



普通高等教育“十三五”规划教材

PUTONG GAODENG JIAOYU “13·5” GUIHUA JIAOCAI

English for Professional Engineers

Materials Forming and Control Engineering

(Second Edition)

Xu Guang

Hu Haijiang

Pan Chenggang Yan Wenqing



冶金工业出版社
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内 容 提 要

本教材为高等院校材料成型与控制工程专业的专业英语教学用书,全书共15章,第1章介绍材料科学相关基础知识;第2章介绍金属材料强化机理等内容;第3~7章为轧制方面的内容,包括轧制的发展历史、轧机的分类、中厚板轧机、热带轧机以及最新的薄带双辊铸造技术等;第8章为铸造方面的内容,主要介绍金属铸造工艺;第9~11章为锻造、冲压和挤压方面的内容,包括金属材料锻造分类和设备、冲压成型方法、挤压分类及原理等;第12~15章为焊接方面的内容,包括焊接过程的分类、焊接原理、手工电弧焊技术及应用和气体保护焊技术及应用等;附录为钢铁材料领域学术论文实例。

本书既可作为高等院校材料成型与控制工程专业的专业英语教学用书,也可作为从事金属材料研究与生产的科技人员的参考书。

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第2版前言

随着我国高等院校专业调整,原有的轧制、铸造、模具、焊接等专业合并为一个新的本科专业——材料成型与控制工程专业。为了适应合并后的材料成型与控制工程专业英语的教学要求,我们编写了《English for Professional Engineers—Materials Forming and Control Engineering》。该书自出版以来,已被很多高校材料成型与控制工程专业教学采用。为了适应形势的发展和专业要求,作者对本书进行了修订,扩充了材料科学领域相关基础知识,其中包括晶格结构、晶系、材料强化和软化机制等,专业英语知识涉及面更为广泛、更为系统。附录给出了作者发表的几篇学术论文,供本专业研究生和工程技术人员撰写英文学术论文参考,也可以作为研究生专业文献阅读资料。

本书第1和2章、第6~8章由胡海江修订,第3~5章由徐光修订,第9~11章由潘成刚修订,第12~15章由闫文青修订,全书由徐光审定定稿。

本教材根据作者多年专业英语教学实践和经验编写而成,读者对象为高等院校材料成型与控制工程专业专科、本科生和研究生,以及本领域内工程技术与科研人员。

由于时间仓促,加之作者水平所限,书中不妥之处,恳请读者批评指正。

徐 光

2017年5月1日

第1版前言

随着我国高等院校专业调整,原有的轧制、铸造、模具、焊接等专业合并为一个新的本科专业——材料成型与控制工程专业。原有的上述各专业专业英语教材已不适应合并后专业的英语教学需求。为了适应合并后的材料成型与控制工程专业英语教学要求,我们编写了本教材。

本教材由武汉科技大学材料成型与控制工程系徐光教授、张诗昌副教授、潘成刚和闫文青讲师共同编著。本书共分16章,其中第1章~第6章由徐光编写,主要涉及轧制方面的内容;第7章~第9章由张诗昌编写,主要涉及铸造方面的内容;第10章~第12章由潘成刚编写,主要涉及其他金属塑性成型和模具方面的内容;第13章~第16章由闫文青编写,主要涉及焊接方面的内容。全书由徐光审定。

本教材是作者根据多年专业英语教学实践和经验编写而成,读者对象为高等院校材料成型与控制工程专业专科、本科生,以及研究生和本领域内工程技术人员。

由于作者水平所限,书中不妥之处在所难免,恳请专家和读者批评指正。

徐 光

2006年11月2日

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composition that may be achieved by stress in the solid state. Within this framework, the basic concepts of metallic crystals are introduced. For metallic crystalline solids, the nature of crystal structure is presented, expressed in terms of a unit cell. The three common crystal structures found in metals are then presented, along with the schemes by which crystallographic directions and planes are expressed.

