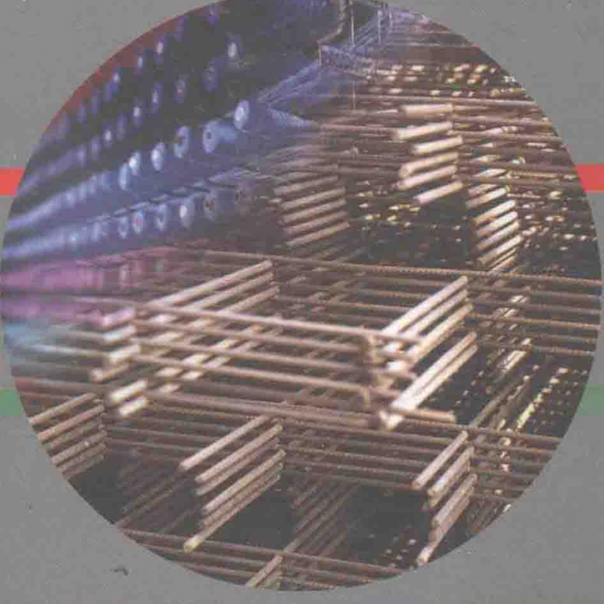
轮机工程材料

Marine Engineering Materials

（英文版）

主编 严志军 朱新河 程 东 于桂峰



大连海事大学出版社

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藏书章

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前　言

轮机工程对材料的选用有其特殊的要求，例如，柴油机活塞和连杆零件需要承受交变高机械载荷；排气阀和增压器废气涡轮叶片需要在较高温度下工作；在选用材料时，还需要考虑工作环境的影响。材料选用不当往往意味着设备的故障和事故，造成经济损失甚至人身伤害，因此对于从事轮机工程行业的人员，具备一定的工程材料选用知识和能力是十分必要的。

本教材针对轮机工程专业教学要求，介绍工程材料的基础知识以及工程材料的选择方法。第 1 章简要介绍材料的分类；第 2 章介绍钢铁材料的生产；第 3 章介绍金属材料的主要性能和测试方法；第 4 章介绍晶体的结构以及金属的结晶过程等；第 5 章介绍金属材料冷态塑性变形以及加热过程中的再结晶过程等知识；第 6 章和第 7 章是本教材重点内容，介绍相图（特别是铁碳合金相图）以及常用的热处理方法等；第 8 章至第 11 章介绍各种钢、铸铁、有色金属及非金属材料的特性和选用；第 12 章介绍典型材料应用实例。

本教材主要由严志军编写。朱新河教授、程东教授和于桂峰老师参与部分章节（第 9 章、第 10 章、第 11 章和第 12 章）的编写。在教材编写过程中得到众多同事的支持和帮助，教材中采纳了他们很多好的建议，在此表示由衷的感谢。

严志军

2011 年 12 月

Preface

Marine engineering has special demands on the materials. The parts such as pistons and connecting rods of diesel engine undertake huge and complex mechanical forces. The exhaust valves and blades of turbocharger have to bear relatively high temperature. When selecting materials, some factors including operational environment should also be taken into account. Bad using of materials means accidents, and accidents cost lives as well as a lot of money, or possible loss of ship. So, possessing the ability to select and use the right materials is vital for any personnel who will engage in the career relating to marine engineering.

This course is designed to present students the basic fundamentals of materials engineering, and prepare students for selection of right materials in the field of marine engineering. Chapter 1 will give brief introduction of material types; Chapter 2 will introduce the manufacture of iron and steel products; Chapter 3 will discuss some major properties of metals and testing methods; Chapter 4 will discuss crystal structures and solidification of metals; Chapter 5 will discuss plastic deformation and recrystallization of metals; Chapter 6 and 7 are important contents which will introduce the phase diagrams of alloy, especially of iron-iron carbide alloys, and common heat-treatment methods; Chapter 8 to 11 will introduce various engineering materials including industrial steels, cast irons, non-ferrous metals and alloys, non-metallic materials; The last Chapter 12 will chiefly give some typical examples of applications of the materials.

The major content of the book is written by Yan Zhijun. Prof. Zhu Xinhe, Prof. Cheng Dong, and Mr. Yu Guifeng took part in some chapters' work (Chapter 9 to 12). I wish to express my sincere thanks to many of my colleagues who gave me a lot of help and support. Many of the good suggestions have been incorporated into this book.

