

Materials have always been important to the advance of civilization (文明): entire eras (时代, 时期) are named for them. After evolving from the Stone Age through, the Bronze and Iron Ages, now in the modern era we have vast numbers of tailored materials to make use of. We are really living in the Materials Age.

材料对文明进步一直是重要的: 整个世纪用材料命名, 从石器时代到青铜时代再到铁器时代, 再到当今世纪, 我们利用了大量的定制材料。我们的确活在材料时代。

Work and study in the field of materials science and engineering is grounded (较好的) in an understanding of why materials behave the way they do, and encompasses (围绕) how materials are made and how new ones can be developed. For example, the way materials are processed is often important. People in the Iron Age discovered this when they learned that soft iron could be heated and then quickly cooled to make a material hard enough to plow (耕, 犁) the earth; and the same strategy is used today to make high-strength aluminum alloys for jet aircraft (喷气式飞机).

Today we demand more from our materials than mechanical strength, of course—electrical, optical (光学), and magnetic properties (磁性能), for example, are crucial (至关重要的) for many applications. As a result, modern materials science focuses on ceramics, polymers, and semiconductors, as well as on materials, such as metals and glasses, that have a long history of use.

在材料科学与工程领域的工作和研究是建立在对材料为什么能表现出这种行为、材料怎样被制造及材料如何被开发的理解的基础上。举个例子, 材料加工方式很重要。生活在铁器时代的人们发现了通过对软铁加热, 再快冷可以使材料足够硬以致于可以用来犁地。同样的方式在今天被用来制造喷气式飞机中的高强度铝合金。今天我们对材料的要求远不止力学性能, 当然还有电流、磁方面的性能, 这些性能对许多应用很重要。因此, 现代材料科学致力于研究陶瓷、高分子、半导体, 同样也研究像金属、玻璃之类具有悠久使用历史的材料。

Material science is the investigation of the relationship among processing (加工), structure, properties (性能), and performance (功能) of materials. The relationship is depicted with a tetrahedron of materials science and engineering as shown in Figure 1.1.

The discipline of materials science involves investigating the relationships that exist between the structures and properties of materials. In contrast, materials engineering is, on the basis of these structure-property correlations, designing or engineering the structure of a material to produce a predetermined (预订的) set of properties.

The structure of a material usually relates to the arrangement of its internal components (内部组成). Subatomic (亚原子) structure involves electrons within the individual atoms and interactions with their nuclei. On an atomic level, structure encompasses the organization of atoms or molecules (分子) relative to one another. The next larger structural realm (领域), which contains large groups of atoms that are normally agglomerated (聚集) together, is termed "microscopic", meaning that which is subject to direct observation using some type of microscope (显微镜). Finally, structural elements that may be viewed with the naked eye (肉眼) are termed "macroscopic".

Property is a material trait (特性) in terms of the kind and magnitude of response to a specific imposed stimulus. Generally, definitions of properties are made independent of material shape and size. Virtually (实质上) all important properties of solid materials may be grouped into six different categories (类): mechanical, electrical, thermal, magnetic, optical, and deteriorative (劣化). For each there is a characteristic type of stimulus capable of provoking (诱发) different responses.

In addition to structure and properties, two other important components are involved in the science and engineering of materials. They are "processing" and "performance." With regard to the relationships of these four components, the structure of a material will depend on how it is processed. Furthermore, a material's performance will be a function of its properties.1.1

材料科学和工程的含义

材料科学是研究材料的加工组织性能和功能之间关系的科学。他们之间的关系用材料科学与工程的一个四

面体形象表示，见图 1.1.

材料科学这门学科包括研究存在于材料组织和性能之间的关系。对比于材料科学，材料工程是在组织——性能关系的基础上，对材料的组织进行设计，以获得一系列预定的性能。

材料的组织通常指的是它内部组元的排列。亚原子结构包括个体原子内的电子和原子核相互作用。从原子尺度看，组织包括原子或分子之间的组织排列。下一级尺寸大一些的组织称为“显微组织”，由聚集在一起的大量原子构成，使用某种类型的显微镜可直接观察。最后，组织元素可以用肉眼观察到的组织被称为“宏观组织”。

材料的性质就是材料对某一具体的外加刺激的反映的形式和程度大小。通常，性质的定义和材料的形状、尺寸有关。实际上，固体材料的所有重要性质可以被分成六个不同种类：力学、电学、热学、磁学、光学和劣化。对于每一种性质，对应于某一特定刺激来诱发不同的反应。

除了组织和性质，材料科学与工程还包括另外两种重要组元，它们是加工和功能。就这四个组元间的关系而言，材料的组织将决定它如何被加工。此外，材料的功能是它的性质的函数。

Materials are classified (分为) into five groups: metals, ceramics (陶瓷), polymers (聚合体), semiconductors (半导体), and composite materials (合成材料). Materials in each of these groups possess different structures and properties. 1.2 材料分类

材料被分为五种：金属、陶瓷、高分子、半导体、复合材料。各个组别的材料具有不同的结构和性能。

Metals

Metals and alloys generally have the characteristics of good electrical and thermal conductivity, relatively high strength, high stiffness (刚度), ductility (韧性) or formability (可锻性), and shock resistance (抗冲击性). They are particularly useful for structural or load-bearing applications. Although pure metals are occasionally used, combinations of metals called alloys provide improvement in a particular desirable property or permit better combinations of properties. 金属

金属和合金具有良好的导电性、导热性，较高的强度和刚度，好的塑性和成形性，较高的抗击性能。在结构和承击载荷应用中具有特殊的用途。偶尔才使用纯金属，而把金属组合起来可以获得更好的性能组织，可以使需要的某一特定性能获得提高，这种金属组合成为合金。

Ceramics

Ceramics are compounds between metallic and nonmetallic elements; they are most frequently oxides (氧化物), nitrides (氮化物), and carbide (碳化物). The wide range of materials that falls within this classification includes ceramics that are composed of clay minerals (粘土), cement (水泥), and glass. These materials have poor electrical and thermal conductivity. Although ceramics may have good strength and hardness, their ductility, formability, and shock resistance are poor. Consequently, ceramics are less often used for structural or load-bearing applications than are metals. However, many ceramics have excellent resistance to high temperatures and certain corrosive media (腐蚀性介质) and have a number of unusual and desirable optical, electrical and thermal properties. 陶瓷

陶瓷是介于金属和非金属元素之间的一种化合物，绝大部分是氧化物、氮化物和碳化物。从广义上说，陶瓷由黏土矿物、水泥和玻璃组成。这些材料导电、导热性较差。尽管陶瓷可能具有高强度和高硬度，它们的塑性成形、性抗击性较差。所以，相比于金属，陶瓷在结构和承击载荷应用中较少使用。但是，许多陶瓷材料有非常的耐高温性、耐强酸腐蚀性，并有大量的非常特殊的光学、电学和热学性能。

Polymers

Polymers include rubber (橡胶), plastics (塑料), and many types of adhesives (粘合剂). They are produced by creating large molecular structures from organic (有机的) molecules, obtained from petroleum (石油) or agricultural products, in a process known as polymerization (聚合). Polymers have low electrical and thermal

conductivity, have low strengths, and are not suitable for use at high temperatures. Some polymers (thermoplastics 热塑塑料) have excellent ductility, formability, and shock resistance while others (thermosets 热固塑料) have the opposite properties. Polymers are lightweight and frequently have excellent resistance to corrosion. 高分子

高分子材料包括橡胶、塑料和一些种类的胶。他们是用从石油或农产品中获得的有机物分子通过一个称为聚合的工艺生成大分子结构而制造出来的。高分子材料具有低的导电性和导热性、低的强度，在高温下不适合使用。一些高分子材料（热塑性塑料）有很好的塑性、成形性和抗击性，而其他的高分子材料（热固性塑料）具有相反的性能。高分子材料是轻质的，并有相当好的耐腐蚀性。

Semiconductors

Semiconductors have electrical properties that are intermediate between the electrical conductors and insulators (绝缘体). Furthermore, the electrical characteristics of these materials are extremely sensitive to the presence of minute (微小的) concentrations of impurity atoms, which concentrations may be controlled over very small spatial regions. The semiconductors have made possible the advent of integrated circuitry (集成电路) that has totally revolutionized the electronics and computer industries. 半导体

半导体的导电性介于导体和绝缘体之间。此外，这些材料的电学性易受杂质元素浓度的影响，这个浓度可以被控制在一个很小的范围内。半导体使集成电路的出现成为可能，使电子和计算机工业有完全的改革。

Composites

Composites are formed from two or more materials, producing properties that cannot be obtained by any single material. Concrete (混凝土) and fiberglass (玻璃纤维) are typical examples of composite materials. A composite is designed to display a combination of the best characteristics of each of the component materials. With composites we can produce lightweight, strong, ductile, high temperature-resistant materials that are otherwise unobtainable, or produce hard yet shock-resistant cutting tools that would otherwise shatter (破碎). 复合物

复合物由两种或更多的材料组成，具有的性质是任一单一的材料不可能获得的。混凝土和玻璃纤维是典型的复合材料。将每一种组元材料最好的性能组合起来形成复合物，我们可以用复合材料生产轻质、强度高、塑性好、耐高温材料，否则靠单一材料无法获得。或者也可用复合材料生产硬的、抗击的刀具。否则用单种材料制造的刀具易破碎。

The structure of a material can be considered on several levels, all of which influence the final behavior of the product. At the finest level is the structure of the individual atoms that compose the material. The arrangement of the electrons surrounding the nucleus of the atom significantly affects electrical, magnetic, thermal, and optical behavior and may also influence corrosion resistance. Furthermore, the electronic arrangement influences how the atoms are bonded to one another and helps determine the type of material - metal, ceramic, or polymer.

At the next level, the arrangement of the atoms in space is considered. Metals, many ceramics, and some polymers have a very regular atomic arrangement, or crystal structure. The crystal structure influences the mechanical properties of metals such as ductility, strength, and shock resistance. Other ceramic materials and most polymers have no orderly atomic arrangement—these amorphous (无定形的, 非晶的) or glassy materials behave much differently from crystalline materials. For instance, glassy polyethylene (聚乙烯) is transparent while crystalline polyethylene is translucent (半透明的). Defects in this atomic arrangement exist and may be controlled to produce profound changes in properties.

A grain (晶粒) structure is found in most metals, some ceramics, and occasionally in polymers. Between the grains, the atomic arrangement changes its orientation and thus influences properties. The size and shape of the grains play a key role at this level.

Finally, in most materials, more than one phase (相) is present, with each phase having its unique atomic arrangement and properties. Control of the type, size, distribution and amount of these phases within the main body of the material provides an additional way to control properties.

1.3 材料结构

材料结构可以从很多方面认知,每一种最终将影响产品的表现行为。从最细微的水平看,各个原子的组织形成了材料。原子核周围的电子排列大大影响了材料的导电性、磁性、导热性和光学性,同时也可能影响其耐腐蚀性。此外,电子排布影响了原子间的组合,有助于区别金属、陶瓷、高分子材料。

再放大一点层次,考虑空间原子的排布。金属、许多陶瓷、一些高分子很有规律的原子排布或晶体结构。晶体结构会影响金属的力学性,诸如塑性强度和抗击性。一些陶瓷材料和大部分高分子没有规律的原子排列——这些非晶态或玻璃态的材料的表现不同于晶体材料。举个例子,玻璃态的聚乙烯是透明的,而晶态的聚乙烯是半透明的。原子排列存在缺陷,可加以控制以获得性能上深刻的改变。

在绝大部分金属、一些陶瓷和较少的高分子当中发现了晶粒组织、晶粒间的原子排布改变方向从而影响材料性能。晶粒的尺寸和形状起关键作用。

最后,在绝大部分材料中,不止存在一个相,每一个相都有其独特的原子排布和性能。通过对材料主体部分相的种类、尺寸、分布和数量的控制,可以控制材料的性能,提供一种新的方式。

1.3.1 Atomic-scale Structures

Atomic structure influences how the atoms are bonded together, which in turn helps us to categorize (分类) materials as metals, ceramics, and polymers and permits us to draw some general conclusions concerning the mechanical properties and physical behavior of these three classes of materials.

There are four mechanisms by which atoms are bonded together. In three of the four mechanisms, bonding is achieved when the atoms fill their outer s and p levels.

1.3.1 原子级的组织

原子组织影响原子间的结合,反过来帮助我们对材料进行分类,如金属、陶瓷和高分子使我们可以对这三种材料的力学性能和物理表现作出一些大概的结论。

原子结合有四种机制,其中三种结合机制通过原子外层 s 和 p 能级被充满来获得。

1.3.1.1 Ionic Bonding (离子键)

Ionic bonding is always found in compounds (化合物) that are composed of both metallic and nonmetallic elements, elements that are situated at the horizontal extremities of the periodic table (元素周期表每行最靠两端的元素). A metallic atom easily gives up its valence electrons (价电子) to the nonmetallic atom. Both atoms now have filled (or empty) outer energy levels but both have acquired an electrical charge and behave as ions. The atom that contributes the electrons is left with a net positive charge and is a cation (阳离子), while the atom that accepts the electrons acquires a net negative charge and is an anion (阴离子). The oppositely charged ions are then attracted to one another and produce the ionic bond. For example, attraction between sodium (钠) and chloride (氯) ions (Figure 1.2) produces sodium chloride (氯化钠).

1.3.1.1 离子键

离子键经常存在于由金属元素和非金属元素组成的化合物中。这些元素位于元素周期表每行最靠两端处。金属原子易将其价电子给非金属原子,使得两种原子的最外层电子充满(空),两者都需要电荷成为离子。提供电子的原子带正电荷而称为正离子,得到电子的原子带负电荷而成为负离子。这两种带相反电荷的离子相互吸引形成离子键。举例,钠离子和氯离子的结合生成氯化钠。

当对氯化钠晶体施加一外力,离子间的电荷平衡被打破。由于这个原因,离子键结合的材料表现出易裂的行为,其导电性也很差。通过所有离子的移动实现电荷转换,不像电荷移动那样容易,许多陶瓷材料和矿物至少部分以离子键结合。

1.3.1.2 Covalent Bonding (共价键)

Covalently bonded materials share electrons between two or more atoms. For example, a silicon (硅) atom,

which has a valence (化合价) of four, obtains eight electrons in its outer energy shell by sharing its electrons with four surrounding silicon atoms (Figure 1.3). Each instance of sharing represents one covalent bond; thus each silicon atom is bonded to four neighboring atoms by four covalent bonds.

1.3.1.2 共价键

以共价键结合的材料在两种或更多种原子间共享电子。比如，硅原子有四个价电子，在它的外层能量级上通过和其他四个硅原子共享电子而得到八个电子，每个共享电子过程形成一个共价键，所以每个硅原子通过四个共价键和它相邻的原子结合。

由于共价键的形成，硅原子必须以可以使每个共价键间有固定的方向的方式排列。就拿硅来说，它的排布形成一个四面体，共价键间形成 109° 角度。共价键很稳固，以这种键结合的材料塑性和导电性差；许多陶瓷和分子材料全部或部分以共价键结合。

1.3.1.3 Metallic Bonding (金属键)

The metallic elements, which have a low valence, give up their valence electrons to form a “sea” of electrons (电子云) surrounding the atoms (Figure 1.4). Since negatively charged electrons are missing from the core, the core becomes an ion with a positive charge. The valence electrons, which are no longer associated with any particular atom, move freely within the electron sea and become associated with several atom cores. The positively charged atom cores are held together by mutual attraction to the electron, thus producing the strong metallic bond.

金属键

化学价低的金属元素给出他们的价电子形成包围原子的电子云。由于带负电荷的电子离开原子核，使原子核变成一个带正电的例子。这些价电子由于不和任一热定的原子联合，所以可以在电子云中自由移动，和多个原子核联系。这些带正电的原子核通过电子间的相互作用结合在一起，形成强烈的金属键。

金属键没有方向性，将原子结合在一起的电子不固定于一个位置。当金属被弯曲时，原子试图改变它们之间的关系，只发生了键的方向振动，而不是断裂。这就使得金属有好的塑性，并可以被加工成许多有用的形状。

金属键也可以使金属成为良好的导体。在施加一定电压的影响下，如果电路是闭合的，那么价电子的移动会产生电流。其他结合机制如果使电子脱离结合键需要更高的电压。

1.3.1.4 Van de Waals Bonding (范德华键)

Van de Waals bonds join molecules or groups of atoms by weak electrostatic attractions. Many plastics, ceramics, water and other molecules are permanently polarized (极化); that is, some portions of the molecule tend to be positively charged, while other portions are negatively charged. The electrostatic attraction between the positively charged regions of one molecule and the negatively charged regions of a second molecule weakly bond the two molecules together. Van de Waals bonding is a secondary bond, and exists between virtually all atoms or molecules.

1.3.1.4

范德华键通过静电性力使分子或成群的原子结合在一起。许多塑料、陶瓷、水和其他分子是永久极化的，就是说，分子的某些部分倾向于带正电，而另外一些部分带负电。一个分子带正电的部分和另一个分子带负电的部分通过静电性力结合。范德华键是一种弱键，几乎存在于所有的原子或分子中。

1.3.2 Crystal Structures

Solid materials may be classified according to the regularity with which atoms or ions are arranged with respect to one another. A crystalline material is one in which the atoms are situated in a repeating or periodic array over large atomic distances. The atoms form a regular, repetitive gridlike pattern, or lattice*. The lattice is a collection of points, called lattice points, which are arranged in a periodic pattern so that the surroundings of each point in the

lattice are identical. ^ One or more atoms are associated with each lattice point. The lattice differs from material to material in both shape and size, depending on the size of the atoms and the type of bonding between the atoms. The crystal structure* of a material refers to the size, shape, and atomic arrangement within the lattice.

1.3.2 晶体结构

根据原子或离子相互间排列的规律可对固体材料分类。晶体材料的原子在较大的原子尺度范围内重复或周期性排列的。原子形成规律的、重复的栅栏结构或空间点阵（空间点阵就是点的结合，称点阵，阵点周期性排列，每个阵点周围相同）。一个或多个原子和阵点相互联系。不同材料的空间点阵的形状和大小不同，取决于材料的尺寸及原子间的结合方式。材料的晶体结构指的是点阵的大小、形状和原子排布。

1.3.2.1 IMCells

The unit cell is a subdivision of the lattice that still retains the overall characteristics of the entire lattice.1— By stacking identical unit cells, the entire lattice can be constructed. We identify 14 types of unit cells, or Bravais lattices, grouped in seven crystal structures (Figure 1.5). Lattice points are located at the corners of the unit cells and, in some cases, the faces or the center of the unit cell.

