Status of Titanium Alloy Industry for Aviation in the World and Development Strategy of Chinese Enterprises

Kyong-Ho SIM\(^1,3\), Guo-feng WANG\(^2\) and Tae-Jong KIM\(^1,3\)

\(^1\)School of Management, Harbin Institute of Technology, Harbin 150001, China
\(^2\)National Key Laboratory for Precision Hot Processing of Metals, Harbin Institute of Technology, Harbin 150001, China
\(^3\)Faculty of Material Science and Engineering, Kimchaek University of Technology, Pyongyang 950003, Democratic People’s Republic of Korea

*Corresponding author

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**Abstract.** With the rapid development of the world aviation industry, the demand for aeronautical titanium alloys is increasing day by day. A stable and rapid development of the titanium alloy market has been formed. Based on the analysis of the industrialization status quo in the United States, Russia, Japan and China, the problems in the development of the aeronautical titanium alloy industry in China are put forward. In order to solve these problems, it is suggested to develop advanced titanium alloys and processing technologies, adjust the industrial structure and further improve the material standards for aeronautical titanium alloys.

**Introduction**

Now, titanium alloys have become one of the new materials for aviation, due to their good comprehensive performance [1,2]. Since titanium alloys were applied firstly for manufacturing fighters in the United States in the 1950s, titanium alloys have been used primarily in aircraft engines and aircraft skeleton structures due to their superior properties such as the specific strength, fracture toughness, heat resistance and corrosion resistance.

In recent years, the world’s titanium alloy processing technology has been rapidly developed, and the production and consumption of titanium alloys have reached a high level. China’s titanium is rich in resources, and the reserves are the most in the world. It has become the world’s fourth largest titanium industrial country with the complete industrial system and production capacity after the United States, Russia and Japan. Strengthening the research and application of titanium alloys for aviation and promoting their industrialization are of great significance for the development of Chinese aviation industry. In this paper, the current status of the aeronautical titanium alloy industry in four major titanium industrialized countries are introduced in detail, and the development strategies of Chinese aeronautical titanium alloy enterprises are discussed.

**Status of Titanium Alloys Industry for Aviation in Various Countries**

**United States**

Table 1 shows the annual shipments of titanium alloy products in various countries.

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<tbody>
<tr>
<td>United States</td>
<td>15,700</td>
<td>28,000</td>
<td>45,500</td>
<td>38,200</td>
<td></td>
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<tr>
<td>Russia</td>
<td>16,663</td>
<td>25,000</td>
<td>29,110</td>
<td>29,000</td>
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<tr>
<td>Japan</td>
<td>13,838</td>
<td>17,317</td>
<td>19,358</td>
<td>16,497</td>
<td></td>
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<tr>
<td>China</td>
<td>7,080</td>
<td>13,879</td>
<td>50,962</td>
<td>49,483</td>
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Titanium alloy products shipped in the United States in 2011 were 45,500 t, including forgings and ingots of 40%, plates of 40%, wires and bar of 15%, and others of 5%. Titanium alloys are mainly used in military and civil aircraft engines and airframes. From the perspective of industrial structure, the three titanium and titanium alloy production enterprises: TIMET, RTI and ATI, have determined the technical level and development direction of the United States titanium alloy industry.

TIMET is one of the world's leading producers of titanium alloy products and it is also the largest supplier of titanium alloys in the United States. TIMET (PCC) has sold a total of $7.2 billion in 2011, and titanium alloys for aerospace industry such as aircraft engines as its main products. RTI is a professional manufacturer of titanium and titanium alloys for over 50 years. It is mainly engaged in the production and sale of titanium alloys for aviation, and it is the main supplier of Boeing, Airbus and British Aerospace Systems. The shipment volume of titanium and titanium alloy products was 6700 t in 2011 and 7500 t in 2012. ATI is the largest special steel producer and the third largest titanium and titanium alloy producer in the United States. It is also the largest and most diversified professional metal producer in the world. In 2011, ATI acquired forging giant Ladish for $900 million, making it a true titanium and titanium alloy manufacturer by integrating titanium ingots, forgings and sheet metal production. ATI's products are mostly used in aeronautical titanium alloy products. Its main products include flat rolling products, high performance metals and engineering products. The shipment volume of titanium and titanium alloy products was 115,000 t in 2010 and 12,000 t in 2011.

Russia

Russia has the world’s largest full-process titanium alloy producer - VSMPO-AVISMA. In 2011, the output of titanium and titanium alloy products in Russia was 29,100 t, of which VSMPO-AVISMA produced 24,200 t. In 2012, the output reached 32,400 t, of which 40% was used to meet domestic demand and 60% was exported.

