Application and Optimization Design of Titanium Alloy in Sports Equipment

Ming Li\textsuperscript{1,a*}, Yang Pan\textsuperscript{1,b}, Yunpeng Zou\textsuperscript{2,c}

\textsuperscript{1}Sports Department of Dalian University of Science and Technology, Dalian, Liaoning, China
\textsuperscript{2}Sports Department of Huiwen Middle School, Dalian, Liaoning, China
\textsuperscript{a}email: liming@dlust.edu.cn, \textsuperscript{b}email: 13342417@qq.com, \textsuperscript{c}email: 956526339@qq.com

Abstract: Titanium (Ti) was discovered in 1789. Norway and the United States began to produce titanium dioxide with the sulfuric acid method in 1908, the titanium sponge was prepared by the sponge titanium in the laboratory for the first time in 1910, and the United States Dupont company used the magnesium method to produce tons of titanium sponge in 1948, which marks the beginning of the industrial production of titanium sponge. Titanium and its alloys are one of the most promising light alloy structural materials in the 21st century due to their advantages of low density, high specific strength and specific stiffness, corrosion and fatigue resistance, high temperature resistance and weldability. In recent years, the world titanium industry and titanium processing technology has developed rapidly. The production and consumption of sponge titanium, wrought titanium alloy and ferroalloy processed materials have reached a very high level, and their application fields have been extended to almost all military and civilian industrial sectors. This paper focuses on the application of titanium alloy in sports equipment, and the optimization design of titanium alloy sports equipment.

1. TITANIUM ALLOYS AND THEIR CHARACTERISTICS

1.1 Properties of Titanium
Titanium has poor heat-conducting property, and its heat conductivity is slightly lower than that of stainless steel. The thermal conductivity of commercial pure titanium reaches the maximum value (17.56 W/(m·K)) at 250K and the minimum value (16.89 W/(m·K)) at about 580K. Titanium alloy has high chemical activity, and it is easy to produce scale cinder when heated in air. It is easy to absorb hydrogen and cause hydrogen embrittlement during heating and pickling. Titanium alloys can be used for pressure machining, mechanical cutting processing, welding and other joining processing. Titanium alloys have excellent corrosion resistance to seawater or fresh water.

1.2 Titanium Alloys and Their Classifications
The classification of titanium alloys according to the composition of metastable phases is a more scientific method. Titanium alloys can be roughly divided into six types: a type, near a type, martensite a + p type, near metastable p type, and metastable R type. Table 1 shows the classification of existing industrial titanium alloys according to the above classification method.
1.3 Processing Performance of Titanium Alloys
Due to the characteristics of crystalline structure, physical and chemical properties, titanium alloys have the comprehensive processing performance that is fundamentally different from that of steel, aluminum and heavy metal alloys. Titanium alloys generally tend to melt large round-section ingot with a diameter of 900mm or more and a weight of 10 ~ 15t. An important feature of vacuum arc melting is the integration of melting, casting and solidification processes. It is necessary to use large amount of deformation to achieve the required performance level because of the large smelting overheat degree and the easy formation of coarse casting structure.

Figure 1 Titanium Alloy Characteristic Diagram

2. CURRENT MAIN APPLICATION FIELDS OF TITANIUM ALLOYS

2.1 Aerospace Field
The largest user of titanium is the aerospace industry, mainly used in aircraft engines, racks, landing gears, rockets and missiles. Since the 21st century, the world’s two aircraft manufacturing companies, Boeing and Airbus, have increased their aircraft output, and delivered nearly 1,000 civil aircraft each year.

2.2 Industrial Field
Titanium is a very popular structural material in almost all industrial fields, such as petroleum, chemical industry, textile industry, metallurgy and electric power industry. Titanium is used in the manufacture of chemical corrosion-resistant reactors, iron anodes and titanium cathode plates for electrolysis, titanium anodes for chlorine-alkali production, oxygen cooling heat exchangers, etc., titanium mesh baskets, hoisting sets, titanium anodes and the like in the electroplating industry, condenser, steam turbine generator, turbine blades and the like used in power plants, oil drilling equipment and subsea pipelines, etc.

2.3 Information Engineering Field
In information engineering, titanium can be used to make computer hard disk substrates. It has higher strength than aluminum, allowing for reduced thickness, increased storage density and increased disk speed; higher surface finish, allowing for reduced distance between the read and write head and the disk, and increased storage density; higher allowable limits for damage and surface hardness; titanium also has non-magnetic properties, which prevents disk data storage interference; titanium is more resistant to high temperatures than aluminum and can be treated with a high-temperature coatings. It is estimated that with the rapid development of information industry and fierce competition in the market, titanium will have a better application market for computers.