1.3.2.1 晶胞

晶胞就是保持整个空间点阵总体性质的最小单元。通过堆叠相同的晶胞，形成整个点阵。我们定义了 14 种点阵类型，或称布拉菲点阵，归属于 7 个晶系。阵点位于晶胞的各个角上，一些情况下，阵点位于晶胞的面上或体心。

1.3.2.2 Metallic Crystal Structures

The atomic bonding in this group of materials is metallic, and thus nondirectional in nature. Consequently, there are no restrictions as to the number and position of nearest-neighbor atoms; this leads to relatively large numbers of nearest neighbors and dense atomic packing for most metallic crystal structures. Three relatively simple crystal structures are found for most of the common metals: face-centered cubic, body-centered cubic, and hexagonal close-packed*. 这类材料的原子结合是离子键，本项上无方向性。所以，最近邻的原子的数目和位置没有限制，从而使得绝大部分金属晶体结构有大量的相互联系的近邻原子和密集的原子排布。三种简单的晶体结构存在于大部分金属中：面心立方、体心立方、密排六方结构。

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 (Figure 1.6). It is aptly called the face-centered cubic (FCC) crystal structure. Some of the familiar metals having this crystal structure are copper, aluminum, silver, and gold. 一些金属的晶体结构有一个几何立方的晶胞，原子排在立方晶胞的每个角和每个面上，称为面心立方结构。拥有这种结构的金属有铜、铝、银、金。

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 single atom at the cube center. This is called a body-centered cubic (BCC) crystal structure (Figure 1. 7). Chromium*, iron and tungsten exhibit a BCC structure. 原子排在立方晶胞的八个角上，1 个原子位于体心，称为体心立方结构，对应的金属有铬。

Hexagonal Close-packed Crystal Structure

A special form of the hexagonal lattice, the hexagonal close-packed (HCP) structure, is shown in Figure 1.8. The unit cell is the skewed* prism* outlined in the hexagonal lattice. The HCP metals include cadmium*, magnesium, titanium, and zinc. 密排六方结构比较特殊，晶胞是斜棱柱，相应的金属是镁、锌。

1.3.2.3 Directions and Planes in the Unit Cell

When dealing with crystalline materials, it often becomes necessary to specify some particular crystallographic

plane of atoms or a crystallographic direction. Labeling conventions have been established in which three integers or indices are used to designate directions and planes. ^ The basis for determining index values is the unit cell, with a coordinate system* consisting of three (x, y, and z) axes situated at one of the corners and coinciding with the unit cell edges.对于晶体类金属, 明确规定原子的晶面或晶向非常必要。建立了一种采用三个整数, 也成为指数来表示晶向和晶面的方法。以一个晶胞来研究晶体指数, 建立坐标系统 x,y,z 与晶胞边缘相对齐。

Directions in the Unit Cell

Certain directions in the unit cell are of particular importance. Metals deform, for example, in directions along which atoms are in closest contact. Properties of a material may depend on the direction in the crystal along which the property is measured. Miller indices for directions are the shorthand notation used to describe these directions. The procedure for finding the Miller indices for directions is as follows:晶胞的某些晶向很重要。比如, 金属沿原子紧密排布的方向变形。测定材料性能时可能会依赖于晶向。密勒指数就是形容晶向的一套所见的符号, 确定晶向指数的步骤如下所述:

- (a) Using a right-hand coordinate system, determine the coordinates of two points that lie on the direction.
 - (b) Subtract the coordinates of the "tail" point from the coordinates of the "head" point to obtain the number of lattice parameters traveled in the direction of each axis of the coordinate system.
 - (c) Clear fractions and/or reduce the results obtained from the subtraction to lowest integers.
 - (d) Enclose the numbers in square brackets []. If a negative sign is produced, represent the negative sign with a bar over the number.
- a)运用右手坐标系, 确定位于该方向上的亮点。
b)用重点的坐标减去起点的坐标, 以确定在每个坐标轴方向上亮点之间的坐标差是几个晶格常数。
c)去掉小数部分化为最小整数。
d)将数字放于【】中。如向晶向指标为负方向, 在晶向指数的数字上方写符号。

The [100], [110], and [111] directions are common ones; they are drawn in the unit cell shown in Figure 1.9.【100】、【110】、【111】是常见的晶向指数。

Planes in the Unit Cell

Certain planes of atoms in a crystal are also significant; for example, metals deform along planes of atoms that are most tightly together. Miller indices can be used as a shorthand notation to identify these important planes, as described in the following procedure.原子中的某些晶面指数也很重要。比如原子沿晶面上排布最紧密变形。可以用简化的密勒指数表示重要的晶面, 用一下步骤确定:

- (a) Identify the points at which the plane intercepts the x, y, and z coordinates in terms of the number of lattice parameters. If the plane passes through the origin, the origin of the coordinate system must be moved.
 - (b) Take reciprocals of these intercepts.
 - (c) Clear fractions but do not reduce to lowest integers.
 - (d) Enclose the resulting numbers in parentheses* (). Again, negative numbers should be written with a bar over the number.
- (a)定义晶面在 x,y,z 轴上拦截的晶格常数的数目, 如果晶面经过原点, 坐标系的原点需移动; (b)取截距倒数; (c)去掉小数部分, 但不需要化到最小整数; (d)将数字放于 () 中, 负截距则在相应指数上加负号。

1.3.3 Point Defects and Diffusion

1.3.3.1 Point Defects

Point defects are localized disruptions of the lattice involving one or possibly several atoms (Figure 1.10).

A vacancy* is produced when an atom is missing from a normal lattice point. Vacancies are introduced into the

crystal structure during solidification, at high temperatures, or as a consequence of radiation damage.

An interstitial defect is formed when an extra atom is inserted into the lattice structure at a site which is not a normal lattice point. A substitutional defect is introduced when an atom is replaced by a different type of atom. The substitutional atom remains at the original normal lattice point. Both interstitial and substitutional defects are present in materials as impurities and may also be intentionally introduced as number of these defects is usually independent of temperature.

点缺陷指的是点阵中一个或多个原子的缺损。原子从正常的点阵位置消失形成空位。固化、高温及辐射都可能产生空位。当额外原子挤入非正常点阵位置的间隙中就形成了间隙原子缺陷。当原子被不同原子替换时形成置换原子缺陷，置换原子仍在正常的阵点位置上。间隙原子和置换原子以杂质元素存在于材料中，也可能是人为添加的合金元素，缺陷的数量往往和温度有关。

Point defects disturb the perfect arrangement of the surrounding atoms. When a vacancy or a small Substitutional atom is present, the surrounding atoms collapse towards the point defect, stretching the bonds between the surrounding atoms and producing a tensile stress field. An interstitial or large Substitutional atom pushes the surrounding atoms together, producing a compressive stress field. In either case the effect is widespread. Intentional addition of interstitial and Substitutional atoms into the structure of a material forms the basis for solid solution strengthening* of materials.点缺陷破坏了周围原子排列的完整性。当存在空位或小的置换原子时，周围的原子会向点缺陷靠近，拉伸周围原子间的键，产生拉应力场。间隙原子或大的置换原子推挤周围原子产生应力场。任何一种情况产生的影响广泛扩散。人为地添加间隙原子或置换原子形成固溶强化。

1.3.3.2 Diffusion

Diffusion is the movement of atoms within a material. Atoms move in an orderly fashion to eliminate concentration differences and produce a homogeneous uniform composition. Movement of atoms is required for many of the treatments that we perform on materials. Diffusion is required for the heat treatment of metals, the manufacture of ceramics, the solidification of materials, the manufacture of transistors and solar cells*, and even the electrical conductivity of many ceramic materials.

1.3.3.3 Diffusion Mechanisms *

From an atomic perspective, diffusion is just the stepwise migration of atoms from lattice site to lattice site. In fact, the atoms in solid materials are in constant motion, rapidly changing positions. For an atom to make such a move, two conditions must be met: (1) there must be an empty adjacent site, and (2) the atom must have sufficient energy to break bonds with its neighbor atoms and then cause some lattice distortion during the displacement. This energy is vibrational in nature. At a specific temperature some small fraction of the total number of atoms is capable of diffusive motion, by virtue of the magnitudes of their vibrational energies. This fraction increases with rising temperature.

Several different models for this atomic motion have been proposed; of these possibilities, two dominate for metallic diffusion.

Vacancy diffusion. In self-diffusion and diffusion involving substitutional atoms, an atom leaves its lattice site to fill a nearby vacancy (thus creating a new vacancy at the original lattice site). As diffusion continues, we have a countercurrent flow of atoms and vacancies. This mechanism is shown in Figure 1.11.

Interstitial diffusion. When a small interstitial atom is present in the crystal structure, the atom moves from one interstitial site to another. No vacancies are required for this mechanism to work. This mechanism is shown in Figure 1.12.

1.3.3.4 Rate of Diffusion (Fick's First Law)

The rate at which atoms diffuse in a material can be measured by the flux J , which is defined as the number of

atoms passing through a plane of unit area per unit time. Fick's first law explains the net flux of atoms,

$$J = -D \frac{dc}{dx} \quad (1.1)$$

where J is the flux [atoms ($m^2 \cdot s$)⁻¹], D is the diffusivity or diffusion coefficient ($m^2 \cdot s^{-1}$), and dc/dx is the concentration gradient [atoms (m^{-1})⁻¹].

1.3.4 Linear and Planar Defects

1.3.4.1 Dislocations*—Linear Defects

Dislocations are line imperfections in an otherwise perfect lattice. We can identify two types of dislocations - the screw dislocation* and the edge dislocation*. The screw dislocation (Figure 1. 13) can be illustrated by cutting partway through a perfect crystal, then skewing the crystal one atom spacing. If we were to follow a crystallographic plane one revolution around the axis on which the crystal was skewed, traveling equal atom spacings in each direction, we would finish one atom spacing below our starting point. The vector required to complete the loop and return us to our starting point is the Burgers vector*. A. If we continued our rotation, we would trace out a spiral path. The axis, or line, around which we trace out this path is the screw dislocation. We see that the Burgers vector is parallel to the screw dislocation. An edge dislocation (Figure 1.14) can be illustrated by slicing partway through a perfect crystal, spreading the crystal apart, and partly filling the cut with an extra plane of atoms. The bottom edge of the inserted plane represents the edge dislocation. If we describe a clockwise loop around the edge dislocation by going an equal number of atom spacings in each direction, we would finish one atom spacing from our starting point. The vector that is required to complete the loop is again the Burgers vector. In this case, the Burgers vector is perpendicular to the edge dislocation.位错就是完整晶格中的线缺陷，将晶体扭曲-原子间距，我们将位错分为两种-螺形位错和刃型位错。螺形位错可以表示为在一个完整点阵中剪切，【1】回到起点，形成一闭合回路的这一矢量称为柏氏矢量 b 。如果我们继续旋转，将描出一条螺旋状轨道。该轨道环绕的轴或线就是螺旋位错。螺形位错的柏氏矢量与其位错线相平行，刃型位错可以表示在一个完整点阵中切开，将点阵分开，加入一额外原子面，原子平面中断处的边缘就是一个刃型位错。如果我们绕着刃型位错顺时针走一周，每个方向行走相同的晶格数的话，终点会回到起点处，形成闭合回路的这一矢量仍是柏氏矢量，刃型位错的柏氏矢量垂直于其位错线。

Grain Boundaries

The microstructure of metals and many other solid materials consists of many grains. A grain is a portion of the material within which the arrangement, or crystal structure, is different for each adjoining grain. A grain boundary* is the surface that separates the individual grains and is a narrow zone in which the atoms are not properly spaced. A grain boundary is represented schematically from an atomic perspective in Figure 1. 15. "Within the grain boundary region, which is probably just several atom distances wide, there is some atomic mismatch in a transition from the crystalline orientation of one grain to that of an adjacent one.金属和其他许多固体材料的微观结构包括许多晶粒，相邻晶粒间的排列，晶粒结构的不同。晶界是将晶粒分隔开的一表面，是原子排布不规律的一狭窄区域。图 1.15 显示了原子层面的晶界【2】

Various degrees of crystallographic misalignment between adjacent grains are possible. When this orientation mismatch is slight, on the order of a few degrees, then the term small - (or low -) angle grain boundary is used. These boundaries can be described in terms of dislocation arrays. One simple small-angle grain boundary is formed when edge dislocations are aligned in the manner of Figure 1.16. This type is called a tilt boundary*. ③相邻晶粒间存在位向差，如果错排程度小，只有几度，称为小角度晶界。这些晶界可以用位错阵列来形容。小角度晶界轴对称的刃型位错构成。见图 1.16，称为倾侧晶界

Twin Boundaries*

A twin boundary is a plane

across which there is a special mirror image relationship of the lattice structure (Figure 1.17). Twins can be

produced when a shear force, acting along the twin boundary, causes the atoms to shift out of position. Twinning occurs during deformation or heat treatment of certain metals. The twin boundaries increase the strength of the metal④孪晶界就是跨过一个镜面对称的点阵结构的面。在孪晶界，施加一剪切力使原子脱离其原位可以形成孪晶。在一些金属的成形或热处理过程中产生孪晶性，孪晶界的存在可以提高金属的强度。

1.3.5 Non-crystalline* Materials

Non-crystalline solids lack a systematic and regular arrangement of atoms over relatively large atomic distances. Sometimes such materials are also called amorphous, or supercooled liquids, inasmuch as their atomic structure resembles that of a liquid. An amorphous condition may be illustrated by comparison of the crystalline and non-crystalline structures of the ceramic compound silicon dioxide (SiO_2), which may exist in both states. Figure 1.18 (a) and 1.18 (b) present two-dimensional schematic diagrams for both structures of SiO_2 , in which the SiO_4 tetrahedron is the basic unit. Even though each silicon ion bonds to four oxygen ions for both states, beyond this, the structure is much more disordered and irregular for the non-crystalline structure. Whether a crystalline or amorphous solid forms depends on the ease with which a random atomic structure in the liquid can transform to an ordered state during solidification. Amorphous materials, therefore, are characterized by atomic or molecular structures that are relatively complex and become ordered only with some difficulty. Furthermore, rapidly cooling through the freezing temperature favors the formation of a non-crystalline solid, since little time is allowed for the ordering process. Metals normally form crystalline solids; but some ceramic materials are crystalline, whereas others are amorphous. Polymers may be completely non-crystalline and semi-crystalline consisting of varying degrees of crystallinity*. 非晶金属

①在相当大的原子距离内，非晶固体的原子排布缺乏条理性 and 规律性。有时这些材料由于结构类似于液体也被称为不定型的或过冷液体。通过晶体 SiO_2 和非晶体 SiO_2 的比较，两者可能都存在不定型的情况。图 1.15 (a) (b) 展示了两种 SiO_2 结构的尺寸图，其中四面体 SiO_4 是基本组成单元。不管两种结构中，Si 和四个 O 结合，非晶结构的 SiO_2 的结构更加无序。【1】非晶材料的原子或分子结构复杂，达到有序状态较困难。此外，凝固温度下的快冷有助于形成非晶固体。金属通常是晶体固体，但一些陶瓷材料是晶体的，而另一些则不是。由于没有足够的排序时间聚合物可能是包含不同结晶度的非晶体或部分晶体。

When describing the structure of a material, we make a clear distinction between its crystal structure and its microstructure. The term “crystal structure” is used to describe the average positions of atoms within the unit cell (晶胞), and is completely specified by the lattice type (点阵类型) and the fractional coordinates (相对坐标) of the atoms. In other words, the crystal structure describes the appearance of the material on an atomic length scale. The term “microstructure” is used to describe the appearance of the material on the nm-cm length scale. A reasonable working definition of microstructure is “the arrangement of phases (相) and defects (缺陷) within a material.”

Many times, the physical properties and, in particular, the mechanical behavior of a material depend on the microstructure. Microstructure is subject to direct microscopic observation, using optical or electron microscopes. In many alloys, microstructure is characterized by the number of phases present, their proportions, and the manner in which they are distributed or arranged. The microstructure of an alloy depends on such variables as the alloying elements present, their concentration, and the heat treatment of the alloy.

1.3.6 微观结构

①当描述一种材料的结构时，我们会对他的晶体结构和微观结构划分明确。晶体结构用来形容晶胞中原子的平均位置【1】也可以说晶体结构从原子水平描绘了材料的形状，而微观结构从 nm-cm 水平描绘了材料，微观组织的明确定义是“相的组成和材料内部缺陷”

②很多情形下，材料的物理性能，尤其是力学性能依赖于微观结构，通过使用光学或电子显微镜，可以直

接观察到显微组织。在许多合金中，通过相的数目，比例及排布方式来划分显微组织。合金的显微组织和合金元素的可变性，浓度及热处理方式有关。

1.3.6.1 Phase Diagrams (相图)

Much of the information about the control of microstructure or phase structure of a particular alloy system is conveniently and concisely displayed in what is called a phase diagram, also often termed an equilibrium or constitutional diagram. Many microstructures develop from phase transformation, the changes that occur between phases when the temperature is altered (ordinarily upon cooling). This may involve the transition from one phase to another, or the appearance or disappearance of a phase. Phase diagrams are helpful in predicting phase transformations and the resulting microstructures, which may have equilibrium or nonequilibrium character.

1.3.6.1 相图

①能方便简明的描述一种特定合金的显微组织或相结构的控制因素的图叫做相图，也称为平衡相图。相变过程中微观结构会改变，随着温度变化，相与相之间也会产生变化，包括相与相之间的转变或相的出现与消失，相图便于预测相变，推断出最终显微组织的平衡或非平衡性。

The understanding of phase diagrams for alloy systems is extremely important because there is a strong correlation between microstructure and mechanical properties, and the development of microstructure of an alloy is related to the characteristics of its phase diagram. In addition, phase diagrams provide valuable information about melting (熔炼), casting (铸造), crystallization (结晶), and other phenomena.②【2】除此之外，相图在熔化浇铸，结晶和其它现象中提供重要信息

Binary Isomorphous Systems (二元匀晶)

The easiest type of binary phase diagram to understand and interpret is that which is characterized by the copper-nickel system (Figure 1.19). Three different phase regions, or fields, appear on the diagram, an alpha (α) field, a liquid (L) field, and a two-phase $\alpha + L$ field. The liquid L is a homogeneous liquid solution composed of both copper and nickel. The α phase is a substitutional solid solution(置换型固溶体) consisting of both Cu and Ni atoms, and having an FCC crystal structure. At temperatures below about 1080°C, copper and nickel are mutually soluble in each other in the solid state for all compositions. The copper-nickel system is termed isomorphous (同行的) because of this complete liquid and solid solubility of the two components.

For a binary system of known composition and temperature that is at equilibrium, at least three kinds of information are available:

二元相图最易理解的是铜-镍合金相图，相图中包括三个不同的部分， α ，L， $\alpha + L$ ，液相 L 是铜-镍混合物， α 相是铜-镍的替代固相，具有 FCC 点阵类型，在 1080°C 以下，铜镍互溶，由于铜，镍在固态，液态下能无限互溶，被称为匀晶系统，在特定组成和温度下，二元相图是平衡的，至少三条信息是必要的：

- (1) the phases that are present.
- (2) the compositions of these phases.
- (3) the percentages or fractions of the phases. The procedures for making these determinations will be demonstrated using the copper-nickel system.