VSMPO-AVISMA actively develops relationships with Western companies. On June 30, 2008, VSMPO-AVISMA signed a framework agreement with Airbus under EADS (European Aviation Defense Company) for the supply of aeronautical titanium alloys. The agreement stipulates that VSMPO-AVISMA will supply the required titanium alloys to Airbus under EADS in 2020. The agreement is worth $4 billion. VSMPO-AVISMA also signed new long-term contract to supply titanium with French aircraft engine manufacturer SNECMA under SAFRAN, supplying titanium alloy plates, rods and cakes to SNECMA and other companies that have joined the SAFRAN Group to produce aero engines. It is estimated that the total revenue of the current contract will reach $300 million. In order to further expand its revenue, VSMPO-AVISMA strives to increase the added value of its products, such as increasing the proportion of forgings and re-selling its products after mechanical processing. The main task of the company in recent years is to continue the production of titanium and titanium alloys, to strive to account for one-third of the world titanium market share and to strengthen the relationship with partners. Now the company's production has entered a period of rapid development, but also turned to the field of further-processing.

Japan

Japan has owned a complete titanium industry chain with reasonable industrial structure and advanced technology. In Japan, there are five companies producing titanium alloy products, namely Nippon Steel & Sumitomo Metal, JFE Stainless Steel, Kobe Steel, Datong Special Steel and Aichi Steel. In Japan 85% of titanium alloy products are used in fields other than aviation such as chemical, electric power, automotive, construction and medical [4]. At present, with the rapid development of the aviation industry, the Japanese titanium alloy industry has signed contracts with aircraft component manufacturers. At the beginning of January 2016, Japan’s Nippon Steel & Sumitomo Metal and the SAFRAN Group of France’s SNECMA reached a new agreement on the long-term supply of titanium alloy billets for aviation. In July 2016, Kobe Steel began mass production of large titanium alloy forgings for Airbus A350XWB.
China

China's titanium industry started in the first five-year plan of the country, that is, in 1954. In the past 64 years, China's titanium industry has experienced three important stages of development: the start-up period (1954~1978), the growth period (1979~2000) and the rise period (2001~present) [5,6]. The rise period is a soaring period for China to become a major titanium industry in the world.

Under the background of rapid development of the national economy and accession to the WTO, the titanium market expanded significantly, and social capital was spontaneously entered the titanium industry. As a result, the level of the titanium industry increased significantly, and research and production showed a thriving situation. Titanium production rose sharply year after year, creating new records every year as shown in Figure 1. In 2016, the total output of titanium ingots in 27 titanium ingot manufacturing enterprises in China was 66,500 t, and the total output of titanium alloy products in 30 titanium processing materials production enterprises was 49,500 t, which far exceeds other titanium industrial countries such as the United States, as shown in Table 1. However, from the application field, China's titanium industry mainly produces general industrial titanium and titanium alloy products. In 2006, the demand for aeronautical titanium alloys accounted for only 9.7% (1338.8 t) of the total demand for titanium in China. In 2007, it rose to 17.2% (4061 t). In 2008, it was affected by the economic crisis and fell back to 12.8% (3575 t). Meanwhile, the average value of aviation field in the world is 50% and the United States is more than 70%.

![Figure 1. Changes in output of titanium and titanium alloy products in China (1964~2016).](image)

In recent years, China's large aircraft, space station, and lunar exploration project (Chang'e project) will produce a large number of aerospace titanium alloy demand. Especially in large aircraft projects, the application of aerospace titanium alloy will gradually increase. The launch of major projects in the aerospace industry is an opportunity and challenge for the China's aviation titanium industry. In response to these trends, China has made great efforts to promote the research and large-scale production of high-performance aeronautical titanium alloys, and achieved some achievements. Taking the market as the guide, BaoTi Group has developed large diameter bar and superplastic forming sheet of Ti-6Al-4V alloy for aeronautical structural parts. In addition, it has passed the quality system, process technology and product certification and audit of Boeing Company, French Aerospace Company, European Airbus Company, Rolls Royce Company of Britain, GOODRICH Company and other companies, and can provide products that meet the user requirements.

Prospective Analysis of Aeronautical Titanium Alloy Market

The demand for titanium alloys for various military aircraft and civil aircraft is increasing. Titanium alloys used in F15, F22, F35, F117, B1, B2 and V22 fighters are 27%, 41%, 27%, 25%, 21%, 26% and 16%, respectively [8,9].