Yan Zhijun

Dec. 2011

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Chapter 1 Introduction

Various materials are found to be used in marine area. Different materials have different properties that render them useful, so it is crucial for a marine engineer understanding basic knowledge about engineering materials and having the ability to choose the right materials for certain applications. In the first chapter of the book, we will discuss some basic concepts, including the states of matter, bonds of solid materials and types of engineering materials.

1.1 States of materials

1.1.1 Three common states of matter

Matter, as we know it, exists in three common states. These three states are *solid*, *liquid*, and *gas*. The atomic or molecular interactions (forces) that occur within a substance determine its state. These forces arise because of differences in the electron clouds of atoms. The valence electrons or those in the outer shell, of atoms have significant influence on their attraction for their neighbors.

When physical attraction between molecules or atoms of a material is great, the material is held tightly together. Molecules in solids are bound tightly together. When the attractions are weaker, the substance may be in a liquid form and free to flow. Gases exhibit virtually no attractive forces between atoms or molecules, and their particles are free to move independently of each other.

1.1.2 Order in microstructures

Solids have greater interatomic attractions than liquids and gases. However, there are wide variations in the properties of solid materials used for engineering purposes. The properties of materials depend on their interatomic bonds (We will discuss this topic later in this chapter). These same bonds also dictate the space between the configurations of atoms in solids.

All solids may be classified as either amorphous (无定形体) or crystalline (晶体) according to the regularity of configuration.

(1) Amorphous

Amorphous materials have no regular arrangement of their molecules. Materials like glass and paraffin are considered amorphous. Amorphous materials have the properties of solids. They have definite shape and volume and diffuse slowly. These materials also lack sharply defined melting points. In many respects, they resemble liquids that flow very slowly at room temperature.

(2) Crystalline

In a crystalline structure, the atoms are arranged in a three-dimensional array called a *lattice* (晶格). The lattice has a regular repeating configuration in all directions. A group of particles from one part of a crystal has exactly the same geometric relationship as a group from any other part of the same crystal.

1.2 Bonds of solid materials

The types of *bonds* (结合键) in a material are determined by the manner in which forces hold matter together. There are two types of bonds: *Primary bonds* (主要结合键) and Secondary bonds. Primary bonds are the strongest bonds which hold atoms together. The three types of primary bonds are: (1) *Ionic bonds* (离子键), (2) *Covalent bonds* (共价键) and (3) *Metallic bonds* (金属键). Secondary bonds are much weaker than primary bonds. They often provide a "weak link" for deformation or fracture. Examples for secondary bonds are: *Van der Waals bonds* (范德华键) and *Hydrogen bonds* (氢键).

1.2.1 Ionic bonds

Atoms like to have a filled outer shell of electrons. Sometimes, by transferring electrons from one atom to another, electron shells are filled. The donor atom will take a positive charge, and the acceptor will have a negative charge. The charged atoms or ions will be attracted to each other, and form bonds. The compound NaCl, or table salt, is the most common example (Figure 1.2-1).

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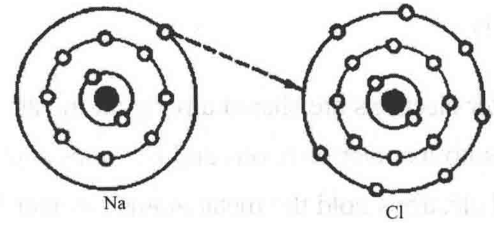

Figure 1.2-1 Formation of ionic bond in NaCl

The electron structure of atoms is relatively stable when the outer shells contain eight electrons (or two in the case of the first shell). An element like sodium with one excess electron will give it up so that it has a completely filled outer shell. It will then have more protons than electrons and become a positive ion (charged atom) with a (+1) charge. An atom of chlorine, on the other hand, with seven electrons in its outer shell would like to accept one electron. When it does, it will have one more electron than protons and become a negative ion with a (-1) charge. When sodium and chlorine atoms are placed together, there is a transfer of electrons from the sodium to the chlorine atoms, resulting in a strong electrostatic attraction between the positive sodium ions and the negative chlorine ions. This explains the strong attraction between paired ions typical of the gas or liquid state.

1.2.2 Covalent bonds

Some atoms like to share electrons to complete their outer shells. Each pair of shared atoms is called a *covalent bond* (Figure 1.2-2). Covalent bonds are called directional because the atoms tend to remain in fixed positions with respect to each other. Covalent bonds are also very strong. Examples include diamond, and the O-O and N-N bonds in oxygen and nitrogen gases.