①存在的相

②相的组成

③相的百分含量，通过 Cu-Ni 相图可以表示这些

Phases Present

The establishment of what phases are present is relatively simple. One just locates the temperature-composition point on the diagram and notes the phase(s) with which the corresponding phase field is

labeled. For example, an alloy of composition ($W_{Ni}=60\%$; $W_{Cu}=40\%$) at 1100°C would be located at point A (Figure 1.19). Since this is within the α region, only the single α phase will be present.

Composition of Each Phase

The first step in the determination of phase compositions is to locate the temperature-composition point on the phase diagram. Different methods are used for single- and two-phase regions. If only one phase is present, the procedure is trivial: the composition of this phase is simply the same as the overall composition of the alloy. For an alloy having composition and temperature located in a two-phase region, the situation is more complicated. In all two-phase regions (and in two-phase regions only), one may imagine a series of horizontal lines, one at every temperature; each of these is known as a tie line (连接线), or sometimes as an isotherm. 1.3.6.1 相图
确定相组成的第一步是要在相图中确定(标出)温度-成分点。单相区和两相区应用着不同的确定方法。如果在单相区,步骤很简单,该相的成分就是整个合金的组成。对于温度-成分点位于两相区的合金,情况比较复杂。在所有的两相区内(也仅限于在两相区内),可以想像出一系列的水平线(在每一个温度上),这些线被称为连接线,或者有时也被称为等温线。

These tie lines extend across the two-phase region and terminate at the phase boundary lines on either side. To compute the equilibrium concentrations of the two phases, the following procedure is used:

这些连接线贯穿两相区并终止于两相区相两侧的边界线,计算两相的平衡浓度,可以用以下方法。

(1) A tie line (连接线) is constructed across the two-phase region at the temperature of the alloy.

(2) The intersections(交叉点) of the tie line and the phase boundaries on either side are noted.

(3) Perpendiculars (垂直的) are dropped from these intersections to the horizontal composition axis, from which the composition of each of the respective phases is read.

(1) 连接线的建立,在合金的温度线上横跨两相区。(2) 要注意连接线和两侧相边界的交点。(3) 各个相的成分通过从这些交点下降到水平成分轴的垂线来读取。

Amount of Each Phase (The Lever Law) 杠杆定律

In single-phase regions, the amount of the single phase is 100%. However, in two-phase regions we must calculate the amount of each phase. If the composition and temperature position is located within a two-phase region, the tie line must be utilized in conjunction with a procedure that is often called the lever law, which is applied as follows:

在单相区,单相的含量是 100%。然而,在两相区我们必须计算出每相的含量。如果成分-温度点位于两相区,连接线的使用必须结合一个通常被称为杠杆定律的规则,应用如下:

1) The tie line is constructed across the two-phase region at the temperature of the alloy.

(2) The overall alloy composition is located on the tie line.

(3) The fraction of one phase is computed by taking the length of the tie line from the overall alloy composition to the phase boundary for the other phase, and dividing by the total tie line length.

(4) The fraction of the other phase is determined in the same manner.

(1)连接线的建立,在合金的温度线上横跨两相区。

(2)整个合金成分点位于连接线上。

(3)其中一相所占的比例的计算,是用整个合金成分点与另外一相相界之间的连接线长度,除以整个连接线的长度。

Binary Eutectic Systems 二元共晶

Another type of common and relatively simple phase diagram found for binary alloys is shown in Figure 1.20 for the copper-silver system. This is known as a binary eutectic phase diagram. Three single-phase regions are found on the diagram: α , β , and liquid. The α phase is a solid solution rich in copper; it has silver as the solute component and FCC crystal structure. The β phase solid solution also has an FCC structure, but copper is the solute. 另一种常见的和相对简单的二元合金相图的类型是如图 1.20 所示的铜-银相图。这就是众所周知的二元共晶

相图。相图上有三个单相区： α 相区， β 相区，和液相区。 α 相是富含铜的固溶体，它含有作为溶质成分的银并拥有面心立方的晶体结构。 β 相固溶体也是面心立方结构，但铜是溶质。

The solubility in each of these solid phases is limited, in that at any temperature below line BEG only a limited concentration of silver will dissolve in copper (for the α phase), and similarly for copper in silver (for the β phase). The solubility limit for the α phase corresponds to the boundary line, labeled GSA, between the $\alpha / (\alpha + \beta)$ and $\alpha / (\alpha + L)$ phase regions; it increases with temperature to a maximum ($w_{Ag} = 8.0\%$ at 779°C) at point B, and decreases back to zero at the melting temperature of pure copper, point A (1085°C). 这些固相每相的溶解度都是有限的。在这些固体中每个相的溶解度是有限的，在任何低于线 BEG 的温度下只有有限含量的银会溶解在铜(α 相)中，同样地只有有限含量的铜溶解在银(β 相)中。 α 相的溶解度极限对应的边界线，标记为线 CBA，在 α 相区和 $(\alpha + \beta)$ 相区，及 α 相区和 $(\alpha + L)$ 相区之间。它随温度升高而增长到最大值 B 点 ($w_{Ag}=8.0\%$ ，在 779°C)，然后在温度升到纯铜的熔融温度 (1085°C ，点 A) 时降低回零。

At temperatures below 779°C , the solid solubility limit line separating the α and $\alpha + \beta$ phase regions is termed a solvus line (固溶线); the boundary AB between the α and $\alpha + L$ fields is the solidus line. The maximum solubility of copper in the (β phase, point G, also occurs at 779°C . This horizontal line BEG, which is parallel to the composition axis and extends between these maximum solubility positions, may also be considered to be a solidus line; it represents the lowest temperature at which a liquid phase may exist for any copper-silver alloy that is at equilibrium. 在温度低于 779°C 时，隔开的 α 和 $\alpha + \beta$ 相区固溶度极限线称固溶线； α 和 $\alpha + L$ 相区之间的边界线 AB 是固相线。 β 相中铜达到最大溶解度，G 点 (也就是在 779°C)。水平线 BEG，平行于成分轴，并处于 α 相和 β 相的最大溶解度位置之间，也可以认为它是一条固相线。它代表任何一种平衡态铜银合金可能存在液相的最低温度。

There are three two-phase regions found for the copper-silver system: $\alpha + L$, $\beta + L$, and $\alpha + \beta$. The α and β phase solid solutions coexist for all compositions and temperatures within the $\alpha + \beta$ phase field; the $\alpha + \text{liquid}$ and $\beta + \text{liquid}$ phases also coexist in their respective phase regions. Compositions and relative amounts for the phases may be determined using tie lines and the lever law. 铜—银相图可以找到三个两相区： $\alpha + L$, $\beta + L$, $\alpha + \beta$ 。 α 相固溶体和 β 相固溶体共存于 $(\alpha + \beta)$ 相区的所有成分和温度范围内； α 相、液相， β 相、液相也共存于在各自的相区内。可使用连接线和杠杆定律确定的各个相的组成和相对含量。

The liquidus lines AE and FE meet at the point E on the phase diagram, through which also passes the horizontal isotherm line BEG. Point E is called an invariant point, which is designated by the composition CE and temperature T_e . An important reaction occurs for an alloy of composition CE as it changes temperature in passing through T_e . Upon cooling, a liquid phase is transformed into the two solid α and β phases at the temperature T_e ; the opposite reaction occurs upon heating. This is called a eutectic reaction, and C_e and t_e represent the eutectic composition and temperature, respectively. $C_{\alpha E}$ and $C_{\beta E}$ are the respective compositions of the α and β phases at T_e . The horizontal solidus line at T_e is called the eutectic isotherm. 相图中液相线 AE 和 FE 交于经过水平等温线的点 E。E 点被称为一个不变的点，这是由成分点 C_e 和温度 T_e 划 (指) 定的。合金成为 C_e 点的合金，随着它改变温度，通过温度线 T_e 时会发生一个重要的反应。

冷却时，在温度为 T_e 时液相转化成固相 α 和固相 β 两个相；加热时出现相反的反应。这被称为共晶反应， C_e 和 T_e 分别代表共晶成分和共晶温度。 $C_{\alpha E}$ 和 $C_{\beta E}$ 是温度为 T_e 时 α 相和 β 相各自的成分。温度为 T_e 的水平固相线被称为共晶等温线。

The Iron-Iron Carbide (Fe-Fe₃C) Phase Diagram

Of all binary alloy systems, the one that is possibly the most important is that for iron and carbon. Both steels and cast irons, primary structural materials in every technologically advanced culture, are essentially iron-carbon alloys. 所有二元共晶系中，铁碳合金可能是最重要的一个。钢和铸铁，(现代文明工业中的主要结构材料 (解释说明))，本质上都是铁碳合金。

A portion of the iron-carbon phase diagram is presented in Figure 1.21. 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(多形态的) transformation (同素异性转变) to FCC austenite, or γ iron, at 912 °C. This austenite persists to 1394 °C, at which temperature the FCC austenite reverts back to a BCC phase known as δ ferrite, which finally melts at 1538 °C. 铁碳合金相图的一部分如图 1.21 所示。纯铁加热时在融化前经历了两种晶体结构的改变。在室温下稳定的形式,称为铁素体或 α 铁,具有体心立方晶体结构。铁素体在 912°C 时经历一个多晶型转变,成为具有面心立方晶体结构的奥氏体,或称 γ 铁。这种奥氏体一直存留到 1394°C,在此温度下奥氏体恢复到一个具有面心立方结构,被称为 δ 铁素体的相。 δ 铁素体最终在 1538°C 熔化。

The composition axis in Figure 1.21 extends only to 6.70% (wc); at this concentration the intermediate compound iron carbide, or cementite (Fe_3C), 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, and the other for compositions between 6.70% and 100 % (wc). In practice, all steels and cast irons have carbon contents less than 6.70% (wc); therefore, we consider only the iron-iron carbide system. Figure 1.21 would be more appropriately labeled the Fe- Fe_3C phase diagram. 在图 1.2 中的成分轴仅延伸 $W_c=6.70\%$ 处。在此浓度形成中间化合物的碳化铁,或称渗碳体(Fe_3C),它由相图上 $W_c=6.70\%$ 的垂直线代表。因此,铁碳合金系统可以分为两部分:一部分富含铁,另一部分为含碳量 6.70% 到 100 % 的成分。在实践中,所有钢材和铸铁的碳含量都小于 6.70%,因此,我们只考虑 Fe- Fe_3C 体系。图 1.21 能更合理地标示 Fe- Fe_3C 相图。

Carbon is an interstitial (间隙) impurity in iron and forms a solid solution with each of α and δ ferrites, and also with austenite. In the BCC α ferrite, only small concentrations of carbon are soluble; the maximum solubility is 0.022% (w) at 727°C. This iron-carbon phase is relatively soft, may be made magnetic at temperatures below 768 °C, and has a density of 7.88 g/cm³. 碳是铁的一种间隙杂质,并分别与 α 、 δ 铁素体、奥氏体形成了固溶体。在体心立方结构 α 铁素体中,只有较小的碳浓度是可溶的,最大溶解度为 727°C 时含碳量为 0.022%。这种铁碳相是相对较软的,在 768°C 以下可能获得磁性,密度为 7.88 g/cm³。

The austenite, when alloyed with just carbon, is not stable below 727 °C. The maximum solubility of carbon in austenite, 2.14% (w), occurs at 1147 °C. This solubility is approximately 100 times greater than the maximum for BCC ferrite. Austenite is nonmagnetic. 奥氏体,合金化时合金元素只有碳元素,低于 727°C 时是不稳定的。在 1147°C 时,碳在奥氏体中的溶解度达到最大值 2.14%。这个溶解度值比体心立方结构的 α 铁素体的最大溶解度大近似 100 倍。奥氏体是无磁性的。

The δ ferrite is virtually the same as α ferrite, except for the range of temperatures over which each exists. Since the δ ferrite is stable only at relatively high temperatures, it is of no technological importance. 除了 δ 铁素体存在的温度范围比 α 铁素体的高, δ 铁素体为 α 铁素体几乎一样。因为 δ 铁素体只有在相对较高的温度下才是稳定的,所以它在技术上没有重要性。

Cementite (Fe_3C) forms when the solubility limit of carbon in α ferrite is exceeded below 727°C. Fe_3C will also coexist with the γ phase between 727 and 1147°C. Mechanically, cementite is very hard and brittle. 在 727°C 以下,当 α 铁素体中碳含量超过它的溶解度极限时,就会析出渗碳体。在 727°C 和 1147°C 之间 Fe_3C 的也与 γ 相共存。力学性能上,渗碳体是非常硬且脆的。

One eutectic exists for the iron-iron carbide system, at 4.30% (WC) and 1147°C. For this eutectic reaction,

$$(1.2)$$

the liquid solidifies to form austenite and cementite phases. Of course, subsequent cooling to room temperature will promote additional phase changes.

A eutectoid invariant point exists at a composition of 0.76% (WC) and a temperature of 727°C. This eutectoid reaction may be represented by

$$(1.3)$$

or, upon cooling, the solid γ phase is transformed into α iron and cementite. Fe-Fe₃C 体系中, 在含碳量为 4.30% (WC), 温度为 1147°C 的点存在共晶组织。对于这个共晶反应, 液相凝固生成奥氏体和渗碳体。当然, 随后冷却至室温时将会促进其他的相变发生。

含碳量为 0.76%, 温度为 727°C 的点为一个不变的共析点。这个共析反应可以由式 1.3 表示, 随着冷却进行固相奥氏体发生相变生成 α 铁和渗碳体。

1.3.6.2 Phase transformations

Mechanical and other properties of many materials depend on their microstructures, which are often produced as a result of phase transformations. These transformations are divided into three transformations. In one group are simple diffusion-dependent transformations in which there is no change in either the number or composition of the phases present. These include solidification of a pure metal, allotropic transformations, and recrystallization and grain growth. 许多材料的力学和其他性能取决于它们的微观结构, 这往往是相变的结果产生的。这些相变被分为三类。一类是单纯的无扩散型相变, 存在相的数量和成分没有改变。这类相变包括纯金属凝固, 同素异性体转变, 再结晶和晶粒长大。

In another type of diffusion-dependent transformations, there is some alteration in phase composition and often in the number of phases present; the final microstructure ordinarily consists of two phases. The eutectoid reaction, described by Equation 1.3, is of this type. The third kind of transformation is diffusionless, wherein a metastable phase is produced. A martensitic transformation, which may be induced in some steel alloys, falls into this category. 在另一种类型的扩散型相变, 存在相(现存的相)的相组成和相的数目方面有一些改变。最终的显微组织通常由两相组成。共析反应, 如方程 1.3 所描述的, 是这种类型。第三类相变是扩散型, 其中有亚稳态的相产生。一些合金钢中可能诱发的马氏体转变就属于这一类。

Consider again the iron-iron carbide eutectoid reaction, which is fundamental to the development of microstructure in steel alloys. Upon cooling, austenite, having an intermediate carbon content, transforms to a ferrite phase, having a much lower carbon content, and also cementite, with a much higher carbon concentration. 再考虑铁-碳化铁(Fe-Fe₃C)的共析反应, 这是合金钢的微观结构发展的根本。冷却后, 有一个中间的碳含量的奥氏体转变为碳含量低得多铁素体相, 也转变成碳浓度更高的渗碳体。

Consider an alloy of eutectoid composition (wC = 0.76%) as it is cooled from a temperature within the γ phase region, say, 800°C, that is, beginning at point a in Figure 1.22 and moving down the vertical line xx'. Initially, the alloy is composed entirely of the austenite phase having a composition of 0.76% (wC) C and corresponding microstructure. As the alloy is cooled, there will occur no changes until the eutectoid temperature (727°C) is reached. Upon crossing this temperature to point b, the austenite transforms according to Equation 1.3.

考虑共析成分的合金 (WC=0.76%), 因为它是由 γ 相区内的温度开始冷却, 就是说在 800°C 时, 从图 1.22 上的点 a 开始沿垂直线 XX 向下移动。最初, 该合金完全是由 Wc=0.76%C 组成的奥氏体相和相应的显微组织组成。随着合金冷却, 没有改变发生, 直到达到共析温度 (727°C)。越过此温度到 B 点后, 根据方程 1.3 奥氏体发生相变。

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 Fe₃C) that form simultaneously during the transformation. In this case, the relative layer thickness is approximately 0.8 to 1. 缓慢冷却通过共析温度的共析钢显微组织包括交替的层或片状的在相变过程中同时形成的 α 和 Fe₃C 两相。在这种情况下, 相对层厚度约 0.8 至 1。

This microstructure, represented schematically in Figure 1. 22, point b, is called pearlite because it has the appearance of mother of pearl when viewed under the microscope at low magnifications. Mechanically, pearlite has properties intermediate between the soft, ductile ferrite and the hard, brittle cementite. 如图 1. 22B 点示意代表的这种微观结构, 被称为珠光体, 因为它在低倍率的显微镜下观察时, 具有珍珠母贝的外观。物理上, 珠光

体具有介于软的、韧性的铁素体和硬的、脆的渗碳体之间的中间性质。

The alternating α and Fe_3C layers in pearlite form because the composition of the parent phase is different from either of the product phases, and the phase transformation requires that there be a redistribution of the carbon by diffusion.

珠光体中形成交替的 α 和 Fe_3C 层, 因为母相的成分与新生成相都不同, 由于相变的需要碳通过扩散进行再分配。

Consider a composition C_0 to the left of the eutectoid, between 0.022% and 0.76% (wC); this is termed a hypoeutectoid alloy. Cooling an alloy of this composition is represented by moving down the vertical line yy' in Figure 1.23. 考虑共析组织左侧成分点为 C_0 的合金, 位于 0.022% 和 0.76% (WC) 之间, 被称为亚共析合金。这个成分的合金的冷却过程由图 1.23 中沿垂直线 yy 向下移动过程来代表。

At about 875°C, point c, the microstructure will consist entirely of grains of the γ phase. In cooling to point d, about 775 °C, which is within the $\alpha + \gamma$ phase region, both these phases will coexist as in the schematic microstructure. Most of the small α particles will form along the original grain boundaries. The compositions of both α and γ phases may be determined using the appropriate tie line. 在 875°C 左右, C 点, 微观结构将完全由 γ 相颗粒组成。冷却至 D 点, 在约 775°C, ($\alpha + \gamma$) 相区内, 这两相将像示意图中的微观结构一样共存。大多数小的 α 粒子会沿着原来的 γ 晶粒的边界形成。 α 和 γ 相的成分, 可使用相应的连接线来确定。

While cooling an alloy through the $\alpha + \gamma$ phase region, the composition of the ferrite phase changes with temperature along the $\alpha - (\alpha + \gamma)$ phase boundary, line MN, becoming slightly richer in carbon. 当合金冷却通过 $\alpha + \gamma$ 相区时, 铁素体相的成分随温度 (降低) 沿 $\alpha - (\alpha + \gamma)$ 相界一线 MN 变化, 渐渐变得碳含量略有富余。

On the other hand, the change in composition of the austenite is more dramatic, proceeding along the $(\alpha + \gamma) - \gamma$ boundary, line MO, as the temperature is reduced. Cooling from point d to e, will produce an increased fraction of the α phase and the α particles will have grown larger. 另一方面, 随着温度的降低, 奥氏体成分的改变更加显著, 沿着 ($\alpha + \gamma$) 相和 γ 相边界线 MO 进行。从 D 点冷却至 E 点, α 相的比例会增加并且 α 粒子将会越长越大。As the temperature is lowered just below the eutectoid, to point f, all the γ phase that was present at temperature T_e , (and having the eutectoid composition) will transform to pearlite, according to the reaction in Equation 1.3.

