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INTRODUCTION TO TITANIUM ALLOY MATERIALS

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Abstract:

The work highlights the physical and mechanical properties and applications of modern industrial titanium alloys in the production of modern equipment, medicine and everyday life. It is shown that in terms of specific strength, anti-corrosion and technological properties, these alloys are very promising for use in mechanical engineering and everyday use.

Keywords: Titanium alloy; properties; applications

Анотація

У роботі висвітлено фізико-механічні властивості та застосування сучасних промислових сплавів тітану у виробництві сучасної техніки, медицині та побуті. Показано, що за питомою міцністю, антикорозійними та технологічними властивостями ці сплави є дуже перспективними для використання у машинобудуванні та повсякденному використанні.

Ключові слова: титанові сплави; властивості; застосування

1. Titanium and Titanium Alloys

Titanium is a transition metal located in Group 4 of the periodic table, with an atomic number of 22, a relative atomic mass of 47.87, and a density of 4.59 g/cm³. Visually, titanium resembles steel, exhibiting a silvery-white appearance. In air, titanium readily forms a thin, dense oxide layer, producing various oxides such as TiO, TiO_2, Ti_2O_3, and Ti_3O_5. Their physicochemical properties are summarized in Table 1. Typically, titanium alloys form a TiO_2 oxide layer.

Table 1 Properties of Titanium Oxides

Oxide	Color	Melting Point (°C)	Density (g/cm³)	Chemical Stability
TiO	Black	1750	4.888	Less stable
TiO_2	White	1800-1875	—	Stable
Ti_2O_3	Purple	1900	4.486	Less stable
Ti_3O_5	Blue-black	2180	4.290	Stable

Due to the uneven distribution of titanium on Earth and the difficulty in extracting it in an era of underdeveloped science and technology, titanium metal was considered a relatively low content metal for a long time. However, in fact, the content of titanium is quite high in nature. It is known that titanium accounts for up to 0.6% of the earth's crust within ten kilometers of the Earth's surface, ranking 10th among many elements in the crust and 4th among structural metals, only behind aluminum, iron, and magnesium, surpassing copper, nickel, lead, zinc, and other metal elements. Its content is even higher than the total content of common metal elements such as zinc, tungsten, chromium, and lead [1-2]. China contains abundant titanium resources, with a large amount of titanium magnetite, rock minerals, and hematite minerals being the main mineral resources for producing titanium metal. With the development of science and technology, the smelting technology of titanium metal is becoming more and more advanced, and titanium is gradually appearing in industry. At the same time, titanium has good physical properties and plasticity, such as high strength and a density only half of iron, making it highly applicable.

The mechanical properties of industrial pure titanium are shown in Table 2. Titanium has relatively stable mechanical properties at room temperature and can maintain a stable state in air and water. However, it can react with water vapor and non metals at high temperatures, and liquid titanium can dissolve all metals. From the perspective of the industrial value and development prospects of titanium, with the deepening of new technologies and industrial revolution, titanium will become the "third metal" rising after iron and silver, and the century is about to be the "century of titanium" [4,5]. Titanium is a very special metal with characteristics such as low density, high specific strength, high and low temperature resistance, corrosion resistance, good plasticity, and low elastic modulus, which has made iron and its alloys widely used in many modern industrial fields [6,7].

Table 2 Mechanical Properties of Industrial Pure Titanium

Density (g/cm^3)	Melting Point (°C)	Thermal Conductivity (W/m·K)	Tensile Strength (MPa)	Elongation (%)	Reduction of Area (%)	Elastic Modulus (MPa)	Hardness (HB)
4.05	1725	15.24	539	25	25	1.078×10^5	195

Adding other metal elements to titanium based materials can form titanium alloys. The classification of titanium alloys is mainly based on different titanium based materials. Titanium elements have different structures in different situations, forming titanium isomers [8]. When titanium is below 882°C, it has a closely packed hexagonal structure, known as α-titanium; When titanium is above 882°C, it has a body centered cubic structure and is called β-titanium. Therefore, titanium alloys based on alpha titanium are called alpha titanium alloys [9], represented by TA, which are single-phase alloys composed of alpha phase solid solutions. They can maintain the alpha phase at any temperature and have stable microstructure in the alloy. Their wear resistance is better than pure titanium and they have good oxidation resistance. At a temperature of around 550°C, its strength and creep resistance can be well maintained; Titanium alloys based on β-titanium are called β-titanium alloys [10], represented by TB. Similar to α-titanium alloys, they belong to single-phase alloys and consist of β-phase solid solutions. Regardless of temperature, β-titanium alloys can have good strength properties. After heat treatment, the performance of β - titanium alloys can be further improved. At normal room temperature, their strength can reach about 1450 MPa. However, the thermal stability of β - titanium alloys is poor, and their use in high-temperature environments is limited. In addition, both α-titanium and β-titanium can coexist in the titanium alloy matrix. At this time, titanium alloy is called (α+β) alloy [11], represented by TC. It is a dual phase alloy composed of α-phase solid solution and β-phase solid solution, which can simultaneously possess the properties of α-titanium alloy and β-titanium alloy. While maintaining good stability, it also has excellent mechanical properties, high hardness, and strong processability, making it an ideal engineering material. Table 3 lists the main performance characteristics of three titanium alloys.

