Molybdenum	Vanadium
Niobium	Zirconium‡
Hexagonal Close-Packed [see Figure 4.1(C)]	
Cobalt*	Titanium‡
Magnesium	Zinc
Tin	Zirconium‡

* Cobalt possesses a face-centered cubic structure at high temperature but transforms to a hexagonal close-packed structure at lower temperatures.
† Iron possesses body-centered cubic structure near the melting temperature and again at low temperatures, but at intermediate temperatures, its structure is face-centered cubic.
‡ Titanium and zirconium possess a body-centered cubic structure at high temperature, but a hexagonal close-packed structure at lower temperatures.