There will be virtually no change in the α phase that existed at point e in crossing the eutectoid temperature—it will normally be present as a continuous matrix phase surrounding the isolated pearlite colonies.

Thus the ferrite phase will be present both in the pearlite and also as the phase that formed while cooling through the $\alpha + \gamma$ phase region. The ferrite that is present in the pearlite is called eutectoid ferrite, whereas the other, that formed above T_e , is termed proeutectoid ferrite. 随着温度降低到略低于共析温度的 F 点, 温度 T_e 下存在的 (拥有共析成分的) 所有 γ 相, 将根据公式 1.3 中的反应转变为珠光体。在通过共析温度时, E 点的 α 相几乎没有变化, 它一般会作为一个连续的基体相围绕着孤立的珠光体集群存在。因此, 铁素体相不仅在珠光体中存在, 冷却通过 $\alpha + \gamma$ 相区时也将作为新相生成。珠光体中存在的铁素体被称为共析铁素体, 而其他在温度 T_e 以上形成的被称为先共析铁素体。

Analogous transformations and microstructures result for hypereutectoid alloys, those containing between 0.76% and 2.14% (wc) carbon, which are cooled from temperatures within the γ phase field. Consider an alloy of composition C_1 in Figure 1.24 which, upon cooling, moves down the line zz' .

At point g only the γ phase will be present with a composition C_1 . Upon cooling into the $\gamma + \text{Fe}_3\text{C}$ phase field, say, to point h, the cementite phase will begin to form along the initial γ grain boundaries. This cementite is called proeutectoid cementite. 类似的相变和微观组织也发生在 (含碳量为 0.76% 和 2.14% (WC) 的) 过共析合金中, 这是从 γ 相区的温度冷却而形成的。考虑图 1.24 中成分为 C_1 的合金, 冷却时沿着线 ZZ' 向下移动。在 G 点只有成分为 C_1 的 γ 相存在。冷却到 $\gamma + \text{Fe}_3\text{C}$ 的相区后, 即到 H 点, 渗碳体相将沿着最初的 γ 相晶界开

始形成。该渗碳体被称为先共析渗碳体。

The cementite composition remains constant as the temperature changes. However, the composition of the austenite phase will move along line PO toward the eutectoid. As the temperature is lowered through the eutectoid to point i, all remaining austenite of eutectoid composition is converted into pearlite. Thus, the resulting microstructure consists of pearlite and proeutectoid cementite as microconstituents. 渗碳体成分，随着温度的变化保持不变。然而，奥氏体相的组成将沿着线 PO 朝着共析组织变化。随着温度的降低，通过共析温度到点 i 时，所有残余的共析成分的奥氏体转变成珠光体。因此，最后的显微组织由珠光体和微量先共析渗碳体组成。

In addition to pearlite, other microconstituents that are products of the austenitic transformation exist; one of these is called bainite. The microstructure of bainite consists of ferrite and cementite phases, and thus diffusional processes are involved in its formation. Bainite forms as needles or plates, depending on the temperature of the transformation. 除了珠光体，还有其他由奥氏体转变生成的微量成分存在，其中之一被称为贝氏体。贝氏体组织由铁素体相和渗碳体相组成，因此它的形成包含有扩散过程。贝氏体的形成有针状或板条状，取决于相变的温度。

Another microconstituent or phase called martensite is formed when austenitized iron-carbon alloys are rapidly cooled to a relatively low temperature. Martensite is a nonequilibrium single-phase structure that results from a diffusionless transformation of austenite.

The martensitic transformation occurs when the quenching rate is rapid enough to prevent carbon diffusion. Any diffusion whatsoever will result in the formation of ferrite and cementite phases.

另一微量成分或相称为马氏体，在奥氏体的铁碳合金快速冷却到一个相对低的温度时形成。马氏体是一个非平衡单相结构，是奥氏体发生非扩散相变的结果。马氏体相变发生在淬火速度快，足以防止碳扩散的情况下。任何形式的扩散都将发生在铁素体相和渗碳体相的形成过程中。

2 Materials

2.1 Ferrous Alloys (p.1 修订版)

More than 90% by weight of the metallic materials used by human beings are ferrous alloys. 人类使用的超过 90% 的金属材料是合金。

This represents an immense family of engineering materials with a wide range of microstructures and related properties. 这代表着巨大工程材料的家庭有着广泛的微观结构和相关的属性。

As a practical matter, these alloys fall into (分为) two broad categories based on (根据) the carbon in the alloy composition. 实际上，这些合金根据的合金成分中的碳分为两大类。

Within the steel category, we shall distinguish whether or not a significant amount of alloying elements other than carbon is used. 在钢铁类，我们应区分是否使用相当数量的除碳以外的合金元素。

A composition of 5.0% total non-carbon additions (添加物) will serve as (可以起到...作用) an arbitrary boundary between low alloy and high alloy steels. 总量达到 5.0% 的非碳添加物可以起到低合金钢和高合金钢之间的任意边界的作用。

These alloy additions are chosen carefully because they invariably bring with them sharply increased material costs[1]. 这些合金元素都经过仔细挑选，因为他们通常都在材料价值方面有很大的进步。

They are justified only by essential improvements in properties such as higher strength or improved corrosion resistance. 他们只有通过必要的改进性能进行分类，如高强度或改进的耐腐蚀性。

Modern industry needs considerable quantities of this metal, either in the form of iron or in the form of steel. 现代工业需要相当数量的这种金属，无论是在铁模或在钢模

A certain number of non-ferrous metals, including aluminum and zinc, are also important, but even today the majority of our engineering products are of iron or steel. 一定数目的非铁金属，包括铝，锌，也重要，但即使在今天，我们的大多数工程产品的铁或钢。

Moreover, iron possesses magnetic properties, which have made the development of electrical power possible. 此外, 铁具有磁学性质, 已使得电力的发展成为可能。

The iron ore* which we find on earth is not pure. It contains some impurities that must be removed by smelting. 我们在地球上找到的铁矿石*不是纯粹的。它包含一些必须通过冶炼除去杂质。

Blasts of hot air enter the furnace from the bottom and provide the oxygen that is necessary for the reduction of the ore. 爆炸的热空气从底部进入炉, 提供的氧气对减少矿石必要的。

The ore becomes molten, and its oxides combine with carbon from the coke.

The non-metallic constituents of the ore combine with the limestone to form a liquid slag*.

This floats on top of the molten iron, and passes out of the furnace through a tap*.

The metal which remains is pig iron*.

矿石熔化, 和其氧化物与焦炭中的碳结合。非金属矿石的成分与石灰石结合, 形成液态渣*。这液态渣浮在铁水上方, 并通过自来水排出炉。残留物是金属生铁*。

We can melt this down again in another furnace-a cupola*-with more coke and limestone, and tap it out into a ladle* or directly into molds. This is cast iron. 我们用更多的焦炭和石灰石在另一冲天炉将其融化, 再装入勺子或直接进入模具。这是铸铁。

But it possesses certain properties that make it very useful in the manufacture of machinery.但它具有某些特性, 使其在机械制造方面非常有用。

In the molten state it is very fluid, therefore, it is easy to cast it into intricate shapes. Also it is easy to machine it. 因此, 它在熔融状态下非常流畅, 很容易熔炼成复杂的形状。此外, 它很容易机加工得到。

These non-metallic constituents of cast iron include carbon, silicon and sulphur, and (同时) the presence of these substances affects the behavior of the metal. 这些非金属铸铁成分包括碳, 硅和硫, (同时), 这些物质的存在影响金属的性质。

Iron which contains a negligible (可忽略的) quantity of carbon, for example, wrought* (可锻的) iron behaves differently from iron which contains a lot of carbon [2].其中含碳量可以忽略不计数量的铁, 例如可锻铸铁, 其特性不同于包含大量碳的铁[2]。

The carbon in cast iron is present partly as free graphite and partly as a chemical combination of iron and carbon which is called cementite [3]. However, iron can only hold about 1.5% of cementite. Any carbon content above that percentage is present of the form of a flaky* graphite.铸铁中的碳部分 作为自由石墨存在。任何超过这一比例碳含量的都以片状石墨的形式存在。

We make wire and tubing from mild steel(低碳钢)with a very low carbon content, and drills and cutting tools from high carbon steel. 我们从低碳钢得到线材和管材, 从高碳钢得到钻头和切削刀具

• Carbon Steel

A plain carbon steel (碳素钢) is one in which carbon is the only alloying element. 碳素钢是一种只含有碳作为合金元素的钢。

The amount of carbon in the steel controls its hardness, strength, and ductility.钢铁的含碳量影响着它的硬度, 强度和塑性。

The higher the carbon content, the harder the steel. Carbon steels are classified according to the percentage of carbon they contain. 含碳量越多钢铁硬度越高。碳素钢以其含碳量的百分数分类。

They are referred to (称为) as low, medium, high, and very-high-carbon steels. 它们被分为低碳钢, 中碳钢, 高碳钢和超高碳钢。

Low-carbon Steels 低碳钢

Most of them do not respond to any heat treating process except case hardening*. 它们大多数不适合热处理, 表面渗碳硬化除外。

These steels have a carbon range from 0.30 to 0.45 percent. They are strong and hard but cannot be worked or

welded as easily as low-carbon steels. 这些钢的含碳量在 0.30 至 0.45 之间。它们硬度强度高, 但是加工性和焊接性能都不如低碳钢

Successful welding of these steels often requires special electrodes, but even then greater care must be taken to prevent formation of cracks around the weld area [1]. 通常需要采用特殊焊条才能成功的焊接这类钢材, 即使这样, 也要非常小心, 避免在焊接区周围形成裂纹。

Steels with a carbon range of 0.45 to 0.75 percent are classified as high-carbon and those with 0.75 to 1.7 percent carbon as very-high-carbon steels. (直译)

As a rule, steels up to 0.65 percent carbon can be welded with special electrodes, although preheating and stress relieving techniques must often be used after the welding is completed [2]. 通常来说, 碳含量在 0.65 以下的钢都可以采用特殊的焊条进行焊接, 尽管通常需要采用预热和焊后消除应力处理。

Carbon is the principal element controlling the structure and properties that might be expected from any carbon steel. 碳是控制结构和性能的主要元素, 它能从任何碳钢中测得。

The influence that carbon has in strength-ening and hardening steel is dependent upon the amount of carbon present and upon its microstructure. 碳在强化钢和硬化钢中的影响取决于其在碳钢中的含量和微观结构。

Slowly cooled carbon steels have a relatively soft iron pearlitic* microstructure; whereas rapidly quenched carbon steels have a strong, hard, brittle, martensitic microstructure. * 逐步冷却的碳钢有较软的珠光体微观结构, 而快速淬火碳钢有一个高强度, 高硬度, 脆性的马氏体组织。

In carbon steel, at normal room tempera-ture, the atoms are arranged in a body-centered lattice*. 碳素钢在室温下, 原子的排列为体心晶格*。

This is known as(称作为) alpha iron. 这被称为 α 铁

Each grain of the structure is made up of layers of pure iron (ferrite) and a combination of iron and carbon. The compound of iron and carbon, or iron carbide*, is called cementite*. 每个晶粒的结构都是由纯铁(氧化铁)和铁碳混合物的层组成的。铁和碳的化合物, 或碳化铁, 被称为渗碳*。

The cementite is very hard and has practically no ductility. 渗碳硬度很高, 几乎没有塑性。

In a steel with 0.8 percent carbon, the grains are pearlitic, meaning that all the carbon is combined with iron to form iron carbide. 含碳量在 0.8 的钢, 其晶粒都是珠光体, 意味着所有的碳都是和铁结合称为碳化铁的。

This is known as a eutectoid* (共析的) mixture of carbon and iron. 这被称为铁碳的共析混合物。

If there is less than 0.8 percent carbon, the mixture of pearlite and ferrite is referred to as hypoeutectoid. 如果碳含量小于 0.8, 珠光体和铁素体的混合物就称为亚共析。

An examination of such a mixture would show grains of pure iron and grains of pearlite as shown in Figure 2.2. 这种混合物的组织将显示纯铁颗粒和珠光体晶粒, 如图 2.2 所示。

When the metal contains more than 0.8 percent carbon, the mixture consists of pearlite and iron carbide and is called hypereutectoid 当金属中含有超过 0.8% 的碳, 混合组成的珠光体和铁的碳化物被称为过共析。

In general, the greatest percentage of steel used is of the hypoeutectoid type, that which has less than 0.8 percent carbon. 实际中, 使用量占百分比最大的钢铁是低于 0.8% 的亚共析钢。

An alloy steel is a steel to which one or more of such elements as nickel, chromium*, manganese, molybdenum*, titanium*, cobalt*, tungsten*, or vanadium* have been added. 合金钢材是含有一个或多个元素, 如镍, 铬, 钛, 锰, 钼, 钴, 钨, 或钒*已加入的钢材。

The addition of these elements gives steel greater toughness, strength, resistance to wear, and resistance to corrosion. 这些额外的元素赋予了钢更好的韧性, 强度, 耐磨性, 耐腐蚀性。

Alloy steels are called by the predominating (主要的) element which has been added. 合金钢以其主要加入的元素命名。

Most of them can be welded, provided special electrodes are used. 它们中的大多数可以焊接, 在特殊的电极下使用。

The common elements added to steel and their effects are explained as the following. 常见元素加入钢铁后的影响如下。

The addition of manganese to steel produces a fine grain structure which has greater toughness and ductility. 钢的锰除了产生良好的晶粒结构，还具有较大的韧性和延展性。

Manganese always presents in steel to some extent because it is used as a deoxidiser. 锰在钢中总有一定的存在量，因为它作为一种脱氧剂使用。

When quantities of chromium are added to steel the resulting (最终的) product is a metal having extreme hardness and resistance to wear without making it brittle [3]. Chromium also tends to refine the grain structure of steel, thereby increasing its toughness. 钢中加入大量的铬以后，硬度变得非常高，非常耐磨又不脆。铬也趋于细化钢的晶粒结构，从而增加其韧性

It is used either alone in carbon steel or in combination with other elements such as nickel, vanadium, molybdenum, or tungsten. 它是用来单独或其他元素共同（如镍，钒，钼，钨）共同组合存在碳钢中。

The addition of nickel increases the ductility of steel while allowing it to maintain its strength. 镍除了增加了钢材的延展性，同时又能够保持其强度。

When large quantities of nickel are added (25 to 35 percent), the steels not only become tough but also develop high resistance to corrosion and shock. 当镍的大量增加（25%至35%），钢不仅强度增加，但也增加高抗腐蚀性和抗冲击性。

Tungsten is used mostly in steels designed for metal cutting tools. 钨主要用于金属切削刀具设计的钢

Molybdenum produces the greatest hardening effect of any element except carbon and at the same time it reduces the enlargement of the grain structure. 钼是除碳以外的所有元素有最大硬化影响的元素，同时也降低了扩大晶粒结构的影响

The result is a strong, tough steel. 这样形成了强度硬度高的钢。

Although molybdenum is used alone in some alloys, often it is supplemented by other elements, particularly nickel or chromium or both. 虽然某些合金中钼是单独使用的，大多数情况它都是辅以其他元素，特别是镍或铬或两者共同使用的。

Vanadium is a strong carbide forming element. 钒是强碳化物形成元素。

Addition of this element to steel promotes fine grain structure when the steel is heated above its critical range for heat treatment. 这种钢中除了这种元素以外的其他元素，促进了细晶粒结构钢，当钢高于其临界范围热处理温度加热时。

Titanium is a strong carbide-forming element. It is not used on its own, but added as a carbide stabiliser to some austenitic stainless steels. 钛是一种强碳化物形成元素。它不是自身起作用，但作为碳化物稳定剂加入到一些奥氏体不锈钢。

2.1.3 Cast Irons

As stated earlier, we define cast irons as the ferrous alloys with greater than 2% (w) carbon.

如前所述，我们定义为大于2%（W）碳为有色合金铸铁。

They also generally contain up to 3% (w) silicon for control of carbide formation kinetics 他们还普遍含有高达3%（W）的硅作为碳化物形成的动力。

Cast irons have relatively low melting temperatures and liquid phase viscosities*, do not form undesirable surface films when poured, and undergo moderate shrinkage* during solidification and cooling [1]. 铸铁具有比较低的熔点和液相粘性。浇注时不形成不需要的表面膜，并且在固化和冷却过程中收缩适度。

The cast irons must balance good formability of complex shapes against inferior mechanical properties compared to wrought alloys. 跟锻造合金相比，铸铁必须有更好的复杂形状的成形性，因为它们的劣质机械性。

A cast iron is formed into a final shape by pouring molten metal into a mold. 铸铁最终形状的形成是靠熔融金属浇入模具。

The shape of the mold is retained by the solidified metal. Inferior mechanical properties result from a less uniform microstructure, including some porosity*. 由于凝固金属模具的形状被保留。低劣的机械性能造成不太均匀的微观结构，包括一些气孔*。

Wrought alloys are initially cast but are rolled or forged into final, relatively simple shapes (in fact, "wrought" simply means "worked"). 锻造合金最初铸造但最后是卷或锻造出来的，有相对简单的形状（事实上，“锻造”只是表示“加工步骤”）。

White iron has a characteristic white, crystalline fracture surface. 白口铁有一个特点，它有白色的结晶断口。 Large amounts of Fe₃C are formed during casting, giving a hard, brittle material. 铸造过程中形成大量的 Fe₃C 的，制成一种硬，脆材料。

Gray iron has a gray fracture surface with a finely faceted (有小面的) structure. 灰口铸铁具有精细面 (有小面的) 结构灰色断口。

A significant silicon content (w_{Si} = 2% ~ 3%) promotes graphite (C) precipitation rather than cementite (Fe₃C). 一个较高的硅含量 (WSI=2%~3%) 能促进石墨 (三) 析出，相比渗碳体 (Fe₃C) 更强。

The sharp, pointed graphite flakes contribute to characteristic brittleness in gray iron. 尖锐的片状石墨形成了灰铸铁脆性的特点。

By adding a small amount(w = 0.05%) of magnesium* to the molten metal of the gray iron composition, spheroidal graphite precipitates rather than flakes are produced.[2] 通过少量的 Mg (w=0.05%) 添加到灰铁成分的熔融金属中，就形成球状石墨沉淀而不是片状石墨。

This resulting ductile iron derives (起源) its name from the improved mechanical properties. 因为它改善的机械性能球墨铸铁形成了。

Ductility is increased by a factor of 20, and strength is doubled. 延展性增加了 20 倍，强度增加一倍。

A more traditional form of cast iron with reasonable ductility is malleable* iron, which is first cast as white iron and then heat treated to produce nodular* graphite precipitates[3]. 具有适当的韧性的更传统形式的铸铁是可锻铸铁。它首先被铸成白口铁，然后热处理形成小球状石墨沉淀。

Non-ferrous Alloys

Although ferrous alloys are used in the majority of metallic applications in current engineering designs, non-ferrous alloys play a large and indispensable (不可或缺) role in our technology. As for ferrous alloys, the list of non-ferrous alloys is, of course, long(众多的, 充足的) and complex. We shall briefly list the major families of non-ferrous alloys and their key (主要的) attributes (特性). Aluminum alloys are best known for low density (密度) and corrosion resistance. Electrical conductivity, ease of fabrication, and appearance are also attractive features. Because of these, the world production of aluminum roughly (差不多) doubled in one recent 10-year period. Ore (矿) reserves (蕴藏) for aluminum are large (representing 8% of the earth's crust) and aluminum can be easily recycled.