Table 3 Properties of α, β, and α+β Titanium Alloys

Property	α	β	α+β	Property	α	β	α+β
Density	+	+	-	Corrosion	++	+	+/-
Strength	-	+	++	Oxidation	++	+/-	-
Plasticity	-/+	+	+/-	Weldability	+	+/-	-
Fracture Toughness	+	-/+	+/-	Cold Formability	--	-	-/+

2. Development and Application of Titanium Alloys

With the expansion of application fields and environments, researchers have begun to study the use of titanium alloys. Compared with pure titanium, titanium alloys have better physical and chemical properties, such as better corrosion and wear resistance. Specific titanium alloys can be studied according to different application scenarios, greatly expanding the application scope of titanium and titanium alloys [12]. Titanium and titanium alloys, as emerging metal materials, are mainly used in the following fields.

2.1 Application of Titanium Alloy in Aerospace Field

At present, titanium alloys are mainly used in the aviation and aerospace fields due to their high strength, high wear resistance, high temperature stability, and the need to ensure low density. In the existing materials, it is difficult to find metal materials that can meet the demand. Common aluminum alloy materials have good plasticity, high strength, easy processing, and light weight, which can meet the basic requirements of aerospace equipment. However, aerospace equipment needs to experience high temperature environments with severe friction during use, which is an unavoidable disadvantage of using aluminum alloy to make aerospace equipment. Gradually, titanium alloys with good performance began to replace aluminum alloys as the main material for aerospace equipment. Aircraft frames, shells, engines, etc. made of titanium alloy materials can meet strength requirements while being lightweight. In addition, in aerospace equipment, parts made of titanium alloys can withstand high temperature friction from the atmosphere [13].

2.2 Application of Titanium Alloy in the Medical Field

Titanium alloy not only has good mechanical properties, but also has good biocompatibility in the coordination with living organisms, and can resist corrosion in living organisms without producing harmful substances. The use of titanium alloy as an implant can effectively solve the heterogeneity discomfort between metal implants and bone tissue. In the known medical field, surgical tools made of titanium alloy can effectively prevent foreign objects from infecting the body during surgery; Titanium alloy has good hardness and strength, which can replace damaged teeth, bones, etc. in living organisms, and can adapt to the cellular tissues of living organisms [14]. At present, the widely used biomedical metal materials mainly include five categories: stainless steel, cobalt based alloys, titanium and titanium alloys (including titanium based shape memory alloys), precious metals, and pure metals (niobium, zirconium) [15]. So far, titanium alloy is the best metal material used in clinical practice, mainly in plastic surgery, dentistry, and medical devices. In recent years, the market growth rate of biomedical materials and products has been increasing every year. With the rapid development of medical industries in various countries and the improvement of people's living standards, the number of people in need of plastic surgery and correction has been increasing year by year, making titanium alloys have broader prospects in biomedical fields.

2.3 Application of Titanium Alloy in Daily Life

In recent years, titanium alloys have been widely used in people's daily lives. Titanium alloy has entered the cultural and sports goods market at a very high speed and has formed a certain scale, with golf clubs being a representative example. Titanium golf club heads have the advantages of light weight, large contact sphere, easy control, and easy hitting of targets. In addition to the golf market, the use of tennis rackets is also increasing. The bicycle industry is another promising application area for titanium alloys. The advantages of titanium bicycles are light weight, high strength, and good corrosion resistance, fatigue resistance, and shock resistance. Currently, almost all racing bicycles are made of titanium material. Titanium alloy can also be used to manufacture wheelchair frames, fishing gear, eyeglass frames, watches, cameras, and other daily necessities. Titanium is non-toxic, lightweight, high-strength, and has excellent biocompatibility, making it an ideal medical metal material that can be used as implants and surgical instruments in the human body. Research in this area has a history of several decades.

With the development of technology, the advantages of titanium alloys are constantly being discovered, and their applications are becoming more and more widespread, gradually emerging in various fields and becoming the new favorite of the metal industry. However, in some special cases, the application of titanium alloys is limited [16], such as in environments with high wear coefficients where the properties of titanium alloys themselves cannot meet the requirements for use; In addition, in the processing of titanium alloys, it is easy to react with elements such as O, H, N, and C in the air, especially the H element, which is harmful to any metal [17] and can easily cause various defects such as cracks, hydrides, and embrittlement.

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