1.2 Metallic Crystals Structures

The atomic bonding in a crystal is essentially metallic. Consequently, there are minimal energy barriers to the motion and position of atoms within a crystal. This leads to relatively large volumes of atomic migration and deformation, as well as the most metallic crystal structures. Also, the models, which are the first-order model for the crystal structure, each sphere represents an ion core. Table 1-1 presents the crystal structure of a number of metals. These relatively simple crystal structures are found in most of the elements, metals, alloys, and compounds. These structures are also the basis for the study of the properties of metals and alloys.

Table 1-1 Crystal structure and crystal structure for 10 metals

Metals	Crystal Structure	Atomic Radius (Å)	Metals	Crystal Structure	Atomic Radius (Å)
Aluminum	FCC	0.143	Gold	FCC	0.144
Copper	FCC	0.128	Iron	BCC	0.127
Lead	FCC	0.175	Nickel	FCC	0.125
Platinum	FCC	0.139	Silver	FCC	0.144
Steel	BCC	0.127	Titanium	HCP	0.142
Iron	BCC	0.127	Zinc	HCP	0.125
Lead	FCC	0.175			

FCC = face-centered cubic; BCC = body-centered cubic; HCP = hexagonal close-packed.

The atomic radius (Å) is the distance from the center of the atom to the edge of the atom. The atomic radius (Å) is the distance from the center of the atom to the edge of the atom.

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1 Basic Concepts of Metallic Materials

1.1 Introduction

The present part is devoted to the *microstructure*^① of materials, specifically, to some of the arrangements that may be assumed by atoms in the solid state. Within this framework, the basic concepts of *metallic crystal* are introduced. For metallic crystalline solids, the notion of crystal structure is presented, specified in terms of a unit cell. The three common crystal structures found in metals are then detailed, along with the scheme by which *crystallographic* directions and planes are expressed.

1.2 Metallic Crystals Structures

The atomic bonding in this group of materials is metallic. Consequently, there are minimal restrictions as to the number and position of nearest-neighbor atoms; this leads to relatively large numbers of nearest neighbors and dense atomic packings for most metallic crystal structures. Also, for metals, when we use the *hard-sphere model* for the crystal structure, each sphere represents an ion core. Table 1-1 presents the atomic *radii* for a number of metals. Three relatively simple crystal structures are found for most of the common metals: *face-centered cubic*, *body-centered cubic*, and *hexagonal close-packed*.

Table 1-1 Atomic radii and crystal structures for 16 metals

Metal	Crystal Structure ^①	Atomic Radius ^② /nm	Metal	Crystal Structure ^①	Atomic Radius ^② /nm
Aluminum	FCC	0.1431	Molybdenum	BCC	0.1363
Cadmium	HCP	0.1490	Nickel	FCC	0.1246
Chromium	BCC	0.1249	Platinum	FCC	0.1387
Cobalt	HCP	0.1253	Silver	FCC	0.1445
Copper	FCC	0.1278	Tantalum	BCC	0.1430
Gold	FCC	0.1442	Titanium(α)	HCP	0.1445
Iron(α)	BCC	0.1241	Tungsten	BCC	0.1371
Lead	FCC	0.1750	Zinc	HCP	0.1332

①FCC = face-centered cubic; HCP = hexagonal close-packed; BCC = body-centered cubic.

②A nanometer (nm) equals 10^{-9} m; to convert from nanometers to angstrom units ($\text{\AA}$), multiply the nanometer value by 10.

① The italic technical terms are translated into Chinese at the end of chapters.