在现代工程设计中铁合金虽然是金属应用中最主要的，但是在工业中有色金属也起着重大的不可或缺的作用。相对于铁合金来说，有色金属的种类当然是多且复杂的。下面将简略的列出几种有色金属的主要类型及其主要特征。铝合金由于具有低密度和耐腐蚀性，导电性以及良好的加工性能和活跃的外特性而被大家熟知。正是因为这些特征，在最近十年期间，铝在世界上的生产量差不多翻了一翻。铝矿的储量很大（约为地壳中金属储量的 8%）而且很容易重复利用。

Magnesium alloys(镁合金) have even lower density than aluminum and, as a result(因此, 从而), appear in numerous structural applications such as aerospace (航空) designs. Aluminum is a fcc (face-centered cubic 面心立方晶格) material and therefore has numerous (12) slip systems, leading to good ductility. By contrast, magnesium is hcp (hexagonal close-packed 密堆六方晶格) with only three slip systems and characteristic brittleness.

由于镁合金的密度比铝还要低，因此它出现在许多如航空设计的结构的应用中。铝由于是一种面心立方结构金属且具有多种滑移系统，以至于具有很好的延展性。相比之下，镁是密排六方结构金属并且只有三个滑移系，所以比较脆。

Titanium (钛) alloys have become widely used since World War II. Before that time, a practical method of separating titanium metal from reactive oxides and nitrides(氮化物) was not available. Once formed, titanium's reactivity works to its advantage. A thin, tenacious (坚韧的) oxide coating forms on its surface, giving excellent resistance to corrosion. This "passivation" (钝化) will be discussed in detail later. Titanium alloys, like Al and Mg, are of lower density than iron. Although more dense than Al or Mg, titanium alloys have a distinct (明显的) advantage of retaining strength at moderate service temperatures, leading to (导致) numerous aerospace design applications. Titanium shares the hcp structure with magnesium leading to characteristically low ductility. However, a high temperature bcc (body-centered cubic 体心立方晶格) structure can be stabilized at room temperature by certain alloy additions such as vanadium(钒).

自从第二次世界大战时钛合金就开始得到广泛应用。此前，没有将钛从活性氧化物及氮化物中提取出来的可行途径。钛一旦形成，它就显示出优越的反应活性。在钛的表面有一层薄的坚韧的氧化皮，赋予钛以超强的抗腐蚀性。后面将对这种“钝化”进行详细论述。钛合金，像镁和铝一样，比铁的密度低。虽然密度比镁和铝大，但在中温下，钛合金在强度保持方面具有明显的优势，使其大量应用于航空设计上。钛和镁一样具有六方紧密堆积结构从而导致其具有低延展性。然而，通过添加像钒这样的某种合金，高温的体心结构在室温下也可以拥有良好的延展性。

Copper alloys possess a number of superior properties. Their excellent electrical conductivity makes copper alloys the leading (主要的) material for electrical wiring. Their excellent thermal conductivity leads to applications for radiators (散热器) and heat exchangers. Superior corrosion resistance is exhibited in marine(船舶) and other corrosive environments. The fcc structure contributes to their generally high ductility and formability. Their coloration is frequently used for architectural (建筑上的) appearance. Widespread uses of copper alloy through history have led to a somewhat confusing collection of descriptive terms. The mechanical properties of these alloys rival(竞争) the steels in their variability(可变性). High purity copper is an exceptionally soft material. The addition of 2 wt% beryllium (铍) followed by a heat treatment to produce Cu-Be precipitates is sufficient to push the tensile strength beyond 1000 MPa.

铜合金具有一系列优异的性能。良好的导电性使铜合金成为主要的电线材料，而良好的导热性使得其在散热器和换热器中得以应用。其优良的抗腐蚀性在船舶和其他腐蚀性环境中得以展现。面心结构使得铜合金具有良好的延展性并且使其易于成型。他们的着色性经常用于建筑的外观。历史上铜合金的广泛应用导致了許多令人疑惑的描述性术语。这些合金机械性能的可变性使其能与钢匹敌。高纯度的铜是一种很软的材料。通过加入另外的 2W 铍将会得到一种抗拉强度超过 1000MPa 的称为铍化铜的析出物。

Nickel alloys have much in common with copper alloys. We have already used the Cu-Ni system as the classic example of complete solid solubility. Monel is the name given to commercial alloys(工业合金) with Ni-Cu ratios (比例) of roughly 2:1 by weight. These are good examples of solution hardening. Nickel is harder than copper, but Monel is harder than nickel. Nickel exhibits excellent corrosion resistance and high temperature strength. Zinc alloys are ideally suited for die-castings due to their low melting point and lack of corrosive reaction with steel crucibles (坩埚) and dies (模具). Automobile parts and hardware (五金器具) are typical structural applications. Zinc coatings on ferrous alloys are important means of corrosion protection. This method is termed as galvanization(镀锌).

镍合金与铜合金具有许多相同的地方。例如在以前的固溶性的例子中我们已经使用的铜镍系统。镍铜质量比为 2: 1 的工业合金称为蒙耐合金。这是固溶强化的典型例子。镍比铜的硬度大，但是蒙耐合金的硬度比镍还要大。镍具有展现出很好的耐腐蚀性以及高温下具有良好的强度。锌合金的低熔点以及和铁坩埚与模具不易发生电化学反应，所以很适合用于压铸。汽车部件和五金器具是其典型的结构应用。在有色合金

上涂上锌层是典型的防腐蚀途径。这种方法称为镀锌。

Lead alloys (铅合金) are durable and versatile materials (耐用的通用材料). The lead pipes installed by the Romans at the public baths in Bath, England, nearly 2000 years ago are still in use. Lead's high density and deformability combined with a low melting point adds to its versatility (多用性). Lead alloys find use in battery grids(栅极) (alloyed with calcium or antimony 锑), solders 焊料 (alloyed with tin), radiation shielding(辐射屏障), and sound control structures(声音控制结构). The toxicity(毒性) of lead restricts design applications and the handling of its alloys.

铅合金是一种耐用的多用途材料。2000 年前罗马人在英国巴斯安置在公共浴室中的铅合金管道沿用至今。铅的高密度、高变形性以及低熔点加大了它的多用性。铅合金广泛应用于电池栅电极, 焊料, 辐射屏蔽及隔音结构, 然而铅的毒性限制了他的应用及其合金加工。

The refractory(耐火的, 难熔的) metals include molybdenum(钼), niobium(铌), tantalum(钽), and tungsten(钨). They are, even more than the super-alloys, especially resistant to high temperatures. However, their general reactivity with oxygen requires the high temperature service (高温作业) to be in a controlled atmosphere or with protective coatings.

耐火材料包括钼、铌、钽及钨。他们的耐火性比高温合金还要好, 尤其抗高温性能。然而, 他们与氧的基本反应需要在可控条件下或有保护涂层的高温作业下进行。

The precious metals(贵金属) include gold, indium(铟), osmium(锇), palladium(钯), platinum(铂), rhodium(铑), ruthenium(钌), and silver. Excellent corrosion resistance combined with(联合/同) various inherent properties(固有的性质) justify (证明...是正当的/值得的) the many costly applications of these metals and alloys. Gold circuitry in the electronics industry, various dental alloys (牙科用合金), and platinum coatings for catalytic converters(接触反应转变装置) are a few of the better-known examples.

贵金属包括金、铟、锇、钯、铂、铑、钌及银。良好的耐腐蚀性和各种固有性质证明这些金属和合金的许多高成本应用是值得的。例如在电子工业中金材电路板, 多种的牙科合金和接触反应整流器中的铂层都是一些更为知名的应用

第三章 welding

1、A union between two pieces of metal rendered plastic or liquid by heat or pressure or both. A filler metal with a melting temperature of the same order of that of the parent metal* may or may not be used.

通过对金属加热或加压或者两者并施实现两块金属工件的连接, 用或者不用与母材有相同溶化温度的填充金属。

2、A localized coalescence of metals or nonmetals produced either by heating the materials to the welding temperature, with or without the application of pressure, or by the application of pressure alone, with or without the use of a filler metal.

通过加热材料到焊接温度, 然后施加或者不施加压力, 或者只施加压力, 用或者不用填充金属来实现金属或非金属局部的结合。

3、In fusion welding, a heat source melts the metal to form a bridge between the components.

在溶化极焊接中, 热源溶化金属来形成两个构件的连接。

4、Air in the weld area can be replaced by a gas which does not contaminate the metal, or the weld can be covered with a flux.

焊接区域的空气可以用对熔池金属无污染的气体来代替, 或者用焊剂覆盖来保护焊接。

5、Choosing the most suitable process requires consideration of a number of factors, including type of metal, type of joint, material thickness, production constraints, equipment availability, labour availability, labour costs, costs of consumables, health, safety and the environment consideration.

选择最合适工艺需要考虑许多因素, 其中包括有金属类型, 接头类型, 材料厚度, 生产条件的约束, 可用设备, 可用的劳动力, 劳动成本, 消耗健康安全环境的成本。

6、It has for many years been one of the most common techniques applied to the fabrication of steels.

许多年来，手弧焊都是应用于钢结构件最普通的技术中的一种。

7、In addition to heating and melting the parent material the arc also melts the core of the electrode and thereby provides filler material for the joint.

除了加热和融化母材，电弧也融化焊条焊芯，因此为焊接接头提供填充金属。

8、The flux and electrode chemistry may be formulated to deposit wear- and corrosion-resistant layers for surface protection.

焊剂和焊条化学成分与为（焊缝）金属表面耐磨耐腐蚀的保护层有关。

9、At higher currents high deposition rates may be obtained and the process is used for downhand and horizontal-vertical welds in a wide range of materials—include earth-moving equipment, structural steelwork, weld surfacing with nickel or chromium alloys, aluminum alloy cryogenic vessels and military vehicles.

高电流可以得到高的溶敷率，这种工艺常被用于许多材料的仰焊，平焊和垂直焊包括焊接挖土设备，钢结构，焊缝表面覆有镍或铬的合金，铝合金低温容器和军用车辆。

3.1.2.3 钨极惰性气体保护焊（GTAW）

钨极惰性气体保护焊，如图 3.7 所示，在欧洲大多数被称为钨极氩弧焊（TIG）。

在钨极惰性气体保护焊中，维持在工件和不熔化的钨极间的电弧产生的热量熔化接头区域。电弧在保护焊接熔池和焊条不受大气污染的气体中持续燃烧。操作原理如图 3.8 所示。钨极氩弧焊工艺有如下特点：（1）焊接过程是在化学保护气体中进行的（2）能量密度相对较高（3）焊接过程是可控制的（4）接头质量通常比较好（5）熔敷速度和接头完成速度较低。

这种焊接工艺可应用于很多工程材料的焊接，包括不锈钢，铝合金和活性金属，比如钛。钨极惰性气体保护焊工艺的上述特点决定了其广泛应用于太空，核工业和发电厂以及化工设备，食物生产及娘接设备的制造。

3.1.2.4 等离子弧焊

钨极惰性气体保护焊中使用的电弧使其通过喷嘴上的小孔转变成高能量的电弧。拘束电弧并想成等离子喷射。如图 3.9，等离子弧焊利用收缩电弧产生的热量熔化接头区域，这个电弧是在不熔化的焊条尖端和工件或收缩喷嘴间形成的。根据操作形式和应用场合的不同，很多种的气体起到隔离效果。

等离子弧焊依靠很多特殊的工艺方法比如匙孔。首先等离子弧穿透接头形成通孔。当焊枪沿着接头移动，通孔前方的金属熔化，转为后方并开始凝固。

等离子弧工艺的特点是由于操作形式和电流，但是总的来说等离子弧工艺具有以下特点：

低电流电弧稳定性好

与钨极氩弧焊相比有定向的改善

与钨极氩弧焊相比熔化效率提高

匙孔焊接的可能性

等离子焊的上述特点使其在薄板焊接，电子部件和传感器的封装以及在带和管上的高速纵向焊接中有着广泛的应用。

3.1.2.5 药芯焊丝电弧焊

如图 3.10 所示，药芯焊丝由焊剂矿物和金属粉末的组合充满了金属外皮。药芯焊丝电弧焊工艺规程与熔化极气体保护焊相似，原理如图 3.11 所示。制造药芯焊丝的一般过程为：将薄板带折成 U 型，在其中添加焊剂，将 U 型槽封口获得圆形截面的焊丝，最后通过拉拔或轧制使焊丝达到所需尺寸。可选的结构，如图 3.12 所示，可能会产生重叠或折叠带或耗材将管中填充焊剂，可能进行并拉拔操作以减少直径。典型的焊丝直径在 0.8mm-3.2mm。

药芯焊丝有以下优点：

熔敷效率高

合金由焊剂中产生

焊渣起到屏蔽和载体的作用

提高电弧稳定和屏蔽作用

重要词汇:

GTAW 钨极氩弧焊 maintain 维持 joint 接头 sustain 持续 fuse 熔化 electrode 焊条 deposition rate 熔敷速度 Plasma Welding 等离子焊 constrict 收缩 torch 焊枪 solidify 凝固 current 电流 directionality 定向地 flux 焊剂

第四章 Casting

1、Only the advent(出现)of industry sponsored(赞助、主办)research in the past 10 years has brought any effective degree of understanding of what happens in the one fiftieth of a second(50 分之一秒) or so available for mold filling. (倒装)

在过去的 10 年里, 只有工业赞助科学研究的出现才给了解五十分之一秒左右的充型过程中发生了什么带来有效的帮助。

2、From this research has come a practical system for preengineering(初步的)fill time and gate area in relationship to(与...的关系) metal temperature, die temperature, and casting configuration.

在这次研究中产生了一个初步确定充型时间, 浇口区域和金属温度, 模具温度, 铸件结构之间关系的实用性方法。

3、These systems, too, have provided the springboard*(跳板) for further industry supported research to reduce the minimum wall thickness possible in large zinc* die casting.

这些研究也为后来工业支持关于减少大的锌铸件压铸中的最小壁厚的研究提供了铺垫。

4、Research on this subject continues with the help of modern instrumentation (装置) and high-speed photography(高速摄影术)

在这方面的研究在现代设备和高度摄影技术的帮助下得以继续。

5、The term "shot speed"(压射速度) is used to describe the velocity of the metal injecting plunger, expressed in (用...表示) feet per minute or inches per second.

定义“压射速度”用来描述金属注射活塞的速率, 用英尺/分或英寸/秒表示。“压射活塞”是组成金属泵的活塞, 在“压射管”或“压射缸”中工作。

6、The term "temperature gradient" refers to the difference between the surface and subsurface die temperature.

定义“温度梯度”是指铸型表面与次表面之间的温度差。

7、More recently, the cold chamber process utilizes a piston and cylinder into which the metal charge (金属料) for each cycle is ladled.

最近, 冷室压铸工艺利用活塞和压射室(缸), 每次压铸时把金属料(熔融金属)浇到压射室中。

8、As with any other process(和任何其它的工艺一样), die-casting has its limitations as well as its advantages. For one thing, it is rarely economical to use multiple part (由几部分组成的) cores such as are normal in the permanent mold casting of auto pistons.

与其它工艺相比, 压铸有局限性的同时也有优越性。首先, 像正常由多部分核心组成的金属型那样铸造汽车发动机活塞是不经济的。

9、Further, in considering what alloys are castable, the piston cylinder fit*(配合)and also the temperatures involved must be taken into account (考虑)。

进一步，考虑合金的可铸性，活塞缸体的配合时，还必须考虑铸造过程中包含的温度条件。

10、Almost since the beginnings of the process, engineers and practitioners* have wondered, conjectured*, and guessed at what was happening as the die cavity filled.

几乎是从压铸工艺起源开始，工程师和从业者就想知道，就猜测和推测在压铸型腔充型时发生了什么。在本质上，他们在不理解压铸中所包含机制的情况下成功地应用着这种工艺。

11、The result was two diametrically opposing concepts

结果是正好对立的两种概念。

12、It is most interesting that high-speed movies taken of water injected into plastic molds a few years ago confirm Frommer's concept

最有意思的是几年前拍摄的水注射进入塑料模具的高速影像真是了弗罗姆的观念。

13、Real scientifically research based on metal flow in die-casting did not move forward until researchers at now introduced the concept of water analogy of metal flow. They used clear plastic molds and shot-sleeves to study the action of the water with high-speed photography.

真正的对压铸型中金属流动的科学基础研究直到在 Dow (陶氏) 研究人员引入了水模拟金属流动的概念之后才有了进展。他们在高速摄影技术的帮助下用透明的塑料模具和压射管来研究水的运动。

14、The water analogy studies confirmed that the metal stream, in virtually* all instances (在各种实际情况下), did leap from the gate orifice as a jet, as Frommer had predicted.

水模拟研究证实了金属流动，在各种实际情况下，以喷射方式从浇口冲出，正如弗罗姆所预言的。

These include the freezing point(金属的凝固点)

15、Equating fills time, cavity volume, and a chosen gate velocity gives gate area.

这些参数的大小是在充型时间内可允许的最大值。 $A = V/vt$ (由充型时间、型腔体积和一个事先选好的充型速度可以计算出充填区域的面积)

16、So, with 10 years of concentrated research on the subject of metal flow, the Die Casting Research Foundation (DCRF) was able to develop a viable* system (可行的方法) of gate sizing.

随着近十年压铸研究基金会专注于金属流动方面的研究，在关于确定浇口大小方面，该组织已经探索出了一套实用的理论体系。

17、The factors that are "plugged in" (与...有关) to the DCRF system include: (1) casting configuration in terms of relative thinness, expressed as pounds per square foot of total surface area;

与 DCRF 理论体系相关的因素包括：1 铸件结构上，它的相对分型厚度，这个厚度用每平方英尺上所承受的磅数来表示；2 铸型内腔表面的平均温度（内腔表面指被浇入金属液浸入的部分）3 保温炉内金属的温度。

18、Members who produce plating (电镀) quality zinc die castings have found by experience that they must make an adjustment to about 60 percent of the fill time (is) determined by incorporating (结合) the factors listed above. 镀锌压铸件的生产者们在生产中发现，对于由上述各个因素所决定的充型时间，他们必须将这个值调整为它的 60%。

19、How many die casters have, in years past,(在过去的岁月中) selected a plunger/sleeve size because it held sufficient metal, then made defective*(有缺陷的)shot after shot, not realizing that the limited plunger speed would never produce a quality part?

