应用型数控、模具专业基础课系列教材

机械制造专业英语

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机械制造专业英语

Technical English For Machine Manufacturing

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内 容 提 要

　　本书为高职高专教材,是根据"高职高专机械类专业人才培养目标及基本规格"的要求编写的。全书内容包括纯金属的结构、凝固机理、二相合金、钢及热处理、铸造生产、锻造、冲压和轧制、轴和联轴器、紧固件和弹簧、机械零件的强度、滚动轴承、机构机械设计基础、机械设计概论、材料选择、机床及机械加工、金属切削刀具、钻模与夹具、尺寸公差与表面粗糙度、质量与检测、计算机与制造业、计算机辅助编制工艺规程、数字控制、工业机器人及拉伸试验等方面的英文资料。

　　本书可作为高职、高专、成人高校及本科院校举办的二级职业技术学院机械类专业英语教材,也可作为从事机械设计和机械加工人员的阅读教材。

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Structure of Metals

1. Crystal Structure of Metals

Because they have relatively high densities, metals must consist of atoms which are packed very closely together. To a first approximation it is permissible to think of the atoms of a metal as hard, round spheres that exert attractive forces in all directions. Given a number of these hard-sphere atoms, how can they be arranged so as to be close-packed, i. e, so as to occupy a minimum volume? It is easiest to consider the two-dimensional case first. When a given number of atoms are fitted together in a hexagonal pattern like the cells of a honeycomb, they cover a minimum area. This pattern is shown in Fig. 1.1. It represents the closest possible packing of spheres on a flat sheet. To make a three-dimensional array of spheres occupying a minimum volume, it is necessary only to stack up the sheets shown in Fig. 1.1 in a certain way. In order to make these sheets fit together as closely as possible, it will be necessary to place the centers of the atoms of the second sheet over the holes between the atoms of the first sheet. In Fig. 1.2 the locations of the centers of the atoms of the second sheet are shown by crosses; note that only half the holes in the first sheet are covered by the atoms of the second sheet. The other set of holes, the ones not marked by crosses, could equally well be used for the atom centers of the second
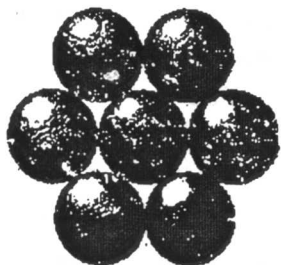
Fig. 1. 1 Packing of equal-sized spheres
on a single plane
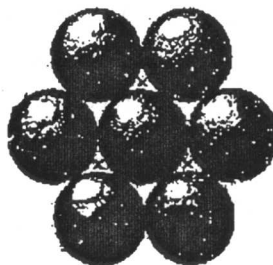
Fig. 1. 2 Location of the centers of
the atoms of the second layer

sheet. The atomic structure of the two layers would look just the same in either case.

The metal crystal that has been constructed by stacking up hard spheres is so far only two layers of atoms thick. A third layer introduces a slight complication because there are two different ways in which it can be added. One way is to put the centers of the atoms of the third layer over the holes of the first layer that are not marked by ✕'s. In order to describe this structure, let the first layer be called A, the second layer, with its atom centers at the ✕ positions, be called B, and the third layer, with its atom centers over the unmarked holes in A, be called C. The stacking sequence of close-packed layers is then ABC in this case.
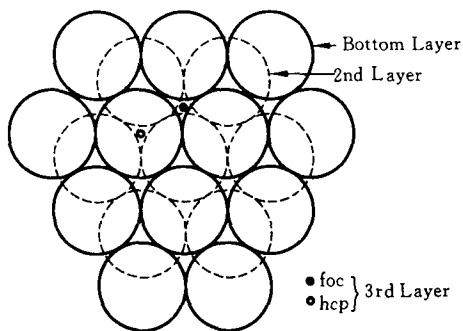
Fig. 1. 3   **Three-dimensional array of spheres**

The possible alternative positions for close-packed layers have been used up in this stack of three layers of atoms, but the fourth layer can be added in the A position again. In this way a sequence of layers ABCABCA···can be built up to any desired thickness. The result is a three-dimensional array of spheres packed as closely as possible. Fig. 1. 3 shows a plan view of this structure.