1.2.1 The Face-centered Cubic Crystal Structure

The crystal structure found for many metals has a *unit cell* of cubic geometry, with atoms located at each of the corners and the centers of all the cube faces. It is called the face-centered cubic (FCC) crystal structure. Fig. 1-1(a) shows a hard-sphere model for the FCC unit cell, whereas in Fig. 1-1(b) the atom centers are represented by small circles to provide a better perspective on atom positions. The *aggregate* of atoms in Fig. 1-1(c) represents a section of crystal consisting of many FCC unit cells. These spheres or ion cores touch one another across a face *diagonal*; the *cube edge length* a and the atomic radius R are related through.

$$a = 2R\sqrt{2} \quad (1-1)$$

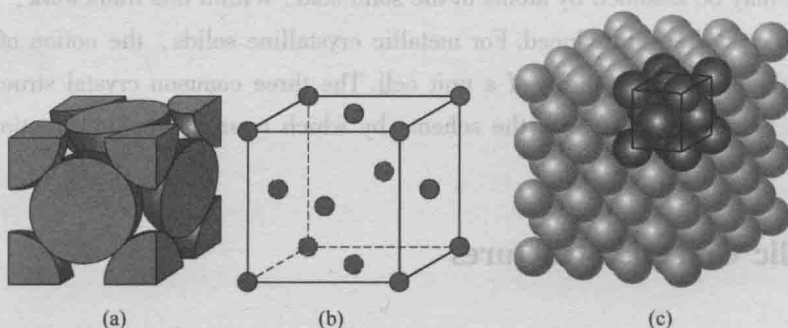


Fig. 1-1 For the face-centered cubic crystal structure, (a) a hard-sphere unit cell representation, (b) a reduced-sphere unit cell, and (c) an aggregate of many atoms

On occasion, we need to determine the number of atoms associated with each unit cell. Depending on an atom's location, it may be considered to be shared with adjacent unit cells, that is, only some fraction of the atom is assigned to a specific cell. For example, for cubic unit cells, an atom completely within the interior belongs to that unit cell, one at a cell face is shared with one other cell, and an atom located at a corner is shared among eight. The number of atoms per unit cell, N , can be calculated using the following formula:

$$N = N_i + \frac{N_f}{2} + \frac{N_c}{8} \quad (1-2)$$

Where

N_i = the number of interior atoms

N_f = the number of face atoms

N_c = the number of corner atoms

For the FCC crystal structure, there are eight corner atoms ($N_i=8$), six face atoms ($N_f=6$), and no interior atoms ($N_i=0$). Thus, from Eq. (1-2)

$$N = 0 + \frac{6}{2} + \frac{8}{8} = 4$$

so a total of four whole atoms may be assigned to a given unit cell. This can be described in Fig. 1-1(a), where only sphere portions are represented within the confines of the cube. The cell is

composed of the volume of the cube that is generated from the centers of the corner atoms, as shown in the figure.

Corner and face positions are really equivalent, that is, change of the cube corner from an original corner atom to the center of a face atom will not alter the cell structure. Two other important characteristics of a crystal structure are the *coordination number* and the *atomic packing factor* (APF). For metals, each atom has the same number of nearest-neighbor or touching atoms, which is the coordination number. For face-centered cubics, the coordination number is 12. This may be confirmed by examination of Fig. 1-1(a); the front face atom has four corner nearest-neighbor atoms surrounding it, four face atoms that are in contact from behind, and four other equivalent face atoms located in the next unit cell to the front (not shown).

The APF is the sum of the sphere volumes of all atoms within a unit cell (assuming the atomic hard-sphere model) divided by the unit cell volume, that is,

$$\text{APF} = \frac{\text{volume of atoms in a unit cell}}{\text{total unit cell volume}} \quad (1-3)$$

For the FCC structure, the atomic packing factor is 0.74, which is the maximum packing possible for spheres all having the same diameter.