在过去的岁月中，有多少压铸工们在选择活塞/套筒时只考虑它是否能容纳足够的金属？结果他们生产出是一件又一件的不合格的废品。他们没有意识到当活塞压射速度受到限制时，是永远不可能生产出合格的产品。

20、Industry has not yet conducted(进行)sufficient systematic research to be able to predict where to place the gate or how to distribute the gate area.

压铸行业内目前还没有开展足够的系统研究来预测浇口的安放位置 and 如何分配浇口各部分区域的大小

21、Each new job is a challenge to the mold designer as to (关于) where to place the gate and how to aim it to provide proper metal distribution.

对于模具设计者来说, 安放浇口的位置和如何提供合适的金属用于分配, 这对于压铸研究而言是一个多产的领域。

22、Boxes with flanges*(法兰) are subject to(遭受) similar problems. It is surprising to some that the most difficult shape to fill with good surface finish is a flat plate (平板) .

带有凸缘的箱子也面临着类似的问题, 另人惊讶的是, 最难浇注成型的铸件居然是有着较低表面粗糙度的大平板件。

23、With the advent of (随着...的出现/到来) industrial research in metal flow, the nature of metal flow and die filling is becoming better understood. With this better understanding in hand,(在较好地掌握了金属的流动特性之后) the die caster is becoming more adept*(熟练的) at directing (引导) the gate stream logically and scientifically (科学和合理)

随着对金属流动的工业化研究的出现, 人们对金属流动和压铸充型本质的认识越来越深刻。正是得益于此, 压铸工们在科学并合理地引导金属液流方面也变得更加熟练。

24、What was happening was that as they enlarged the gate area they reduced the gate velocity, virtually canceling the possible benefits of their efforts at redirection.

发生的事情就是当他们扩大内浇道面积时, 内浇道填充速度减小, 实际上也就是消除了他们在改变方向上的努力可能带来的益处。

25、Researchers who have explored the influence of gate velocity at some length (比较详细地) have frequently reported a "no man's land" in the velocity scale.

部分比较细致的研究了内浇口金属液流动速度的研究者们已经多次说过, 在金属液的速度尺寸上, 还没有人涉足过

26、In an effort to understand further the role of gate velocity, the DCRF is currently sponsoring additional work under Wallace at Case Western Reserve University. By means of (依靠, 借助于) high-speed photography (5 000 frames/sec), the influence of velocity on the nature of the metal stream emerging from (自...出现) the gate orifice is being studied. At this time several things have been learned

在致力于深化对内浇口金属液流速所扮演的角色的认识上, DCRF 目前在 Case Western Reserve 大学还发起了额外的研究工作。借助于高速摄影技术, 人们正在研究速度对内浇口孔内的金属流的影响。在这期间人们取得了好几项成果。

5.2.1upsetting

Upsetting is defined as “free forming”, by which a workpiece segment is reduced in dimension between usually plane, parallel platens(模板). It also includes coining and heading. Closed-die forming(净成形), shape upsetting(形状成形, 体积镦粗), or die heading involve tools which contain the intended shape wholly or in part.

5.2.1 镦粗

镦粗定义为“工件在平面和平板间部分尺寸变小的自由成形”。也包括压印和顶镦。闭式模锻、镦粗、冲模顶镦需要的工具能容纳预期形状的全部或部分。

Upsetting is of interest for theoretical studies as a model process. Among the processes of metal forming it represents a basic process which can be varied in many ways. A large segment of industry depends primarily on the

predominant application of upsetting processes. Parts produced are screw, nuts, rivets, nails, and bolts.

镦粗理论研究模型过程是很重要的。金属的塑性成形工艺是一个基本工艺,可以通过很多方法来变形。大部分工业主要依靠镦粗工艺的运用。其部分产品有螺丝钉、螺母、铆钉、钉子、螺栓。

Although upsetting has great significance for metal forming, research remains to be done with regard to stresses and deformation which occur during the process. This is due to significant difficulties which result from the transient nature of the process and the difficulty of defining friction conditions between tool and workpiece.

尽管镦粗对金属成形是很重要的,但是关于加工过程的应力、应变仍需进一步研究。这是由于加工过程的瞬时性和工具与工件之间复杂的摩擦情况所引起的重大困难。

Upsetting is a transient forming process, that is, streamlines and flow lines do not coincide during forming. Material flow, characterized by streamlines(流线型) and flow lines(变形流线), can be made visible through grid lines or photos of light dots. Both the state of motion and the deformation distribution are affected more profoundly by friction than by temperature and strain rate. The severity of friction increases for large reductions and for workpiece with initially high diameter-to-thickness ratios. For such cases good lubrication becomes especially important.

镦粗是种瞬时变形过程,即成形过程中金属流线(流线型)与流动方向不一致。材料的流动特点可通过金属流线和流动方向来表示,通过网格线和光点照片是可见的。(比起金属流线和金属流动方向),变形分布和运动状态受摩擦和应变速率的影响更大。大变形和大的高径比的工件摩擦的重要性更大。由于这些原因,良好的润滑变得特别的重要。

Deformation distribution can be determined by micro-hardness scanning. A distribution is obtained which had previously been provided qualitatively by Siebel: deformation is concentrated on an area, which extends diagonally outward from the center of the sample. In hot upsetting, the distribution of local deformation becomes more uniform with increasing tool contact speed [0.445m/s]. This is indicated by diminishing bulging(凸起,凸出) of the peripheral(外围的) surface. However, cold upsetting with high tool contact velocities [0.1445m/s] results in a deformation distribution which is less uniform in the upset direction, but more uniform perpendicular to it.

变形的分布能够通过显微硬度扫描测定。分布状态是先前 Siebel 定性地提供的:分布集中在一个区域,并由中心线沿对角线向外延伸。在热镦粗中,局部变形的分布随着工具速度[0.445m/s]的增加更加均匀。通过减少鼓形的周围表面来表明。然而,在冷镦粗中,高的工具速度[0.1445m/s]会导致镦粗方向变形分布不均匀,但在垂直方向上要更均匀些。

The contact areas expand by both sliding and fold-over(重合) of parts of the free surface onto the die face. By choosing the inclination of the platens sliding can be influenced, resulting in a change of the relative amounts of sliding and fold-over. In hot upsetting the increase in tool-workpiece contact area of cylindrical samples is greatly dependent upon work material, tooling, initial diameter-to-length ratio, and strain.

接触区靠模具表面上自由面的滑移和折叠扩展。滑移受平板倾斜程度影响,并引起滑移和折叠相对数量的变化。在热镦粗中,模具与工件的圆柱形试样接触区的增加依靠于工件材料、模具、初始高径比、应力。

5.2.2 Forging

The term advanced forging techniques is used here to describe processes which either produce a much more accurate surface finish or aim at achieving special mechanical properties. In many cases the processes discussed aim at making improvements in both of these directions. Particular impetus(动力,冲量) for the development of advanced techniques and processes in the areas of primary forming and forging has come from the aerospace industry and its rapid development over the past 40 years. The need to manufacture highly stressed airframe and engine components led very rapidly to the combination of specific primary forming and forging and forging processes. Exactly how many “new techniques” have been created in this way is difficult to estimate, but it is true

to say that more and more applications are now being found in other fields too, such as in automobile and machine tool manufacture, as a result of the increasing pressure to save time, material, and energy.

5.2.2 锻造

先进的锻造技术

“先进锻造技术”用以描述生产一个精度更高的表面或致力于达到特殊性能的工艺。在许多情形下，对工艺的讨论在于使这两个方面得到改善。在过去 40 年，初始成型与锻造领域的先进技术所需的冲压力来自航天工业及其本身的迅速发展。制造高强度的机身和发动机部件的需要，迅速导致了特种成型和锻造的结合。尤其在粉末冶金工业与锻造工艺的结合取得巨大进展。要准确估计用这种方法衍生出多少新技术是很困难的，但由于节约时间、材料和能量的压力越来越大，在如汽车与机械零件制造行业确实能看到该方法日益增多的应用。

精锻与高精锻

The term precision forging is used to describe closed-die forging processes in which manufacturing accuracy with regard to shape and dimensional tolerances as well as surface finish exceeds the normal standards by such an amount that at least one finish-machining operation can be saved.

“精锻”用于描述对工艺形状、尺寸公差和表面光洁度的制造精度都超过了普通锻造标准的闭式模锻工艺，至少减少了一道精整工艺。

Precision forging differ from conventional forgings in the following respects: the draft angle is 0° or close to this value, tolerances are narrower, length and width tolerances including offsetting are typically only half those of conventional forging, and thickness tolerances are reduced to about two-thirds of their former values.

在下面几个方面中精锻不同于传统的锻造：拔模斜度为零度或接近此值，公差等级更小，长度与宽度公差等级只有传统锻造的一半，厚度公差等级减少到传统厚度公差等级的 $2/3$ 。

The manufacturing processes used in conventional and precision forging are similar in principle. Precision forging may be considered as an intermediate stage between closed die forging with and without flash. In order to reduce the die load, provision has been made for flash on the web, although the flash thickness must be kept to a minimum. This may be achieved by accurately controlling the weight of the intermediate forging. The flash is subsequently removed by sawing.

原则上传统锻造与精锻在制造过程上是相似的。精锻被看作为有无毛刺的闭式模锻的中间状态。为了减少模具负载，在毛坯上提供毛刺，但毛刺必须是最小的。这种方法或许能通过精确地控制中间锻造的比例来实现。随后毛刺通过锯切消除。

A kind of precision forging without side draft is a part of an aircraft window made of aluminum alloy. The component is subjected to a complex of tensile and torque stresses corresponding closely to the stresses in the fuselage shells of the aircraft. A conventional forging requires almost complete machining on all sides. Value analysis showed the great economic savings of using a precision forging which eliminates all the machining required except for the machining of the fixing holes. Furthermore the elimination of surface machining improves the mechanical properties of the component with respect to fatigue and stress corrosion since the grain flow is not interrupted. Draft on precision forging is reduced from 5° to 1.5° , the minimum web thickness are also smaller. The length and width tolerances, on the other hand, are the same as with conventional forging, although offsetting is reduced and the demands on flatness are higher. A further consideration is the need for exact and even trimming, since no residual flash is permissible either on the outside or on the inside of the part.

一种无拔模斜度精锻应用在合金机窗制造。组件受复杂拉力与力矩系统的影响，与飞机机舱外表面所受的压力近似相等。传统的锻造需要各个方面的完整加工。价值分析表明用于精锻的主要的经济节约可以

消除所有的加工需要,除了孔加工外。此外,表面精加工能改善晶体流动是的疲劳和应力腐蚀的力学性能。精锻的拔模斜度从 5 减少到 1.5,最小毛坯厚度以 3.05mm 代替了(传统精锻的)6.35mm,过度半径和部分厚度也相当的小。另一方面,尽管补偿减少及对平整度的要求更高,长度公差与宽度公差与传统锻造相等。深入考虑精确和平整整形是必要的,因为不管在工件的内外表面都不允许毛刺的存在。

High precision forging may be considered a special case of precision forging. Through high-precision forging components can be produced ready for assembly to an accuracy normally only achieved by machining. High demands are made not only on dimensional and shape accuracy, but also on surface finish, but this not just with entire workpiece or a major part of it, as in the case of turbine blades. Thus it is possible to make a distinction between precision and high-precision forging, even though the boundary is blurred.

高精锻是精锻中的特例。通过高精锻使得组元件的配合达到机加工的精度。不仅对尺寸和形状精度,还对表面光洁度有高的要求,这些要求不仅仅只针对个别的尺寸和表面,而是对整个工件或者工件的大部分而言的,例如涡轮机叶片。所以区分精锻和高精锻是可能的,尽管它们之间的界限比较模糊。

In high-precision forging the conditions must be respected even more closely than with precision. In particular, the following points must be observed.

与精密锻造相比高精密锻造的条件必须准确地遵守,尤其是以下几点必须遵守:

(1) High-quality finish of the die cavity, corresponding at least to ISO quality IT 8.

(1) 高光洁度的模腔,相应的精度等级至少要达到国际标准 IT8 级。

(2) Reduction of tool wear suitable choice of die material. Avoidance of scale formation through rapid heating of the workpiece, heating in an inert atmosphere(惰性气氛), or forging in the warm condition (i.e., at reduced temperature). Attention must be paid to good agreement between intermediate and final shapes.

(2) 通过选择合适的模具材料来减少刀具的磨损。可以通过快速加热工件、在惰性气氛中加热、在较低温度下温锻等来避免氧化皮的形成。

(3) Precision control of both die and workpiece temperature.

(3) 精确控制模具和工件的温度。

(4) Precision control of the volume of the starting material. In addition, the material should be clean and free of surface defects. In some cases this may necessitate machining prior to forging.

(4) 精确控制起始物料的体积。除此之外,材料应清洁,并且没有表面缺陷。某些情况下,锻造之前可能需要预先加工。

It is necessary to avoid oxidation and decarburization as far as possible during heating, forging, and heat treatment. In order to improve surface finish after forging and heat-treatment operations, parts are usually pickled and then polished.

在加热、锻造和热处理时尽可能地避免氧化和脱碳是必要的。其后为了提高表面光洁度,零件通常要酸洗然后抛光。

5.2.3 轧制

The rolling process belongs to the compressive deformation processes, and has been classified based on kinematics, tool geometry, and workpiece geometry.

轧制工艺属于常规的压缩成型过程,并根据运动学、刀具几何形状、工件几何形状分类。

Rolling can be defined as a compressive deformation process in which there is either a continuous or a stepwise deformation with or more rotary tools (rolls). Additional tools, such as mandrels, guide blocks, and support bars, may also be used in the rolling process. The force transmission is achieved either by power-driven rolls or by the workpiece transport.

轧制可以定义为一种用一个或多个旋转的刀具(轧辊)进行连续的或逐步成型的过程。一些额外的工具,例如心轴,导板和支撑杆,在轧制过程中也可能用到。力的传输是通过电力驱动的辊或工件传输实现

的。

Based on kinematics, the rolling process can be classified as follows: longitudinal, cross, and skewed(斜). In longitudinal rolling the rolled workpiece moves through the rolling gap perpendicular to the axis of the rolls, without rotation about the workpiece axis. Cross rolling is characterized by rotary movement of the workpiece without translational motion. In skewed rolling a combination of both rotary and translation movements of the workpiece occurs.

基于运动学，轧制工艺可以分为：纵轧，横轧，斜轧。在纵向轧制中，被轧制的工件通过轧制间隙垂直于辊轴移动，没有绕工件轴旋转。横向轧制的特征是绕工件轴旋转运动，没有平移运动。在斜向的轧制中，工件做旋转和平移的组合运动。

The tool geometry is another characteristic that can be used to classify the rolling process. The process of rolling where the rolls have along their contact surface either a cylindrical or a conical(锥形) form in the rolling gap is termed flat-rolling. If the contact surface of the rolls deviates from the cylindrical or conical form, the process is called profile rolling.

刀具的形状是另外一个可以用来对轧制工艺进行分类的特征。轧辊沿着他们的接触面在轧制间隙中做圆柱形或圆锥形成形的轧制过程，被称为平辊轧制。如果轧辊的接触面偏离圆柱形或圆锥形成形，轧制过程被称为孔型轧制。

The rolling process can be further classified depending upon whether a solid or a hollow workpiece is rolled.

轧制可以根据轧件是实的还是中空的进行进一步分类。

The process of sheet rolling is convenient for defining the various basic parameters. Furthermore, the sheet is the form of starting material that is used for many processes of tensile, compressive, and combination forming. The characteristics (dimensional accuracy, forming behavior, and surface quality) and thus the manufacturing conditions of the sheets are very important for their optimum use in the various deformation process.

用板材轧制的过程来定义众多基本参量很方便。此外，板材是起始物料的形式，用于许多拉伸、压缩和组合成形过程。在各种成形过程中，板料的特征（尺寸精度，成形性能，表面质量）和制造条件，对于板料能被最优化的利用非常重要。

5.2.4 挤压

Owing to the fibrous structure developed in the extrusion direction, the mechanical properties of extruded products are directionally oriented (mechanical anisotropy). The anisotropy may be caused in different ways, such as a straight-line arrangement and linking of the heterogeneous structure elements in the extrusion direction (geometric anisotropy), banding of the structure, or the creation of preferential orientation(择优取向) in the crystals (texture). The practical consequence of mechanical anisotropy is generally a reduction in strength at a right angle to the extrusion direction, which, however, is unimportant in most cases.

由于在挤压方向纤维性结构的形成，挤压件的机械性能是有方向性的（各向异性）。各向异性可由不同方式引起，例如直线的规律排列和在挤压方向不同类结构元素的连接（几何的各向异性），组织的聚合，或者在晶粒中优先取向的形成（织构）。机械性能各向异性的实际实际结果是在与挤压方向垂直的方向强度的降低，然而，其在大部分情况下并不重要。

Recrystallization plays an important part in determining the structure of extruded products, not only in materials that recrystallized during deformation (e.g., copper, brass), but also in those subject to dynamic recovery during extrusion (e.g., aluminum and aluminum alloys). Recrystallization may in part be superimposed on the recovery processes during extrusion. It may, on the other hand, only begin after deformation when the deformation rate is greater than the rate of the recovery and crystallization processes, thus causing no major reduction in work hardening.

再结晶是决定挤压件结构的重要一部分，不仅对于那些在挤压过程中再结晶的材料（例如，铝和铝合

金), 还有挤压过程的动态回复 (如铝与铝合金)。挤压过程中再结晶和回复可能会部分重叠。另一方面, 当成型速率大于恢复速率和再结晶过程, 再结晶才在变形后发生, 因此, 不会导致加工硬化大的减少。

The grain formed by recrystallization may vary considerably in size, both in the direction of extrusion and at a right angle to it. The size depends on the type of material, the strain imparted, and the temperature. Large strains lead to a smaller grain size, high temperatures during deformation tend to increase grain size. This results in an irregular structure and thus variations in the mechanical properties. This takes the form of an increase in strength from the center to the edge of the cross section and from the beginning to end of the extrusion (assuming no subsequent heat treatment is performed). Variations in strength across the cross section can mostly be overcome by the use of larger strains.