There is a second way in which the close-packed layers of Fig. 1. 1 can be stacked up to make a close-packed crystal. The first two layers are stacked as in Fig. 1. 2, but the third layer is now added so that it is directly over the first. This structure is obviously close-packed, like the one derived above, but the stacking sequence is ABABA ··· A great many metals are found to have either the ABCABCA···or the ABABA···type of close-packed structure. Some metals have more complicated structures; this will be described later.

2. Unit Cells

For many purposes it is convenient to think of the close-packed structures as stacks of close-packed layers according to the description given above. Sometimes, however, it is convenient to single out a small group of atoms in the stack and then describe the atom arrangement in this group. The group of atoms

chosen for this purpose is called a unit cell of the structure. One is at liberty to choose whatever unit cell he thinks will be useful.

Experience has shown that for each structure there is one cell which is most easily visualized and which best shows the symmetry of the atom arrangement. For the close-packed structure of the ABCABCA... type, the group of atoms forming the unit cell is shown in Fig. 1. 4(b). Note that the close-packed layers are in an inclined orientation in this drawing. Fig. 1. 4 (a) shows a schematic representation of the atoms in this structure. In this representation the cubic symmetry of the atomic arrangement is evident. Because of the arrangement of atoms in the unit cell, the ABCABCA... type of close-packed structure is given the name face-centered cubic structure (usually abbreviated fcc). Typical fcc metals are copper, aluminum, and nickel.

(a)   (b)
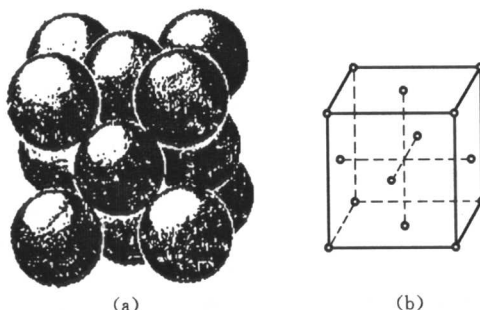
Fig. 1. 4   Unit cell of the FCC structure

The group of atoms forming the unit cell for the ABABA... type of structure is shown in Fig. 1. 5 (b). In this case the close-packed planes are horizontal and are easily recognized. The hexagonal symmetry of the atom arrangement can be seen from Fig. 1. 5 (a). The structure is called hexagonal

(a)   (b)
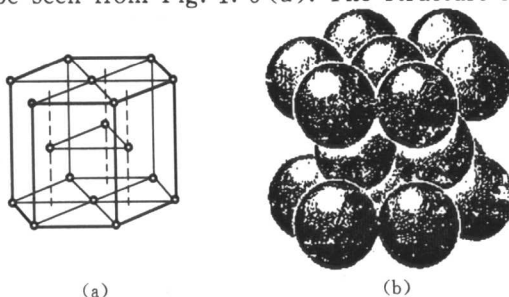
Fig. 1. 5   Unit cell of the HCP structure

close-packed(usually abbreviated hcp). Magnesium and zinc are examples of hcp metals.

3. Other Structures Found in Metals

If the hypothesis that the atoms of metals are hard, round spheres exerting attractive forces equally in all directions were true in all cases, then it would be expected that all metals would have either the FCC or the HCP structure. It is

(a)　　　　　　　　　(b)
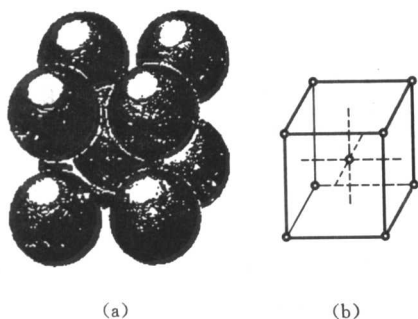
Fig. 1. 6　Unit cell of the BCC structure

known from the study of chemistry, however, that many atoms do not attract other atoms equally in all directions but tend to form bonds preferentially in certain directions. Some metal atoms behave in this way, and the resulting crystal structures are not close-packed. One structure which deviates only slightly from being close-packed is the body-centered cubic (BCC) one shown in Fig. 1. 6. Many of the important metals, including iron, chromium, and tungsten, have the BCC structure.

The structures of a number of metals deviate more markedly from close packing. Bismuth, antimony, and gallium have an atomic arrangement with the symmetry of a rhombohedron rather than that of a cube. These metals have so-called open structures, meaning that there is a substantial amount of empty space surrounding each atom, considered as a hard sphere. It is interesting in this connection that these metals decrease in volume when they melt, whereas most metals have a greater specific volume in the liquid state than in the solid state.