1.2.2 The Body-centered Cubic Crystal Structure

Another common metallic crystal structure also has a cubic unit cell with atoms located at all eight corners and a single atom at the cube center. This is called a body-centered cubic (BCC) crystal structure. A collection of spheres depicting this crystal structure is shown in Fig. 1-2(c), whereas Fig. 1-2(a) and Fig. 1-2(b) are diagrams of BCC unit cells with the atoms represented by hard-sphere and *reduced-sphere models*, respectively. Center and corner atoms touch one another along cube diagonals, and unit cell length a and atomic radius R are related by

$$a = \frac{4R}{\sqrt{3}} \quad (1-4)$$

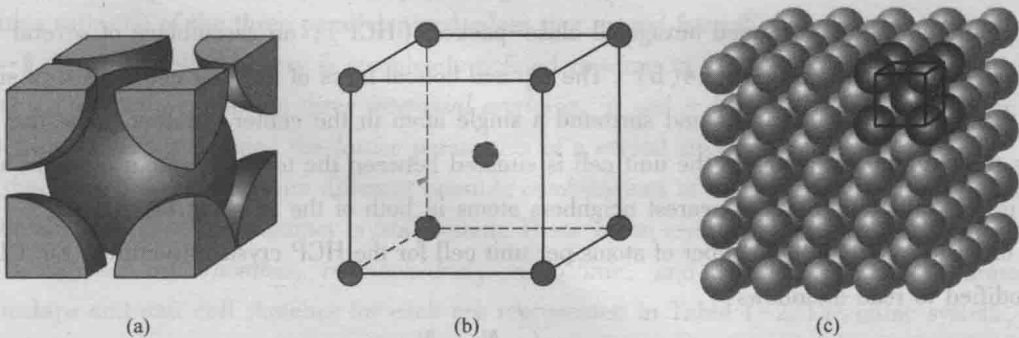


Fig. 1-2 For the body-centered cubic crystal structure, (a) a hard-sphere unit cell representation, (b) a reduced-sphere unit cell, and (c) an aggregate of many atoms

Chromium, iron, *tungsten*, and several other metals listed in Table 1-1 exhibit a BCC structure. Each BCC unit cell has eight corner atoms and a single center atom, which is contained

within its cell; therefore, from Eq. (1-2), the number of atoms per BCC unit cell is

$$N = N_i + \frac{N_f}{2} + \frac{N_c}{8} = 1 + 0 + \frac{8}{8} = 2$$

The coordination number for the BCC crystal structure is 8; each center atom has as nearest neighbors its eight corner atoms. Because the coordination number is less for BCC than for FCC, the atomic packing factor is also lower for BCC—0.68 versus 0.74.

It is also possible to have a unit cell that consists of atoms situated only at the corners of a cube. This is called the simple cubic (SC) crystal structure; hard-sphere and reduced-sphere models are shown, respectively, in Fig. 1-3 (a) and Fig. 1-3 (b). None of the metallic elements have this crystal structure because of its relatively low atomic packing factor. The only simple-cubic element is *polonium*, which is considered to be a *metalloid* (or semi-metal).

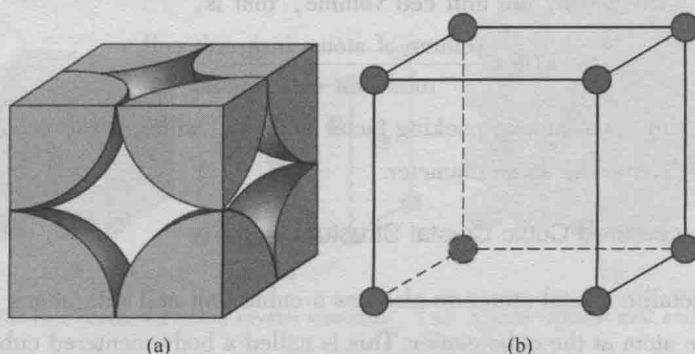


Fig. 1-3 For the simple cubic crystal structure, (a) a hard-sphere unit cell, and (b) a reduced-sphere unit cell

1.2.3 The Hexagonal Close-packed Crystal Structure

Not all metals have unit cells with cubic *symmetry*; the final common metallic crystal structure to be discussed has a unit cell that is hexagonal. Fig. 1-4(a) shows a reduced-sphere unit cell for this structure, which is termed hexagonal close-packed (HCP); an assemblage of several HCP unit cells is presented in Fig. 1-4(b). The top and bottom faces of the unit cell consist of six atoms that form regular hexagons and surround a single atom in the center. Another plane that provides three additional atoms to the unit cell is situated between the top and bottom planes. The atoms in this midplane have as nearest neighbors atoms in both of the adjacent two planes.