2.4 Medical Field
In medical treatment, titanium is mainly used as dentures, joints for human prosthetics, bone plates for orthopedics, intramedullary needles and artificial heart valve prosthesis, shells for implanted heat pacemaker, vascular clamps for cranial surgery, etc. Titanium footprints have been found from the
needles used to suture small blood vessels, electrocardiographic electrode materials and ophthalmic instruments used in the early days to the recent heart retractors and heart plugs.

3. APPLICATION OF TITANIUM IN SPORTS EQUIPMENT
The application of titanium in sports equipment from the earliest tennis rackets and badminton rackets to the widely used golf heads, handles and racing cars in recent years, has made a big step forward in people’s understanding of titanium.

3.1 Golf Clubs and Head
The titanium golf club and head are still a major pillar of the application of titanium in the civilian field, every manufacturer in the world appears to have produced the golf clubs and heads. Golfers always want to play with clubs with bigger heads. Titanium is small in specific gravity and high in strength enough to make the golf head larger without increasing the total weight of the club. In a wide range of experiments, the average hit rate of golfers with titanium heads was higher than that with steel heads, and the hitting distance has been improved. At present, the larger golf heads require a very thin surface, so the surface material needs to be very durable. The new titanium alloy developed by Nippon Kokan KK has high strength and good formability. It has been used as the surface material of golf heads recently and is popular in the golf market.

3.2 Tennis and Badminton Racket
At present, the application of titanium in tennis racket is mainly to bury a net made of pure titanium into the racket frame. In this way, not only the monetary inertia force of the tennis racket hitting the ball is improved, but even when the ball does not hit the center of the racket, the ball is easily shot out, which enhances the hitting power of the racket and is well received by users. In recent years, the demand for titanium tennis rackets in Japan is on the rise. Nearly every tennis racket manufacturer in Japan is selling titanium rackets, which account for about half of the racket market. In order to grade the rackets, manufacturers also use titanium-nickel super-elastic alloy materials and coating processing methods on the handles of the tennis rackets according to the characteristics of titanium, in order to develop the new uses for titanium.

Recently, the use of titanium’s rebound force to enhance the hitting effect has attracted much attention. Some Japanese companies are currently developing new titanium fiber materials for tennis rackets. The alloy is a shape memory alloy with super-elastic function, and even if it deforms under load, it will return to its original shape as soon as the external forces are removed. When this material is buried in the left and right sides of the racket handle, the rebound force can be increased obviously when hitting the ball. Like tennis rackets, badminton rackets made of pure titanium for the frame and titanium alloy for the long handle have been developed and commercialized.

3.3 Racing Bicycle
Bicycles are driven by humans, so they need to be very light, especially for racing bicycles where speed is a consideration. If the weight of the racing bicycle is reduced by one gram, it will gain the time of a thousandth of a second. Normal bicycles use 36 stripes, while titanium bicycles use 24 stripes, which not only reduces weight but also reduces wind resistance. Titanium and titanium alloys are first used in components. Currently, some companies have already used titanium and titanium alloys to manufacture various components for racing bicycles, including pins for encapsulated variators, left-handed nuts, pinless crank shaft, front and rear hub shafts, left and right foot pedal shafts, etc.

Over the past decade, the bicycle frames made of industrial pure titanium tubes and non-aviation (sport-grade) titanium alloys have been very popular. At present, there are nearly 58 companies producing titanium bicycles, and the United States has long been the largest producer and consumer of titanium bicycles. Now cycling is widely carried out all over the world, and titanium bicycles are particularly suitable for high-end bicycle sports, so titanium bicycle are gradually growing.
3.4 Racing Cars
Due to its excellent physical and mechanical properties, titanium has been used in racing cars and in the limited production of exotic sports cars. The application of titanium in automobile industry can greatly reduce the weight of automobile, reduce its fuel consumption, protect environment and reduce noise. The properties of titanium have been well represented in racing cars. Almost all the metal parts of the car can be made of titanium and titanium alloy, such as bolts, connecting rods, rockers, buffer back brackets, exhaust pipes, return pipes, valves, valve springs, brakes, transmission parts. In addition, titanium can also be used for surface coating, and has been used to improve the surface performance of brake plates, which can ensure that the brake plates are light and have long life. Titanium is used in automobiles to extend the service life of valves, springs, and connecting rods.