New Words

hexagonal *adj.* 六角形的,六边形的

honeycomb *n.* 蜂窝状物

crystal *n.* 结晶;晶粒

cell *n.* 晶胞

hypothesis *n.* (*pl.* -ses) 假设,假说

bismuth *n.* 铋

antimony *n.* 锑

(A) Lattice Parameters

The term lattice is frequently used in the description of crystal structures. A lattice is an array of points repeated regularly throughout space. If a point is placed at the center of each of the atoms in the FCC crystal structure, the array of points so generated is the FCC lattice. Lattices for the BCC and HCP structures can be generated in the same way.

One important characteristic of a metal is its lattice parameters, the dimensions of its unit cell. In the metals having cubic symmetry the size of the lattice is fixed when the length of the edge of the cubic unit cell is given. Cubic metals have therefore only one lattice parameter.

The lattice parameter of a metal can be measured by observing the diffraction of an X-ray beam passed through the metal. The results of such measurements are usually reported in angstroms, where $1A = 10^{-8}$cm. Typical values of the lattice parameters of cubic metals are 14.04 Å and Mo3.14 Å.

When the unit cell does not have cubic symmetry, more than one lattice parameter have to be specified. In hexagonal crystals these are, first, a, the distance between neighboring lattice points in the close-packed planes (or basal planes, as they are often called) and, second, c, the distance from the top to the bottom of the unit cell. If a hexagonal metal is truly close-packed, i.e. is made up of spherical atoms stacked ABABA... then the distances a and c must bear a fixed relation to each other. In fact the ratio $c/a = (8/3)^{1/2} = 1.633$ for perfect close packing. The forces between the atoms in most metals that crystallize in the hexagonal structure are such that there are usually slight deviations from ideal close packing. In zinc this deviation is unusually large, and the axial ratio c/a is 1.85.

(B) Density

If the lattice parameters of a metal and the mass of its individual atoms are

known (from measurements with a mass spectrometer or calculated as the atomic weight over Avogadro's number), it should be an easy matter to calculate its density. The first step in carrying out such a calculation is to find the number of atoms contained in a volume equal to that of the unit cell. In simple structures this number can be found by inspection: it is necessary only to imagine the unit cell displaced slightly so that it contains whole lattice points and then count the number of points in it. An alternative method , which does not tax the observer's three-dimensional visualization so much, is illustrated in the following examples: consider a BCC unit cell. Each of the corner atoms is shared between eight cells, and so the total number of atoms in the cell is

$$1 \text{ center atom} + 8 \times 1/8 \text{ corner atoms} = 2 \text{ atoms per unit cell}$$

For the FCC unit cell one finds in the same way that

$$6 \times 1/2 \text{ face atoms} + 8 \times 1/8 \text{ corner atoms} = 4 \text{ atoms per unit cell}$$

In order to find the density of a crystal , all that is necessary is to find the mass of all the atoms in the unit cell and then divided by the volume of the cell. For example, the density of iron, which is BCC, would be calculated in the following way:

$$\frac{2 \times 55.85}{6.025 \times 10^{23}} \div (2.861\ 0 \times 10^{-8})^3 = \text{density of iron}, \text{g/cm}^3$$

Since the atomic weight of iron is 55. 85 and the lattice parameter is 2. 861 0 A. The density so calculated is the density of a perfect iron crystal. The presence of imperfections in the crystal, such as voids, will make the measured density of the crystal less than that calculated. Thus density measurements can be used as a measure of crystal perfection.

New Words

lattice *n.* 晶格
symmetry *n.* 对称,匀称
density *n.* 密度
imperfection *n.* 不完全,不足

Lesson 2　Mechanism of Solidification

It is free energy that determines whether or not one phase is stable relative to another phase. Free energy per mole is defined as

$$F = E - TS$$

E is the internal energy of the phase, the amount of work which must be done to completely separate its atoms to infinity. The greater the cohesive forces between the atoms, the greater this work and the more negative the internal energy. In the second term in the above definition, T is the temperature and S the entropy, a measure of the amount of disorder in the arrangement of atoms in the phase. In a solid crystal, entropy arises primarily because of the thermal vibration of the atoms. In a liquid, where there is no regular atomic arrangement, the entropy is due both to vibration and to structural disorder.