In order to calculate the number of atoms per unit cell for the HCP crystal structure, Eq. (1-2) is modified to read as follows:

$$N = N_i + \frac{N_f}{2} + \frac{N_c}{6} \quad (1-5)$$

That is, one-sixth of each corner atom is assigned to a unit cell (instead of 8 as with the cubic structure). Because for HCP there are 6 corner atoms in each of the top and bottom faces (for a total of 12 corner atoms), 2 face center atoms (one from each of the top and bottom faces), and

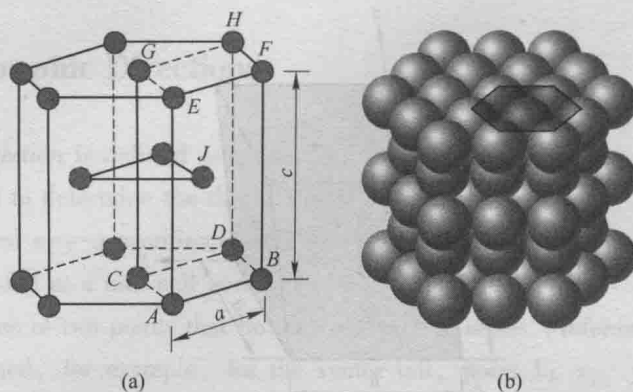


Fig. 1-4 For the hexagonal close-packed crystal structure, (a) a reduced-sphere unit cell

(a and c represent the short and long edge lengths, respectively), and (b) an aggregate of many atoms

3 midplane interior atoms, the value of N for HCP is found, using Eq. (1-5), to be

$$N = 3 + \frac{2}{2} + \frac{12}{6} = 6$$

Thus, 6 atoms are assigned to each unit cell.

If a and c represent, respectively, the short and long unit cell dimensions of Fig. 1-4(a), the c/a ratio should be 1.633; however, for some HCP metals, this ratio deviates from the ideal value. The coordination number and the atomic packing factor for the HCP crystal structure are the same as for FCC: 12 and 0.74, respectively.

1.3 Crystal Systems

Because there are many different possible crystal structures, it is sometimes convenient to divide them into groups according to unit cell configurations and/or atomic arrangements. One such scheme is based on the unit cell geometry, that is, the shape of the appropriate unit cell parallelepiped without regard to the atomic positions in the cell. Within this framework, an xyz coordinate system is established with its origin at one of the unit cell corners; each of the x , y , and z axes coincides with one of the three parallelepiped edges that extend from this corner, as illustrated in Fig. 1-5. The unit cell geometry is completely defined in terms of six parameters: the three edge lengths a , b , and c , and the three *interaxial angles* α , β and γ . These are indicated in Fig. 1-5, and are sometimes termed the *lattice parameters* of a crystal structure.

On this basis, there are seven different possible combinations of a , b , and c and α , β and γ , each of which represents a distinct crystal system. These seven crystal systems are cubic, *tetragonal*, hexagonal, *orthorhombic*, *rhombohedral*, *monoclinic*, and *triclinic*. The lattice parameter relationships and unit cell sketches for each are represented in Table 1-2. The cubic system, for which $a=b=c$ and $\alpha=\beta=\gamma=90^\circ$, has the greatest degree of symmetry. The least symmetry is displayed by the triclinic system, because $a \neq b \neq c$ and $\alpha \neq \beta \neq \gamma$.

From the discussion of metallic crystal structures, it is obvious that both FCC and BCC structures belong to the cubic crystal system, whereas HCP falls within the hexagonal system. The conventional hexagonal unit cell really consists of three parallelepipeds situated as shown in Table 1-2.