再结晶的晶粒在形状上有很大的差别, 挤压方向和垂直方向都是如此。晶粒形状受材料类型、原始晶粒和温度影响。大应变会使晶粒变小, 而挤压过程中较高温度则会使晶粒粗化。这些将导致组织不规则和机械性能变化。这造成了从挤压开始到结束截面上从中心到边缘部分强度的增加形式。通过更大的应变可以消除截面上强度的变化。

Coarse grain may be found in the boundary layer of the extrusion when a critical value of residual stress still remains after recovery or recrystallization. Above all, this has been observed in aluminum-copper-magnesium and aluminum-magnesium-silicon alloys after solution heat treatment. The coarsely recrystallized layer is thinnest at the beginning of the extrusion and thickens toward the end. The material properties are very different in the coarse-grain zone from those in the extrusion core. Thus, for example, corrosion resistance is less, and the strength in the extrusion direction is also reduced. In contrast to the typical characteristics of extruded products (anisotropy), extrusions with coarse-grain zones may exhibit higher strength in the transverse direction than in the direction of extrusion, even though the structures in the coarse-grain zone may have grains parallel to the extrusion direction. Coarse-grain zones tend to cause surface roughening during subsequent forming operations and lead to the formation of cracks during quenching.

在回复和再结晶结束后如果仍存在临界残余应力, 将会在挤压边界层发现粗晶。尤其会在 Al-Cu-Mg 和 Al-Mg-Si 合金固溶热处理后观察到这种情况。再结晶粗晶层从挤压开始最薄到结束慢慢增厚。粗晶区与挤压中心的力学性能差别很大。因此, 例如挤压方向上的抗腐蚀性能差些, 强度也会降低。相比于挤压件的典型特征, 即使粗晶区的组织结构或许有与挤压方向平行的晶粒, 带有粗晶区的挤压件在横向上会比挤压方向上表现出更高的强度。粗晶区容易在后续加工中使表面粗糙并且导致淬火时开裂。

Heat Treatment

6.1. Heat Treatment of Steel 钢的热处理

We can alter the characteristics of steel in various ways. In the first place, steel which contains very little carbon will be milder than steel which contains a higher percentage of carbon, up to the limit of about 1.5%. Secondly, we can heat the steel above a certain critical temperature, and then allow it to cool at different rates. At this critical temperature, changes begin to take place in the molecular structure of the metal. In the process *known as annealing**, we heat the steel above the critical temperature and permit it to cool very slowly. This causes the metal softer than before, and much easier to be machined. Annealing has a second advantage, it helps to relieve any internal stresses which exist in the metal. These stresses are liable to occur through hammering or working the metal, or through rapid cooling. Metal which we cause to cool rapidly contracts more rapidly on the outside than on the inside. This produces unequal contractions, which may give rise to distortion or cracking. Metal which cools slowly is less liable to have these internal stresses than metal which cools quickly.

我们能以很多种方式改变钢的特性。首先, 在含碳量不超过1.5%时, 含有很少量碳的钢要比高含碳量的钢软一些。其次, 我们可以在某一临界温度上对钢进行加热, 然后以不同冷却速度使之冷却。在此临界

温度，钢的分子结构开始发生转变。在退火过程中，我们把钢加热到临界温度以上然后缓慢冷却。这会使钢比开始时更软些，并更容易进行机加工。退火有另一个好处，它帮助消除存在于金属中的内应力。这些内应力容易产生于锤锻或金属加工快速冷却。快速冷却的金属外部的收缩比内部更快。这将产生不平衡收缩，可能导致变形或开裂。金属缓慢冷却相对于快速冷却不容易产生这些内应力。

On the other hand, we can make steel harder by rapid cooling. We heat it up beyond the critical temperature, and then quench* it in water or some other liquid. The rapid temperature drop fixes the structural change in the steel and this hardened steel is more liable to fracture than normal steel. We therefore heat it again to a temperature below the critical temperature, and cool it slowly. This treatment is called tempering*. It helps to relieve the internal stresses, and makes the steel less brittle than before. The properties of tempered steel enable us to use it in the manufacture of tools which need a fairly hard steel. High carbon steel is harder than tempered steel, but it is much more difficult to work.

另一方面，我们可以利用快速冷却使钢的硬度提高。我们将钢在临界温度上进行加热，然后在水或其他液体中淬火。温度快速下降决定了钢结构的改变，这种强化的钢比普通钢更容易断裂。因此，我们将其置于临界温度以下再次加热，然后缓慢冷却。这种处理方法叫做回火。这种处理有助于消除内应力，且没有回火前那么脆。回火钢的特性使得我们可将其用于高硬工具的制造。高碳钢硬度比回火钢高，但是很难进行机加工。

These heat treatments take place during the various shaping operations. We can obtain bars and sheets of steel by rolling the metal through huge rolls in a rolling mill. The roll pressures must be much greater for cold rolling than for hot rolling, but cold rolling enables the operators to produce rolls of great accuracy and uniformity, and with a better surface finish. Other shaping operations include drawing into wire, casting in molds, and forging.

这些热处理方法应用于各种成型过程中。我们可以通过大型轧制机轧制金属得到钢的棒材和板材。冷轧压力比热轧压力高得多，但冷轧能够使操作工人生产出高精密且均匀的，表面光洁度更好的产品。其他成型操作包括拉丝、铸造、锻压。

6.2.Principle of Heat Treatment of Steel 钢的热处理原理

Theoretical study of heat treatment steel was initiated by the discovery of the critical points in steel made by D. K. Chernov in 1868. Chernov's assumption that the properties of steels are determined by the structure and that the latter depends on the heating temperature and rate of cooling has been generally recognized. During the decades which followed the researchers were engaged in establishing the relationships between the structure and the conditions of its formation (mainly the heating temperature and cooling rate). The principal achievements in the theory of heat treatment were, however, made in 1920's and 1930's.

钢的热处理的理论研究是由 D.K.Chernov 在 1868 年发现钢的临界温度点开创的。Chernov 关于钢的性能决定于钢的结构以及后者决定于热处理温度及冷却速度的假说得到了普遍的认可。在九十年里后来的研究人员专注于建立结构与成型条件之间的关系（主要是加热温度和冷却条件）。然后，钢的热处理理论原理在 20 世纪 20 至 30 年代才建成。

Metallurgists have gradually come to the conclusion that the type of structure (its texture*, properties, etc.) is determined by the temperature of its formation. It has become clear that the processes occurring in heat treatment can be explained by studying the kinetics* of transformations at various temperatures and the factors affecting the kinetics.

冶金学家已经渐渐的得出金属结构的类型（组织，性能等）决定于其成型温度这一结论。很显然：热处理过程可以通过对在不同温度下相变动力学和影响动力学的因素的研究得到合理的解释。

These concepts formed the basis of extensive experimental work undertaken by S. S. Steinberg and coworkers in 1930 ~ 1940. They collected a vast experimental material which has constituted the basis of the modern concepts on transformations in steel and the theory of heat treatment of steel.

这些概念基于 1930~1940 S.S.Steinberg 和同事们开始从事的大量的实验形成。他们收集了大量的实验数据，构成了在钢相变的现代化理论和热处理理论的基础。

Studies in the same direction were started by many researchers in other countries at the same time or somewhat later. Among the pioneers in this field, the names of R.F. Mehl and E.C. Bain (USA), and F. Esser, and H. Hannemann (Germany) should be mentioned first; They carried out numerous and detailed studies into the kinetics of transformations in various steels. The nature of hardened steel could only be examined by using X rays and other methods of physical analysis of metals (electron microscopy*, internal friction*, etc.).

很多其他国家的研究人员在同一时期或之后某一时间在同一方向上开始了研究。在这些行业先锋中，R.F.Mehl 和 E.C.Bain（美国），以及 F.Weaver、H.Esser 和 H.Hannemann（德国）的名字应首先被提及，他们对不同种钢材的相变动力学进行了大量且详细的研究。淬火钢的性质只能用 X 射线方法和其他金属物理分析方法进行检测（包括电子显微技术、内耗等）。

Numerous works of G. V. Kurdymov and his followers, and a number of other foreign metal-physicists have revealed important peculiarities* in the fine structure（精细结构）of steel.

G.V.Kurdymov 和他的同事以及很多其他国外的金属学家的大量工作揭露了钢的微结构上的重要特性。

The theory of heat treatment of steel is understood as the analysis of the processes of structure formation (on transformation) and the particularities of structural state of alloys (in non-equilibrium) Here the theory of heat treatment of steel, based on the general theory of phase transformations in undercooled systems will be discussed.

钢的热处理理论被理解为对结构形成过程（如相变）和合金结构状态 reshuffle 的分析（如非平衡态）。基于过冷系统中普通相变理论的钢的热处理理论将在后面讨论。

6.2.1. Formation of Austenite 奥氏体的形成

The transformation of pearlite into austenite can only take place on a very slow heating as follows from the Fe-C constitutional diagram. Under common heating conditions, the transformation is retarded and results in overheating, i.e. occurs at temperatures slightly higher than those indicated in the Fe-C diagram.

从铁碳相图可知，只有在缓慢加热时珠光体才能向奥氏体转变。在普通加热条件下，相变滞后并导致过热，也就是说相变发生在比铁碳相图中指示的更高一点的温度。

When overheated above the critical point, pearlite transforms into austenite, the rate of transformation being dependent on the degree of overheating.

当在临界点以上使钢过热，珠光体开始转变为奥氏体，转变速率受过热度影响。

The time of transformation at various temperatures (depending on the degree of overheating) shows that the transformation takes place faster (in a shorter time) at a higher temperature and occurs at a higher temperature on a quicker heating.

不同温度（决定于过热度）下的相变时间表明在高温下相变更快并且加热越快相变发生的温度越高。

For instance, on quick heating and holding at 780°C, the pearlite to austenite transformation is completed in 2 minutes and on holding at 740 °C, in 8 minutes.

例如，快速加热并在 780°C 保温，珠光体向奥氏体的转变两分钟内即完成，而在 740°C 保温则需 8 分钟。

Irrespective of the heating rate, the transformation occurs immediately after the passage through the equilibrium critical point; the temperature interval on heating determines not the physical beginning and the end of the transformation, but the temperature interval within which the main mass of pearlite changes to austenite.

不考虑加热速率，越过平衡临界点后相变立即发生；加热温度区间不光决定相变的实质性开始和结束，并且在温度区间内大量的珠光体转变为奥氏体。

The end of the transformation is characterized by the formation of austenite and disappearance of pearlite (Ferrite* + Cementite*). This austenite is however inhomogeneous even in the volume of a single grain. In places earlier occupied by lamellae (or grains) of pearlitic cementite the content of carbon is greater than in places of

ferritic lamellae*. This is why the austenite just formed is inhomogeneous.

转变结束以奥氏体的形成及珠光体（铁素体+渗碳体）的消失为标志。该奥氏体无论如何是不均匀的，即便是在一个晶粒内也一样。先前被片状珠光体占据的地方，渗碳体的含碳量高于片状铁素体的含碳量。这就是生成的奥氏体并不均匀的原因。

In order to obtain homogeneous austenite, it is essential in heating not only to pass through the point of the end of pearlite to austenite transformation, but also to overheat the steel above that point and to allow a holding time to complete the diffusion processes in austenitic grains.

为了获得均匀地奥氏体，加热过程中不仅需越过珠光体转变成奥氏体的结束点，而且要使钢过热并保温一段时间使奥氏体晶粒的扩散结束。

The rate of homogenization of austenite appreciably depends on the original structure of the steel, in particular on the dispersity and particle shape of cementite. The transformations described occur more quickly when cementite particles are fine and, therefore, have a large total surface area.

奥氏体均匀化的速率在很大程度上决定于钢的原始组织，特别是渗碳体的弥散程度和颗粒形状。当渗碳体颗粒细小，拥有一个大的完整的表面区域时，前面所描述的转变发生的相当迅速。

6.2.2.Coarsening of Austenite Grains 奥氏体晶粒的粗化

At the beginning of pearlite to austenite transformation, the first grains of austenite form at the boundaries between the ferrite and cementite--the two structural constituents of pearlite. Since these boundaries are very developed, the transformation starts from formation of a multitude of fine grains. Therefore, at the end of the transformation the austenite will be composed of a great multitude of fine grains whose size characterizes what is called the original austenitic grain size.

在珠光体向奥氏体转变的初始阶段，第一批奥氏体晶粒首先在铁素体和渗碳体（这两者是珠光体的组成部分）的晶界处形成。由于这些晶界非常发达，转变从大量细小颗粒的形成开始。因此，转变结束时，奥氏体由大量细小晶粒组成。这些晶粒的尺寸特征被称为奥氏体初晶尺寸。

Further heating (or holding) upon the transformation will cause coarsening of Austenite grains. The process of grain coarsening is spontaneous, since the total surface area of grains diminishes (the surface energy decreases) and a high temperature can only accelerate the rate of this process.

进一步加热（或保温），这种转变将导致奥氏体晶粒的粗化。因为可以减少晶粒表面积（表面能降低），晶粒的粗化过程是自发的，提高温度只能够加快粗化过程。

In that connection, two types of steel *are distinguished*: inherent fine grained and inherent coarse grained, the former being less liable to grain coarsening than the latter.

就此而言，钢被区分为两类：本质细晶粒钢和本质粗晶粒钢，相较后者，前者不容易粗化。

The size of grains formed in steel by heat treatment is called the actual grain size.

钢通过热处理形成的晶粒尺寸称作实际晶粒度。

Thus, a distinction should be made between: (1) original grain, i.e. the size of austenitic grains immediately after the pearlite to austenite transformation; (2) inherent (natural) grain, i.e. the liability of austenite to grain coarsening; and (3) actual grain; i.e. the size of austenitic grains under given particular conditions.

因此，需要区分两者：（1）起始晶粒度，珠光体刚转变为奥氏体时奥氏体的晶粒尺寸；（2）本质晶粒度，奥氏体晶粒粗化的倾向性；（3）实际晶粒度，在给定条件下奥氏体晶粒的尺寸。

The size of pearlitic grains at the same temperature of the austenite to pearlite transformation depends on that of the austenitic grains from which they have formed. Austenitic grains grow only during heating (but are not refined in subsequent cooling), because of which the highest temperature a steel is heated to in the austenitic state and the inherent grain size of that steel determine the final grain size.

在奥氏体转变为珠光体温度下，珠光体晶粒的尺寸取决于已经成形的奥氏体晶粒。奥氏体晶粒反在加

热过程中长大（但在随后的降温过程中不会变细）。因此，在奥氏体状态钢加热的最高温度以及钢的本质晶粒度决定了最终晶粒尺寸。

The properties of steel are affected only by the actual grain size and not by the inherent grain size. If two steels of the same grade (one inherently coarse grained, the other fine grained) have the same actual grain size upon heat treatment at different temperatures, their properties will also be the same; if otherwise, and many properties of the two steels will also be different.

钢的性能仅取决于实质晶粒度，而不是本质晶粒度。如果两种相同级别的钢（一种本质粗晶粒，一种本质细晶粒）在不同的温度下热处理获得相同的实际晶粒度，他们的性能将会是相同的；否则，两种钢的许多性能将会不同。

Coarsening of austenitic grain in steels has almost no effect on the statistic characteristics of mechanical properties (hardness, rupture* resistance, yield* limit, elongation), but can appreciably reduce the impact toughness*, especially at a high hardness (low temperature tempering). This is due to the fact that grain coarsening raised the ductile to brittle transition temperature.

钢中奥氏体晶粒的粗化几乎不影响钢机械性能的静特性（硬度、断裂抗力、屈服极限、延展性），但是可以在很大程度上减小冲击韧性，特别是高硬度钢（低温回火）。这是由于晶粒粗化提高了塑性、脆性转变温度。

Whereas the actual grain size affects the properties of steel, the inherent grain size is decisive for the processes of hot working.

因此实质粗晶粒影响钢的性能，本质晶粒度决定热加工的过程。

Inherently fine-grained steel is insensitive to overheating, i.e. intensive grain coarsening begins at appreciably higher temperatures than in a coarse grained steel. For that reason, the temperature interval of hardening for the former is substantially wider than that for the latter.

本质细晶粒钢对过热不敏感，也就是说，本质细晶粒钢发生严重晶粒粗化的温度比本质晶粒钢的粗化温度高得多。由于这个原因，前者淬火的温度区间实际上远宽于后者。

Inherently fine grained steel can be rolled (or forged) at higher temperature and the process (rolling or forging) can be finished at a higher temperature without danger of forming a coarse grained structure. As a rule, all grades of *killed steel* (镇静钢) are made inherently fine-grained and all *rimming steels* (沸腾钢), inherently coarse grained.

本质细晶粒钢能够在相对较高的温度下轧制（或锻造），轧制和锻造过程能够在较高温度下完成而没有产生粗大晶粒组织的危险。作为一个规则，所有等级的镇静钢由本质细晶粒钢制成，而沸腾钢由本质粗晶粒钢组成。

6.2.3 Descomposition of Austenite 奥氏体的分解

The austenite to pearlite transformation is essentially the decomposition of austenite into almost pure ferrite and cementite.

奥氏体向珠光体的转变实质上是奥氏体分解为铁素体和渗碳体。

At the equilibrium temperature, the transformation is impossible, since the free energy of the original austenite is equal to that of the final product, pearlite.

在相平衡温度，转变是不会发生的，因为此时原奥氏体的自由能与最终产物珠光体的自由能是相等的。

The transformation can only start at a certain undercooling when the free energy of the ferrite carbide mixture (pearlite) is lower than that of austenite.

转变只能发生于珠光体自由能低于奥氏体的某一温度。

The lower the transformation temperature, the higher the degree of undercooling and the greater the difference in free energies and the transformation proceeds at a higher rate.

转变的温度越低，过冷度越大，自由能之差越大，转变速率也越大。

In the pearlite transformation, the new phases sharply differ in their composition from the initial phase; they are ferrite which is almost free of carbon, and cementite which contains 6.67 percent carbon. For that reason the austenite to pearlite transformation is accompanied with the diffusion*, redistribution of carbon. The rate of diffusion sharply diminishes with decreasing temperature; therefore, the transformation should be retarded at a greater undercooling.

在珠光体转变中,生成的新相的组成与原始相截然不同;它们是几乎不含碳的铁素体以及含碳量为 6.67% 的渗碳体。因此,奥氏体向珠光体的转变伴随着碳的扩散和再分布。扩散的速率会随温度的降低而急剧下降,所以在较大的过冷度下转变会受到阻碍。

Thus, we have come to an important conclusion that undercooling (lowering the transformation temperature) may have two opposite effects on the rate of transformation.

因此,我们可以得到一个重要的结论:过冷度(降低转变温度)会对转变速率产生两个相反的作用。

On one hand, a lower temperature (greater undercooling) gives a greater difference in free energies of austenite and pearlite, thus accelerating the transformation; on the other hand, it diminishes the rate of carbon diffusion, and thus slows down the transformation. The combined effect is that the rate of transformation first increases as undercooling is increased to a certain maximum and then decreases with further undercooling.