Fig. 2.1 shows schematically the variation of the free energies of the solid and liquid phases of a metal with temperature. At $T = 0°K$, $F = E$, and the solid, because its interatomic cohesion is greater, has the lowest internal energy and hence the lowest free energy. Increasing the temperature increases the relative importance of the TS term and, since $S > 0$, causes the free energy to decrease. But the entropy of the liquid

Fig. 2.1　*F-T* curves

is greater than that of the solid, and so the free energy of the liquid phase decreases more rapidly than that of the solid as the temperature is raised. Consequently, the two free-energy curves must cross eventually, with liquid having the lower free energy at higher temperatures. The point where the two curves cross corresponds to the melting temperature.

Ideally, as a liquid metal is cooled, it should transform to solid as soon as it reaches the freezing point. Actually, this cannot happen unless, at essentially one instant of time, every atom in the melt transforms itself to its proper position in the solid crystal. Since the probability of all the atoms present making such
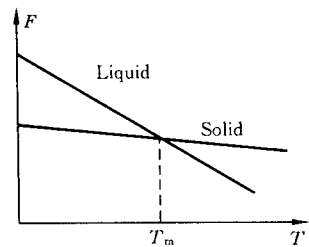
coordinated moves is negligible, solidification must start first in some localized region of the melt with the formation of a small particle of crystalline solid. As soon as such a piece of solid forms, however, a liquid-solid interface is created, an interface which has a definite energy per unit area and which increases the total free energy of the solid. As is the case at the freezing point, the free energies of the bulk liquid and solid are equal, the additional surface energy of the small particle of solid makes its total free energy greater than that of a corresponding mass of liquid and it is therefore unstable. If such a particle of solid were to form in the liquid at the freezing temperature, it would immediately be rediscovered. To get the solidification process started, the liquid phase must be under cooled, cooled to a temperature below the freezing point. Then, because the bulk of solid has a lower free energy than the corresponding amount of liquid, the surface energy of a small particle of solid will not raise its total free energy above that of the liquid——it is stable and can grow. The formation of particles of solid which can grow in the liquid is called nucleation, and the particles capable of growth are called nuclei.

　　There is an important relation between the size of nuclei and the amount of under cooling of the melt. A small particle has a relatively large amount of surface compared with its volume. This is easy to see for spherical particles where the surface-to-volume ratio is

$$\frac{S}{V} = \frac{4\pi r^2}{\frac{4}{3}\pi r^3} = \frac{3}{r}$$

　　In a small particle the surface energy is an important part of the total energy, but in a large particle, the surface area, and hence the surface energy, is relatively unimportant. With a small amount of under cooling, only large particles can become nuclei, whereas, with large under cooling, the particles can be much smaller and still be stable or grow. Because solid particles are formed by chance fluctuation in the liquid, the rate of nucleation is expected to be greater with the greater under cooling. With small under cooling one may have to wait some time for a particle large enough to be capable of growth to form by fluctuation , while with more under cooling the chance of formation of a nucleus is much greater.

　　Theory indicates that the amount of under cooling required to start the

solidification of metals is quite large. In laboratory experiments, liquid metals have been under cooled by amounts as great as a third of their melting temperatures. In practice, however, only a small amount of under cooling is found necessary to initiate solidification. This is because of the phenomenon of heterogeneous nucleation. The surfaces of foreign solid particles in the melt and of the container walls are sites where nuclei of the solid phase can form with a smaller increase in surface energy than in the bulk of liquid. The energy barrier to nucleation is therefore lower at these interfaces, and the probability of a nucleus forming at a given degree of under cooling is correspondingly greater. Homogeneous nucleation, nucleation in the bulk of pure melt, is not ordinarily observed unless special precautions are taken to suppress heterogeneous nucleation.

Once a nucleus is formed, it can proceed to grow as fast as the latent heat of solidification can be carried away. Thus the thermal conductivities, relative masses, and shapes of the melt, the solid, and the mold all influence the growth of the solid phase. The importance of the relative temperatures of the solid and liquid is illustrated by the phenomenon of dendritic growth. If there is a plane interface between solid and liquid, with the solid at a lower temperature than the liquid, then the flow of the latent heat released at the liquid-solid interface will be into the solid. On the other hand, a greatly under cooled liquid is cooler than the solid as a situation of instability obtains; if one part of the interface advances ahead of the rest, it grows into cool liquid and can more readily dissipate the latent heat of solidification. This allows it to grow even further, with the result that a small irregularity on the solid surface can rapidly grow out into a projecting spike. Such a growing spike may send out side branches, creating a network of solid fibers growing into the liquid. This is dendrite growth, and the individual spikes are the dendrites. It is shown in Fig. 2. 2.