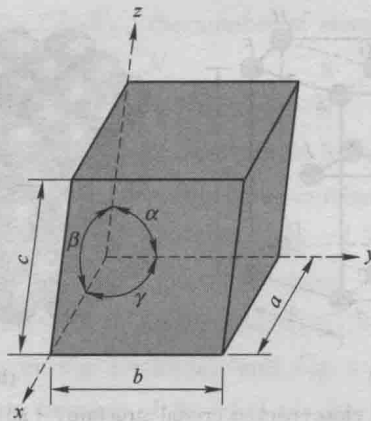


Fig. 1-5 A unit cell with x , y , and z coordinate axes, showing axial lengths (a , b , and c) and interaxial angles (α , β and γ)

Table 1-2 Lattice parameter relationships showing unit cell geometries for the seven crystal systems

Crystal System	Axial Relationships	Interaxial Angles	Unit Cell Geometry
Cubic	$a = b = c$	$\alpha = \beta = \gamma = 90^\circ$	
Hexagonal	$a = b \neq c$	$\alpha = \beta = 90^\circ, \gamma = 120^\circ$	
Tetragonal	$a = b \neq c$	$\alpha = \beta = \gamma = 90^\circ$	
Rhombohedral (Trigonal)	$a = b = c$	$\alpha = \beta = \gamma \neq 90^\circ$	
Orthorhombic	$a \neq b \neq c$	$\alpha = \beta = \gamma = 90^\circ$	
Monoclinic	$a \neq b \neq c$	$\alpha = \gamma = 90^\circ \neq \beta$	
Triclinic	$a \neq b \neq c$	$\alpha \neq \beta \neq \gamma \neq 90^\circ$	

1.4 Crystallographic Directions

A *crystallographic direction* is defined as a line directed between two points, or a vector. The following steps are used to determine the three directional *indices*:

(1) A right-handed x - y - z coordinate system is first constructed. As a matter of convenience, its origin may be located at a unit cell corner.

(2) The coordinates of two points that lie on the direction *vector* (referenced to the coordinate system) are determined, for example, for the vector tail, point 1: x_1 , y_1 , and z_1 ; whereas for the vector head, point 2: x_2 , y_2 , and z_2 .

(3) Tail point coordinates are subtracted from head point components, that is, $x_2 - x_1$, $y_2 - y_1$, and $z_2 - z_1$.

(4) These coordinate differences are then normalized in terms of (i. e., divided by) their respective a , b , and c lattice parameters—that is,

$$\frac{x_2 - x_1}{a}, \frac{y_2 - y_1}{b}, \frac{z_2 - z_1}{c}$$

which yields a set of three numbers.

(5) If necessary, these three numbers are multiplied or divided by a common factor to reduce them to the smallest *integer values*.

(6) The three resulting indices, not separated by commas, are enclosed in square brackets, thus: $[uvw]$. The u , v , and w integers correspond to the normalized coordinate differences referenced to the x , y , and z axes, respectively.

In summary, the u , v , and w indices may be determined using the following equations:

$$u = n \left(\frac{x_2 - x_1}{a} \right) \quad (1-6 \text{ (a)})$$

$$v = n \left(\frac{y_2 - y_1}{b} \right) \quad (1-6 \text{ (b)})$$

$$w = n \left(\frac{z_2 - z_1}{c} \right) \quad (1-6 \text{ (c)})$$

In these expressions, n is the factor that may be required to reduce u , v , and w to integers. For each of the three axes, there are both *positive and negative* coordinates. Thus, negative indices are also possible, which are represented by a bar over the appropriate index. For example, the $[\bar{1}\bar{1}1]$ direction has a component in the $-y$ direction. Also, changing the signs of all indices produces an *antiparallel* direction; that is, $[\bar{1}\bar{1}1]$ is directly opposite to $[\bar{1}\bar{1}\bar{1}]$. If more than one direction (or plane) is to be specified for a particular crystal structure, it is important for maintaining consistency that a positive-negative convention, once established, not be changed.

The $[100]$, $[110]$, and $[111]$ directions are common ones; they are drawn in the unit cell shown in Fig. 1-6.