一方面,更低的温度(更大的过冷度)会使奥氏体和珠光体的自由能之差增大,从而加速转变;另一方面,这会降低碳扩散的速率,从而减缓转变速率。这两方面共同作用的结果是转变的速率会随过冷度的增加首先增大,直至达到一特定的最大值,进而会随过冷度的增大而逐渐减缓。

At 727°C (A_1) and below 200°C, the rate of transformation is zero, since at 727°C the free energy difference is zero and below 200°C the rate of carbon diffusion is zero (more strictly, too low for the transformation to proceed).

在 727°C (A_1 线)或低于 200°C,转变的速率为零,因为在 727°C 自由能之差为零。而在低于 200°C 时,碳扩散的速率也是几乎为零(更严格地说,温度太低而来不及进行转变)。

As has been first indicated by I. L. Mirkin in 1939 and then developed by R. F. Mehl in 1941, the formation of pearlite is the process of nucleation of pearlite and growth of pearlitic crystals.

珠光体的形成可分为珠光体形核和晶体长大,这一结论是 I.L.Mirkin 在 1939 年首先提出的,在 1941 年 R.F.Mehl 又进行了发展。

Therefore, the different rate of the pearlite transformation at various degrees of under-cooling is due to the fact that undercooling differently affects the rate of nuclearion N and the rate of crystal growth G . At temperature A_1 and below 200°C, both parameters of crystallization N and G are equal to zero and have a maximum at an undercooling of 150 ~ 200°C.

因此,在不同的过冷度下珠光体转变速率不同是由于过冷度对晶体成核速率和长大速率的影响不同造成的。在 A_1 线温度和低于 200°C 时, N 和 G 这两个结晶参数都等于零,在过冷度为 150—200°C 时达到最大值。

It follows from the foregoing that as soon as the conditions are favorable, i.e. austenite is undercooled below A_1 , the diffusion of carbon is not zero, centers of crystallization appear, which give rise to crystals. This process occurs with time and can be represented in the form of so called kinetic curve of transformation, which shows the quantity of pearlite that has formed during the time elapsed from the beginning of the transformation.

只要满足条件就会按照之前所说的进行,也就是说当奥氏体过冷到 A_1 线以下,碳的扩散不为零,晶核开始出现,并开始结晶。这个过程是随时间变化的,并可以用被称作相变动力学的图像来表示,它反映了从转变开始随时间变化形成的珠光体数量。

The initial stage is characterized by a very low rate of transformation; this is what is called the incubation* period. The rate of transformation increases with the progress in the transformation. Its maximum approximately corresponds to the moment when roughly 50 percent of austenite has transformed into pearlite. The rate of transformation then diminished and finally stops.

转变开始的阶段是以低的转变速率为特征的，这就是所谓的孕育期。随着转变过程的进行，转变的速率会增大。大概有 50% 的奥氏体转变为珠光体的时刻转变速率也大概会达到最大值。转变的速率随后会减缓，直至停止。

The rate of transformation depends on under-cooling. At low and high degrees of undercooling the transformation proceeds slowly, since N or G are low; in the former case, owing to a low difference in free energies, and in the latter, due to a low diffusion mobility of atoms. At the maximum rate of transformation the kinetic curves have sharp peaks, and the transformation is finished in a short time interval.

转变的速率取决于过冷度。在低的和高的过冷度下转变进行地都很慢，因为在低的过冷度下， N 和 G 这两个结晶参数很小；前者是由于自由能之差很小，后者是因为原子扩散的驱动力很小。在相变动力学曲线的最大值处有一峰值，并且转变会在很短的时间内完成。

At a high temperature (slight undercooling), the transformation proceeds slowly and the time of the incubation period and the time of the transformation proper are long. At a lower temperature of the transformation, i.e. a deeper undercooling, the rate of transformation is greater, and the time of the incubation period and of the transformation is shorter.

在高的温度下（小的过冷度），转变是很缓慢的，孕育期和实现完全转变所需的时间很长。在一更低的温度下进行转变，意味着更大的过冷度，转变的速率会增大，孕育期和转变所用的时间会缩短。

Having determined the time of the beginning of austenite to pearlite transformation (incubation period) and the time of the end of transformation at various degrees of undercooling, we can construct a diagram in which the left hand curve determines the time of the beginning of the transformation, i.e. the time during which austenite still exists in the undercooled state, and the section from the axis of ordinates* to the curve is the measure of its stability. This section is shortest at a temperature of $500 \sim 600^\circ\text{C}$, i.e. the transformation begins in a shortest time at that temperature.

通过确定奥氏体向珠光体转变（孕育期）的开始时间和在不同的过冷度下转变的终了时间，我们可以作出一条曲线。曲线的左手边表示开始转变的时间，此时奥氏体以过冷形式存在，纵轴到曲线的距离是其稳定程度的度量。在 $500\text{—}600^\circ\text{C}$ 时距离最短，此时转变开始时间是最短的。

The right hand curve shows the time needed to complete the transformation at a given degree of undercooling. This time is the shortest at the same temperature ($500 \sim 600^\circ\text{C}$). *Note that the abscissa* of the diagram is logarithmic**. This is done for more convenience, since the rates of formation of pearlite appreciably differ (thousands of seconds near the critical point A_1 and only one or two seconds at the bend of the curve).

曲线的右手边表示在一个给定的过冷度下完成转变所需的时间。在同一温度（ $500\sim 600^\circ\text{C}$ ）下时间最短。图像中横坐标用对数的形式表示。这样是为了更方便，因为珠光体的形成速率是差别很大的（在 A_1 线临界温度需要几千秒，而在拐点处只需一两秒）。

The horizontal line below the curves in the diagram determines the temperature of the diffusionless martensite transformation. The martensite transformation occurs by a different mechanism and will be discussed later.

图像中曲线下方的水平线表示发生非扩散性马氏体相变的温度。马氏体相变是按照一种不同的机制进行的，后面将会进行讨论。

Diagrams of the type *we discussed* are usually called TTT diagrams (time temperature transformation), or C curves, owing to the specific shape of the curves. The structure and properties of the products of austenite decomposition depend on the temperature at which the transformation has taken place. (奥氏体分解)

我们刚刚讨论的曲线由于其形状特殊常被称作 TTT（时间、温度、转变）曲线或 C 曲线。奥氏体分解产物的性能和结构取决于转变进行的温度。

At high temperatures, i.e. low degrees of undercooling, a coarse grained mixture of ferrite and cementite is formed which is easily distinguished in the microscope. This structure is called pearlite.

在高的温度下（低的过冷），将生成由铁素体和渗碳体组成的粗晶混合物，这很容易在显微镜下分辨出

来。这种组织称为珠光体。

At lower temperatures, and therefore, greater degrees of undercooling, more disperse and harder products are formed. The pearlitic structure of this finer type is called sorbite.

在低的温度下（高的过冷），将生成更多弥散且质硬的产物，这种更细的珠光体称为索氏体。

At still lower temperatures (near the end of the C curve), the transformation products are even more disperse, so that the lamellar structure of the ferrite cementite mixture is only distinguishable in the electron microscope. This structure is called troostite.

在更低的温度下（接近 C 曲线底部），转变产物将会更加弥散，以至于片状铁素体和渗碳体只有在电子显微镜下才能分辨出来。这种组织称为屈氏体。

Thus, pearlite, sorbite and troostite are the structures of the same *nature* (ferrite + cementite) but a different dispersity of ferrite and cementite.

所以，珠光体、索氏体、屈氏体的本质结构组织是一致的（铁素体+渗碳体），只是铁素体和渗碳体的弥散程度不一样。

Pearlitic structures may be of two types: granular* (in which cementite is present in the form of grains) or lamellar (with cementite platelets).

珠光体组织有两种形态：片状（渗碳体呈粒状）和粒状（渗碳体呈片状）。

Homogeneous austenite always transforms into lamellar pearlite. Therefore, heating to a high temperature sets up favorable conditions for the formation of a more homogeneous structure and thus promotes the appearance of lamellar structures. Inhomogeneous austenite produces granular* pearlite at all degrees of undercooling, therefore, heating to a low temperature (below AC_3 for hyper-eutectoid* steels) *results in* the formation of granular pearlite on cooling. The formation of granular cementite is probably promoted by the presence of undissolved particles in austenite, which *serve as* additional crystallization nuclei.

均匀的奥氏体往往会转变成片状珠光体。因此，加热到高的温度为更均一组织形成创造了有利的条件，促进了片状组织的形成。不均匀的奥氏体在任意的过冷度下都会转变成粒状的珠光体，因此，加热到一较低的温度（过共析钢 AC_3 线以下）然后冷却将会生产粒状的珠光体。奥氏体中未分解颗粒的存在，作为异质形核的核心，将会促进粒状珠光体的形成。

Initial heating to a temperature up to 900°C gives lamellar pearlite, with more disperse* structure being obtained at lower temperature.

最初加热温度超过 900°C 得到片状珠光体，在更低的温度下能获得更弥散的结构。

The structure of the same steel at the same temperature of transformation but upon a low temperature heating (780°C) is granular pearlite. Cementite grains that are formed in the structure are finer at a lower temperature transformation.

同一种钢，在相同的温度下相变但是在一个低温下加热的组织是粒状珠光体。在更低温度下的相变，形成的渗碳体晶粒更细小。

Consequently, the size of cementite particles depends on the temperature of austenite transformation and their form depends on the temperature of heating (the temperature of austenitization).

因此，渗碳体颗粒的尺寸取决于奥氏体相变温度，奥氏体颗粒的形成决定于加热温度（奥氏体化的温度）。

The transformation at temperature above and below the bend of the C curve differ in the kinetics and the shape of decomposition products.

在高于和低于 C 曲线拐点，分解生成的物质的动力学性质和形状是不同的。

Above the bend of C curve, i.e. at small degrees of undercooling, the transformation begins from a few centers and pearlitic crystals freely grow to interference. Below the bend of C curve there forms an acicular microstructure, since acicular platelets cannot grow freely and the transformation mainly occurs through the formation of new

crystals.

高于 C 曲线的拐点, 在较小的过冷度下, 相变开始于很小的形核中心。珠光体晶粒自由生长到晶界处, 在 C 曲线的拐点以下形成针状显微结构, 由于针状物不能自由生长, 相变主要通过形成新的晶粒来进行。

As indicated above, the rate of isothermal transformation of austenite is determined by the rate of nucleation and crystal growth, N and G.

如上所述, 奥氏体等温相变的速率取决于形核速率和晶粒长大速率分别用 N 和 G 表示

The rate of crystal growth is quite sensitive to various changes in the steel structure and can be strongly affected by the metallurgical nature of the steel, the degree of deoxidization, the presence of undissolved particles, the homogeneity of austenite, and the size of austenitic grains. The presence of undissolved particles increases the value of G, since these particles serve as additional nuclei.

晶粒的生长速率对于钢结构中的各种各样的变化是非常敏感的, 钢的冶金特性、脱氧程度、非溶解颗粒的存在、奥氏体的均匀程度和奥氏体晶粒的尺寸能强烈影响晶粒长大速率。

The value of G diminishes with increasing size of austenitic grains. Crystallization nuclei appear mainly on grain boundaries, therefore, the conditions for nucleation are worse in coarse grained steel where the extent of grain boundaries is smaller.

随着奥氏体晶粒尺寸的增加晶粒生长速度的重要性逐渐减小。结晶核心主要出现在晶界上, 因此, 在晶界长度比较小的粗晶粒钢中, 形核条件比较差。

The factors mentioned have, however, no effect on the nucleation rate, N. The value of N depends only on steel composition and for a steel of a given composition, is a natural characteristic depending only on the degree of undercooling.

然而, 上述因素, 对于形核速率 N 没有影响, N 的重要性仅取决于钢的成分, 对于一个给定成分的钢, N 作为一种固有特性仅取决于过冷度。

We have discussed the austenite to pearlite transformation in steels whose composition is close to eutectoid. If the content of carbon in a steel differs from the eutectoid value, the pearlite transformation will be preceded with the precipitation of ferrite or cementite (as follows from the iron carbon constitutional diagram)

我们已经讨论了成分接近共析转变点的钢的奥氏体向珠光体的相变。如果钢中含碳量不同于共析转变成分, 珠光体相变的进行将伴随着铁素体或渗碳体的析出 (与铁碳相图相符)

In hypoeutectoid * steels, the transformation of austenite begins with the formation of ferrite and the saturation of the remaining solution with carbon, and in hypereutectoid steels, with the precipitation of cementite and depletion* of the austenite of carbon. [Under equilibrium conditions, the decomposition of austenite into ferrite and cementite (pearlite transformation) begins when the content of carbon in austenite, remained upon precipitation of excess ferrite or cementite, corresponds to 0.8% carbon.

在亚共析钢中, 奥氏体相变开始于铁素体的形成和碳在剩余固溶体中趋于饱和, 而在过共析钢中, 奥氏体相变开始于渗碳体的析出和剩余奥氏体含碳量的降低。平衡条件下, 奥氏体分解为铁素体和渗碳体 (珠光体相变) 开始于当碳在剩余奥氏体中的含量高于析出额外的铁素体或渗碳体时, 相应的碳含量为 0.8%。

The eutectoid which forms from under-cooled austenite and has a concentration differing from the eutectoid value is called quasi*-eutectoid. The quasi-eutectoid in hypereutectoid steels contains more than 0.8 percent carbon and that in hypoeutectoid steels, less than 0.8 percent, the deviation from this value being greater at a lower temperature of transformation. Therefore, the lower the temperature of transformation, the less the excess ferrite (or cementite) precipitates before the pearlite transformation begins. At temperatures near the bend of the C curve and at lower temperatures, decomposition of austenite begins without precipitation of excess phases.

在过冷奥氏体中, 非共析成分得到的共析组织称为伪共析, 在过共析钢中, 伪共析含多于 0.8% 的碳, 而在亚共析钢中, 含碳量少于 0.8%, 在更低的相变温度下此种成分下的偏差将会更大。因此, 相变温度越低, 在珠光体相变之前先共析铁素体 (或渗碳体) 越少, 在 C 曲线拐点附近的温度和更低的温度, 奥氏体

分解的开始没有先共析相的析出。

If we take a hypereutectoid steel instead of hypoeutectoid, the decomposition of austenite at small degrees of undercooling will be preceded with precipitation of cementite.

如果我们用过共析钢代替亚共析钢，小的过冷度下奥氏体的分解将提前析出渗碳体。

If the cooling rate is higher, the transformation has no time to proceed in the upper temperature range, the austenite will be undercooled to a low temperature and will transform into martensite, such a cooling will result in hardening.(淬火) Therefore, to harden steel, it should be cooled at a high rate so that austenite has no time to decompose in the upper temperature range.

如果冷却速率更快，在高温区内相变来不及进行，奥氏体将过冷到低的温度转变为马氏体，这种冷却方法将导致硬化。因此对于淬火钢，应该在高冷却速率下冷却，以使让奥氏体来不及在高温区域分解。

The lowest cooling rate needed to under-cool austenite up to martensite transformation is called the critical rate of hardening. If a steel is to be hardened, it should be cooled at a rate not less than the critical. The critical rate is lower for steels whose curve of the beginning of transformation passes farther to the right. In other words, with a lower rate of austenite to pearlite transformation, it is easier to undercool the austenite to the temperature of martensite transformation and the critical rate of hardening will be lower.

过冷奥氏体向马氏体转变的最低的冷却速率称为临界淬火速率。如果对钢进行淬火，它的冷却速率不能低于临界值，对于相变开始曲线右移的钢，临界速率要低些。换句话说，在更低的奥氏体向珠光体的转变速率下，将奥氏体过冷到马氏体相变温度更容易，临界淬火速率将更低。

If cooling is done at a rate slightly below the critical, the austenite will undergo only a partial transformation in the upper temperature range and the structure will consist of the products of transformation in the upper temperature range (troostite) and martensite.

如果在稍低于临界速率的速度下冷却，仅有极少量的奥氏体经历高温区域的相变。钢的结构将由高温区域的相变产物（屈氏体）和马氏体组成。

The critical rate of hardening can be determined from the diagram of isothermal decomposition of austenite.

临界淬火速度可由奥氏体等温分解相变图确定。

This analysis **shows** that a simple superposition* of cooling curves on the isothermal diagram of austenitic decomposition can give only an approximate quantitative estimation of a transformation occurring in continuous cooling.

这种分析表明，冷却曲线在奥氏体等温分解相图上一个简单的重叠能够给连续冷却条件下发生的相变一个近似的量的评估。

More accurate estimations of the transformations at a continuously varying temperature are made by using the so-called thermo-kinetic, or anisothermal* diagrams of austenite transformations, which characterize the transformation at various cooling rates.

关于连续变温下的相变，更准确的评估通过使用所谓的相变动力学或者奥氏体相变非等温相图来描述各速率下的相变。

Though isothermal transformation diagrams can give us much knowledge on the nature of transformations, the transformations can only seldom be achieved under isothermal conditions in practice.

尽管等温相变图能够为我们提供大量有关相变本质的知识，但是事实上等温条件下的相变很难实现。

With a very quick transformation, the process of decomposition is attained. This is why the isothermal transformation diagrams are quite inaccurate for holding times less than 10s.

在快速相变条件下，能够得到分解过程。这就是对于一个维持少于 10s 等温相变图非常不准确的原因。

When large **sections** are heat-treated, it is impossible to meet another important condition essential for the construction of a diagram, i.e. quick cooling to the given temperature. Isothermal austenite transformation diagrams are of great theoretical significance but are superseded* by anisothermal diagrams in practical cases of

selecting heat treatment conditions.

当大断面工件进行热处理时，找到另一个建造相图不可缺少的重要条件是不可能的，比如快速冷却到给定的温度。奥氏体恒温转变相图具有重大理论意义，但在选择热处理条件的实际应用中被变温相图所替代。

It is possible in laboratories to imitate the conditions of cooling large massive articles and in various quenching on small specimens. During cooling of specimens, the points of the beginning and the end of transformations are determined by dilatometric* (by changes in the dimensions of specimens) or magnetic (austenite is non-magnetic and its products are magnetic) method. The experimentally found cooling curves and the points of transformation are then plotted in a temperature time diagram and the sections of like transformations are combined into regions.

冷却条件已经研究的非常透彻。在实验室里模拟大型件的冷却条件和在小的试样上进行各种各样的淬火试验是能实现的。在试样冷却的过程中，相变的开始点和结束点通过膨胀的（通过试样尺寸的变化）或磁性的（奥氏体是无磁性的，它的产物是有磁性的）方法确定。通过实验建立冷却曲线和相变点，之后被冷却到一个温度时间相图中，并且将相似相变部分结合进这一区域。

Up to this point, we have considered only schematic diagrams of austenite transformation. For exhaustive* information on the transformation a particular grade of steel, however, curves is made of both types of the diagram and of some additional data: grade and composition of the steel, heating temperature, austenitic grain size, properties (at least hardness) of decomposition products, and proportion of the constituents.

到目前为止，我们考虑的仅是奥氏体相变的示意相图。然而，对于一特定牌号的钢更详尽的信息是利用多种典型的相图和一些额外的数据：钢的等级和成分、加热温度、奥氏体晶粒尺寸、分解产物的性能（至少硬度）和成分的比例。