3.5 Other Sporting Goods
Mountaineering and skiing equipment is moving towards the direction of lightweight and miniaturization. Titanium material has the characteristics of light specific gravity, high strength and no reduction in impact value at low temperature. It has been widely used as a superior material for mountaineering and skiing, such as titanium alloy mountaineering sticks, mountaineering spikes, climbing fasteners, ski poles, ice skates and so on. Titanium sporting goods also include fencing protective masks, swords, fishing rods, fishing reels, rowing parts, spikes of running shoes used in track and field athletics, etc.

4. Optimization Design for Application of Sports Equipment

4.1 Generic Technology in the Design Optimization of Sports Equipment
The general generic technology is the manufacturing technology that guides numerous sports equipment. With universality and height, it is the guiding theory of the highest level of sports equipment manufacturing technology, and it mainly includes digital generic technology, personalized generic technology and standardized generic technology. Group generic technology is a system of manufacturing technology for sports equipment with different properties and rules, which is between general generic technology and specific product manufacturing technology, and can cover the manufacturing technology of a certain kind of sports equipment, such as pads and protective equipment, that have the same attributes and requires similar technical indicators such as resilience and depth. Its manufacturing technology belongs to the same category. The group generic technology mainly includes the sports speed bearing generic technology, and it is combined with the guiding thinking of generic technology to promote the design of titanium alloy sports equipment.

| First-level Index$^1$ | Second-level Indicator$^2$ |
|-----------------------|-----------------------------|
| R&D Design$^2$        | Product shape (whether it is beautiful, creative, etc.); product function (whether it meets the demand); product cost (whether it meets the requirements of high quality and low price), etc. $^2$ |
| Raw material selection$^1$ | Safety (whether it causes harm to people in motion); reliability (whether the performance is stable); environmental protection (whether it is harmful to the human body or the environment) $^2$ |
| Manufacturing$^2$ | Process design (whether it is scientific and reasonable); production process (scientific process and management specifications meet the manufacturing requirements of this type of sports goods); production workshop (sanitation, safety, spatial layout); worker skills (proficiency) $^2$ |
| Quality inspection$^1$ | Physics (appearance, structure, smell, etc.); chemistry (stability, safety); mechanics (whether it conforms to the law of motion); performance (with instructions, able to meet industry standards) $^2$ |
| Product sales$^2$ | Sales methods (whether the sales methods are reasonable and effective); sales channels $^2$ |
4.2 Optimization of Titanium Alloy Sports Equipment

For the optimization of any kind of sports equipment, it is necessary to be based on the principle of people-oriented to continuously design and develop equipment and equipment that are more in line with ergonomics, strictly follow the scientific laws of human activities, meet athletes’ sports needs by changing the shape and material of the equipment, and also create favorable conditions for athletes’ performance improvement or the achievement of fitness goals. At present, the titanium alloy sports equipment still stays in the R&D and use of high-end sports items, and has not been able to spread to more kinds of sports, as well as more sports people. The higher production cost and expenses are the reasons why titanium alloy sports equipment cannot be popularized and used in a wider range. Although China is the third largest titanium industry country in the world and its titanium reserves are at a relatively high level, the development of China’s titanium industry is still at a relatively primary stage. There are few kinds of cast titanium alloys, almost no recycling of titanium alloys, unadvanced melting and casting equipment for titanium alloys, and the quality of titanium alloy castings cannot be guaranteed; in addition, the use design of titanium alloy casting is ignored, the production efficiency of titanium alloy is low and so on, all kinds of factors have caused the high cost of titanium alloy products. To change this situation, it is necessary for relevant workers in the titanium industry to work together, diligently research and develop new types of titanium alloys, establish a system and mechanism for titanium alloys recycling, and upgrade the equipment for melting and casting titanium alloys, improve the management and technological level of titanium alloy casting, in order to ensure the quality of titanium alloy casting from all aspects while effectively reducing the production cost of titanium alloy casting.

5. CONCLUSION

With China’s economic development, it brings high-grade material demand, making more Chinese people pursue physical health and exercise, and the demand for civilian leisure sports equipment is also increasing. Based on the excellent characteristics of titanium alloy, more sports equipment that meet the requirements of sports competition law and body-building law have been developed, which provides key technical support for the development of sports equipment industry.

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