Wade Leach [10], vice president of ATI market and product management, predicts that by 2035, the global formations number of commercial aircrafts will reach 50,000, which is more than doubled from the number of commercial aircrafts in the world in 2014. Henry S. Seiner, vice president of business strategy at TIMET, reported that in 2014, a total of 3,160 aerospace engines were produced worldwide, and titanium alloys will continue to be the main material for jet engine compressors. Michael Metz, President of Russia VSMPO, said that by 2021, the total demand for
titanium alloys in Russia will reach 13,100 t. William T. Shaffer, Boeing's director of materials and standards, pointed out that 38,050 new aircrafts will be delivered in the world by 2034. The main type of aircraft is a single channel aircraft with 26730. According to Shaffer, the Boeing 747-8 has 6 million parts and the Boeing 777 has 3 million parts. The number of parts purchased each year reaches 1 billion, costing $43 billion. Waldir Gomes Concalves, senior vice president of global customer support and services at Embraer, predicted that 70~130 seat commercial aircraft of 6,350 will be delivered worldwide in the next 20 years, and the worth is $300 billion. Meanwhile, 9,250 business aircrafts will be delivered worldwide in the next 10 years, and the worth is $265 billion.

Thus, the market demand of aeronautical titanium alloys in the United States, Russia, China and other countries in the world is very huge, and will show a growth trend in the next decade or even decades.

Development Strategy of Titanium Alloy Enterprises for Aviation in China

Problems in the Development of Titanium Alloy Industry for Aviation

At present, China’s titanium industry has still some problems to be solved in the important application fields such as aeronautics and astronautics.

1. The basic research on the heat-resistant titanium alloy system with a service temperature of 650 °C and above for aero engines is insufficient, and the industrialization of new technologies is progressing slowly. It restricts the application of heat-resistant titanium alloys in new types of aeronautical power system.

2. The research on the industrial production technology of high performance titanium alloy products with shorter process and lower cost is insufficient.

3. The existing technical standards for aeronautical titanium alloys (GB, GJB) can't meet the requirements of current applications of new alloy grades.

Development Strategy

1. Develop advanced titanium alloys and processing technologies, and promote the industrialization of new technological achievements. Now, many countries are carrying out research on new titanium alloys with higher service temperature, making some achievements. For example, the service temperature of Ti-Al intermetallic alloys such as Ti₃Al and Ti₂AlNb-based alloys breaks through the traditional titanium alloys [2]. NASA predicts that by 2020, the application of Ti-Al intermetallic alloys on aircraft engines may reach 20%. In China, the development of Ti-Al intermetallic alloys such as Ti₂AlNb-based alloys is basically synchronized with that of the United States and Europe. The systematic research on alloying and microstructure design of the alloy has been carried out, and the breakthroughs have been made in the application field such as satellites and missile engines. Recently, the National Key Laboratory for Precision Hot Processing of Metals (Harbin Institute of Technology) has studied the fabrication of Ti₂AlNb-based alloys by elemental powder metallurgy technology. The Ti₂AlNb-based alloys with ultra-fine microstructure and excellent mechanical properties were produced from cheap elemental powders [11].

2. Promote the adjustment of industrial structure and produce high value-added titanium alloy products with shorter process and lower cost. There are four main ways to reduce costs: firstly, to expand production scale on the basis of increasing demand; secondly, to promote technological progress and improve management level of enterprises; thirdly, to research new technology and processes; and fourthly, to develop new titanium alloys with lower cost. In order to realize the large-scale production of aeronautical titanium alloys, on the one hand, it has reached the economic scale by technological advancement and tapping the potential of old enterprises, and on the other hand, it has built a large-scale production plant for titanium alloy products.

3. Further improve the standards for aeronautical titanium alloys. In the future, the complete work of the standards for aeronautical titanium alloys should be opened depending on the
industrialization of titanium alloys. The types, specifications and processing technology of the newly developed titanium alloys should be formulated as the corresponding national standards, national military standards or aviation industry standards.

Conclusion
At present, China's aeronautical titanium alloy industry is facing new development opportunities, especially with a stable and expanding world aviation market. Under this situation, it is necessary to intensify scientific and technological innovation, develop advanced titanium alloys and processing technology, and develop high value-added products of titanium alloys. In addition, it is very important to promote the adjustment of industrial structure, reduce the cost of titanium alloy products, and further complete the standards for aeronautical titanium alloys for aviation.

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Reference