Fig. 2. 2 Dendrites

A snowflake is an excellent example of a structure formed by dendritic growth, in this case of a solid from a vapor. (Of course, in this case, conduction along the dendrite of the seat of crystal formation is not a factor.) It is observed that in metals dendritic growth occurs in certain preferred directions, the (001)

direction for FCC and BCC and (0001) for HCP metals; these are the directions along the length of the dendritic arms.

Words and Expressions

entropy *n.* （物理学）熵

freezing point 冰点，凝冻点

crystalline *adj.* 水晶的，由水晶做成的；结晶的；*n.* 结晶质，结晶体

nucleation *n.* 成核现象；晶核过程，核子作用；集结

nuclei *n.* (*pl.* nucleus) 晶核

solidification *n.* 凝固；固化作用

fluctuation *n.* 波动，起伏，脉动

homogeneous *adj.* 同种的，同质的，同性的，相似的

heterogeneous *adj.* 异种的，异类的，异质的，不均匀的，多相的

thermal conductivity 导热性；导热系数

dendrite *n.* 枝状晶体

under cooling 过冷

Reading Material

Solidification of Pure Metals

Upon very slow cooling of melt, with all the metal maintained at a uniform temperature, solidification will start just below the freezing point. A few nuclei, distributed throughout the liquid, will form, and each will grow in all its preferred directions (as dendrites) to form a coarse, equiaxed grain structure. If the entire liquid cools uniformly but rapidly, undercooling will be greater and many more nuclei will originate in the melt, *producing a finer-grained equiaxed structure*. If one part of the liquid cools rapidly and another slowly (as in industrial casting processes where a hot liquid is in contact with an originally cool mold), nuclei will form only where under cooling is first attained, i. e. at the mold wall, and these nuclei will grow in the direction of the thermal gradient, giving elongated or columnar crystals. Later, the center , or hotter part, of the casing may reach the freezing temperature before columnar crystals have grown

into this section. Equiaxed grains may be found here.

In castings it is possible to have combinations of coarse and fine, columnar, and eqiaxed crystals. By controlling liquid and mold temperatures, thermal conductivities, and relative masses, it is possible to exercise considerable control of cast structures. Liquid-metal temperatures just above the freezing temperature mean that removal of a small amount of heat will be sufficient for heterogeneous nucleation of the solid crystals to start. Nuclei will form and grow first at the mold wall but seldom can grow extensively before heat flow has brought the next layer of liquid to the temperature for nucleation of the solid. Thus new nuclei will tend to form before the first crystals have grown to this zone. Therefore the tendency is for all grains to be equiaxed, with their size determined by the rate of heat removal, i.e. the temperature, mass, and thermal conductivity of the mold.

Considerable superheat of the liquid, i. e. a temperature well above its freezing point, inevitably means that steeper thermal gradients in the liquid metal are present. Thus, after the first nuclei form at the mold wall, they may be able to grow as fast as heat flows in the opposite direction. The hot liquid may not cool to the freezing temperature appreciably in advance of the growing crystals, and therefore no new nuclei can form. In this case, columnar grains are certain to form, but again their size will be determined by the rate of heat removal. It should be noted, though, that the long axis of the columnar grains will always be normal to the mold wall. In addition, since a crystal does not grow in all crystallographic directions at the same rate, favorably oriented nuclei grow faster, shutting off less favorably oriented crystals. Thus, there is a tendency for the axis of the columnar grain to be in the specific crystallographic directions of preferred growth. In the case of FCC crystals, (100) directions will be perpendicular to the mold wall, for example.

Sectioning, grinding, smooth, and deep etching of a cast metal will not only reveal grain size and shape but it will also often disclose voids. Unfortunately for illustrative purposes, but fortunately for their subsequent use, the small ingots of Fig. 2. 3 are free of these voids. They may originate from gas in solution in the liquid metal that is concentrated in the liquid during solidification and is evolved only when the concentration reaches a critical value. If the metal contained little gas, that point might be reached only in the final stages of solidification and might result in a few voids in the top center part or the part that is last to freeze.