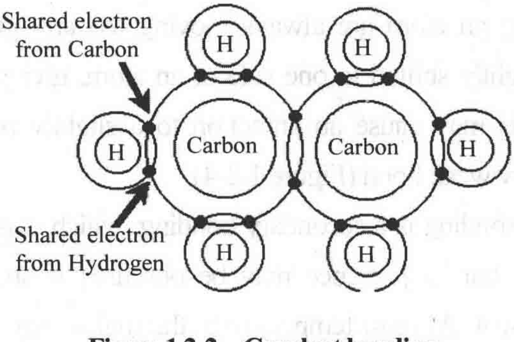

Figure 1.2-2 Covalent bonding

1.2.3 Metallic bonds

In a metal, the outer electrons are shared among all the atoms in the solid (Figure 1.2-3). Each atom gives up its outer electrons and becomes slightly positively charged. The negatively charged electrons hold the metal atoms together. Since the electrons are free to move, they lead to good thermal and electrical conductivity.

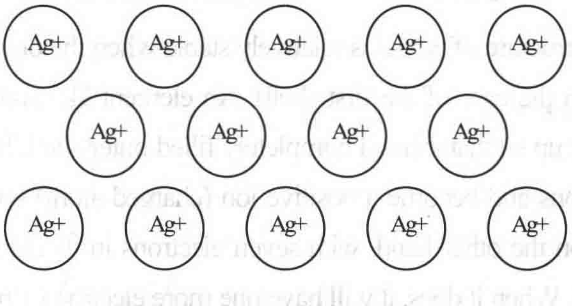

Figure 1.2-3 Metallic bond

The lack of oppositely charged ions in the metallic structure and lack of sufficient valence electrons to form a true covalent bond necessitate the sharing of valence electrons by more than two atoms. Each of the atoms of the metal contributes its valence electrons to the formation of the negative "*electron cloud*". These electrons are not associated with a particular ion but are free to move among the positive metallic ions in definite energy levels. The metallic ions are held together by virtue of their mutual attraction for the negative electron cloud.

1.2.4 Van der Waals bonds

Van der Waals bonds are very weak compared to other types of bonds. These bonds are especially important in noble gases which are cooled to very low temperatures. The electrons surrounding an atom are always moving. At any given point in time, the electrons may be slightly shifted to one side of an atom, giving that side a very small negative charge. This may cause an attraction to a slightly positively charged atom nearby, creating a very weak bond (Figure 1.2-4).

Van der Waals bonding is a secondary bonding, which exists between virtually all atoms or molecules, but its presence may be obscured if any of the three primary bonding types is present. At most temperatures, thermal energy overwhelms the effects of Van der Waals bonds.

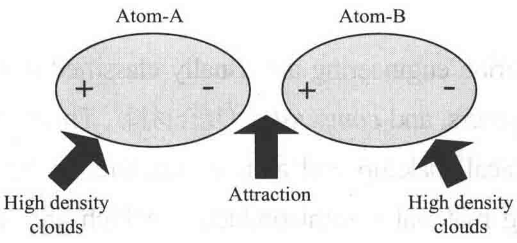

Figure 1.2-4 Van der Waals bond

1.2.5 Hydrogen bonds

Hydrogen bonds are common in covalently bonded molecules which contain hydrogen, such as water (H_2O). Since the bonds are primarily covalent, the electrons are shared between the hydrogen and oxygen atoms (Figure 1.2-5). However, the electrons tend to spend more time around the oxygen atom. This leads to a small positive charge around the hydrogen atoms, and a negative charge around the oxygen atom. When other molecules with this type of charge transfer are nearby, the negatively charged end of one molecule will be weakly attracted to the positively charged end of the other molecule. The attraction is weak compare with the primary bonds because the charge transfer is small, but much stronger than the Van der Waals Bond.

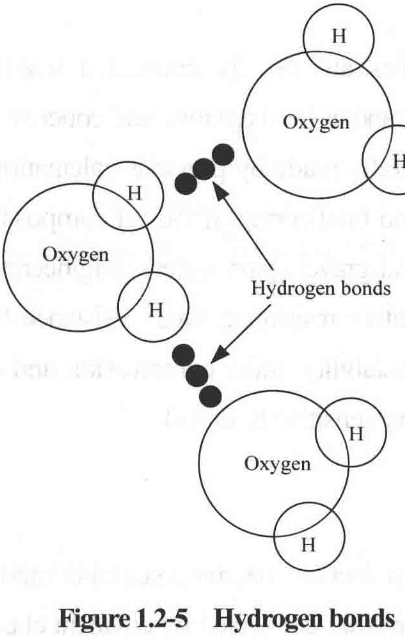

Figure 1.2-5 Hydrogen bonds

1.3 Types of engineering materials

Materials for marine engineering are usually classified in four categories: *metals*, *ceramics*（陶瓷）, polymers, and *composites*（复合材料）. This scheme is basically based on the type of chemical makeup and atomic structure. In addition, there is another important engineering material – semiconductors, which are utilized because of their unusual electrical characteristics. A brief explanation of the material types and representative characteristics is offered in this part.

1.3.1 Metals

Metallic materials are normally combinations of metallic elements. They have large numbers of non-localized electrons; that is, these electrons are not bound to particular atoms. Many properties of metals are directly attributable to these electrons. Metals are ductile and heavy, extremely good conductors of electricity and heat, and not transparent to visible light; a polished metal surface has a lustrous appearance. Furthermore, metals are quite strong, yet deformable, which accounts for their extensive use in structural applications.

1.3.2 Ceramics

The atoms in ceramics are usually connected together through ionic bonds. Ceramics are as soft as clay and as hard as stone and concrete. They are the most ancient (stones, bricks, glasses), usually made by previous calcinations（煅烧）of raw materials (making cement powder) and final curing（固化）of composite mixtures, e.g. concrete is made with cement, sand and gravel (plus water). Engineering ceramics are known for their stiffness, high temperature resistance, wear resistance (but not to impact), lighter than metals, insulating and stability under compression and electrical stress. The main disadvantage is fragility (very sensitive to flaws).

1.3.3 Polymers

A polymer is a large molecule (macromolecule) composed of repeating structural units. These subunits are typically connected by covalent chemical bonds. Although the term polymer is sometimes taken to refer to plastics, it actually encompasses a large class comprising both natural and synthetic materials with a wide variety of properties.

Because of the extraordinary range of properties of polymeric materials, they play an essential in marine engineering. This role ranges from familiar synthetic plastics and elastomers to natural biopolymers. Natural polymeric materials such as amber (*yellowish brown substance used to make jewellery* (琥珀)) and natural rubber have been used for centuries. The list of synthetic polymers includes synthetic rubber, neoprene (氯丁橡胶), nylon, PVC (聚氯乙烯), polystyrene (聚苯乙烯), polyethylene (聚乙烯), and many more.

1.3.4 Composites

Composite materials are structured materials composed of two or more macroscopic phases. Applications range from structural elements such as steel-reinforced concrete, to the thermally insulative tiles which play a key and integral role in NASA's Space Shuttle thermal protection system which is used to protect the surface of the shuttle from the heat of re-entry into the Earth's atmosphere.

1.4 Exercises

1.4.1 Multiple choices

(1) Which of the following is not a form of bonding?

(A) Ionic (B) Crystal (C) Covalent (D) Metallic

(2) What type of bonding involves the transfer of one or more electrons from a metal to a non-metal?

(A) Covalent (B) Ionic (C) Metallic (D) Van der Waals

(3) When a bond shares electrons, it's called a:

(A) Ionic bond (B) Covalent bond

(C) Metallic bond (D) None of the above

(4) What type of bonding involves the formation of an "electron cloud"?

(A) Covalent (B) Ionic (C) Metallic (D) Van der Waals

(5) Which of the following is not a property that an element must have to be considered a

metal?

(A) Ability to deform plastically.

(B) Ability to donate electrons to form (-) ions.

(C) "Crystalline" grain structure.

(D) High thermal and electrical conductivity.

(6) Two or more substances that are combined chemically is a:________________.

(A) Mixture (B) Element (C) Compound (D) Molecule

1.4.2 Questions and practices

(1) State the three states of matter and their characteristics.

(2) State the concepts of amorphous or crystalline and give examples to illustrate their characteristics.

(3) State the five types of bond that occur in materials and their characteristics.

(4) Why are metals good conductors of heat and electricity?

(5) What is the difference between a covalent bond and ionic bond?

(6) State the four types of engineering materials and their characteristics.

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