Recent Progress of Titanium Industry, Research and Development in China

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The progresses of Chinese titanium industry, research and development in the past four years since the Kyoto conference have been reviewed in this plenary paper. Over a rapid development duration, the Chinese titanium industry moves to a relatively stable state. In order to respond to the requirement of manufacture of C919 business aircraft, the titanium producers try to focus their work on the facilities and processing technologies improvement, leading to the fact that large size production can be well produced. For the research and development activities, the new alloy development, parts forming processing simulation, laser forming technology as well as the fundamental research on plastic deformation mechanism, quantitative relationship among processing-microstructure-properties describing and quantitative design method of chemical composition have been reviewed. At the end, the future way of Chinese titanium industry and research is highlighted.

Keywords: Titanium industry, research activities, recent progress, new alloys, manufacture technologies, trends

1. Introduction

On the background of continuous improving in macroeconomy, the titanium industry and research activities keep active and stable increase, the application of titanium and titanium alloys in aerospace, metallurgy, chemical industry as well as others fields have been made a great increas. By the end of 2010, the consumption of titanium mill production reached 35,636 metric tons, among which the consumption of titanium in chemical industry reached more than 20,000 metric tons. Generally, the non-aero application is still occupied to the main application fields and reaches more than 90% in ratio. The manufacturers of titanium sponge and mill products in China focused their much more attention on the processing technology improving and facilities reconstruction during the past four years. In the aspects of research and development activities, China has also done a very good job and made some remarkable achievements. The new alloys developments, components manufacture technologies, the forging process simulation and its application as well as some fundamental research should be light heightened.

In this paper, the progress of titanium industry, research and development of titanium and titanium alloys since the last conference held in Kyoto in 2007 has been reviewed, the future trends for the next 3 to 5 years of titanium industry are forecasted and the research activities are summarized.

2. The Progress of Titanium Industry

2.1 Sponge Titanium

At the end of 2010, the capacity and output of sponge titanium in China are 104,000 metric tons and 58,000 metric tons, respectively. The Figure 1 shows the capacity and output changes of sponge titanium in China in past few years. It indicated that during the years of 2003 to 2007, the yearly increased rate of capacity and output of sponge titanium were very high, and reached more than 390% and 280%, respectively. The capacity increased from a few thousands tons in 2003 to more than 60,000 tons in 2007, meanwhile the output also increased from a few thousands tons to nearly 50,000 tons. However, during the past four years, the increased rates of capacity and output are decreased obviously and only have 20% and 9%, respectively. This situation is mainly due to two reasons, one is influenced by the world economic crisis which affects the demand of the titanium and the other one is the capacity of titanium sponge in China is overlapped.

![Figure 1](image_url)

**Figure 1.** Changes of Capacity and output of sponge titanium in recent years in China

At the end of 2010, there are totally 14 titanium sponge manufacturers in China. The biggest one is Zunyi Titanium Plant, and the capacity and output of sponge titanium are 24,000 metric tons and 14,200 metric tons, and occupy more than 23% and 24% of total capacity and output in China, respectively.

2.2 Ingot

The capacity and output of ingot keeps increasing at a stable rate (near 30% and 10%, respectively) during the past four years, and the capacity and output of
ingot are 89,000 and 46,000 metric tons, respectively, at the end of 2010, Figure 2 shows the changes of capacity and output of titanium ingot during the past four years in China. The maximum weight of ingot fabricated by vacuum arc remelting (VAR) furnace is 11 metric tons with a diameter of 1066 mm, and the ingot fabricated by Electron Beam Cold Hearth Remelting (EBCHR) furnace is 10 metric tons with the size of 400 (W) * 1200 (H) * 4500 (L) mm.

![Figure 2](image1)

**Figure 2.** Changes of Capacity and output of titanium ingot in the past four years in China

At the end of 2010, there are 23 manufacturers related to the titanium ingot, among which Baoti Group is still the biggest one, and the ingot capacity and output are 25,000 metric tons and 20,000 metric tons, respectively in 2010.

### 2.3 Titanium Mill Products

In the past four years, the output of titanium mill products in China keeps increasing with an average rate of 20% even when suffering from the global economic crisis, and the amount reaches to more than 38,000 metric tons in the year 2010 (Figure 3). This mainly appreciated to the domestic demands, especially to chemical industry demands, Figure 4 shows the category structure of titanium mill production in China in 2010. It indicates that the plates and sheets are the majority products, occupied to nearly 55%, and the tube and bars are the second and third one, occupied to more than 22% and 16%, respectively. By the end of 2010, Baoti Group is still the top manufacture of titanium mill products in China with a shipment amount of 13,010 metric tons.

Concerning the consumption of the titanium mill products, Figure 5 shows the changes of consumption during the past few years and Figure 6 show the structure of consumption. Figure 5 indicates that the consumption amount of mill products is 37,000 metric tons in 2010 and keeps increase during the past 7 years, especially in last year, the increase rate reached more than 60% and the net consumption amount of mill products is 13,000 metric tons compared with the consumption amount 24,000 metric tons of the year of 2009. This increased amount should be appreciated to

![Figure 3](image2)

**Figure 3.** Changes of titanium mill products of China in recent years

![Figure 4](image3)

**Figure 4.** Structure of Titanium mill products in China in 2010 (Total: 38,323 metric tons)

![Figure 5](image4)

**Figure 5.** Changes of consumption of Titanium mill products of China in the past few years

![Figure 6](image5)

**Figure 6.** Consumption structure of Titanium mill products of China in 2011
the increased demands of chemical industry. The consumption structure of mill titanium products is showed in Figure 6, it can be seen that the chemical industry consumed more than 53% of the total consumption of mill products in 2010 and take the rank of top. The second one is the aerospace industry, occupied about 9.7%. This kind of consumption structure shows that the civil application still takes the main position in China titanium industry which is the same situation as Japan. However, with the development of Chinese economy, especially the domestic needs, the demands for titanium mill products will keep growing in the next few years even though the consumption of titanium mill products has reached a relatively high level.

Figure 7 show the situation of output of mill production in the main world titanium manufacture countries and its share. It is demonstrated that the titanium mill production output of the world is more than 110,000 metric tons at the end of 2010, the China takes the top position in the scale, occupying more than 34% of the total output of the world. The second one is U. S. A, occupying more than 30%, the third one is CIS, occupying more than 18%, the fourth one is Japan, occupying more than 12%, the last one is Europe, occupying near 4%. Even though, Chinese titanium people still have a lots work to do in the aspects of technology, lowering the cost and improving the quality stability and so on.

2. 4 Technologies and Facilities Improvement

With the continuous quick increase during 2002 to 2007, titanium industry in China steps a relatively stable developing state, and the manufacturers focus their much more attention to improve the processes technique and facilities reconstruction. For the sponge titanium, Zunyi titanium Co., Ltd has done an important work on improving the quality of products and high purity sponge with 4N, which was produced at the end of 2010 successfully. Meanwhile, the biggest sponge bulk (shown in Figure 8) with a weight of 12 metric tons has been introduced at the beginning of 2010 with three technologies application, which are specially designed new structure of oven shell (the diameter is more than 2 meters), forced cooling process and automatic controlled reaction process. By application of those technologies, the zero-grade rate of one sponge bulk is increased from 30% to 65%, and the productivity is increased to more than 80%, and also the power consumption is decreased by 20% compared with the former process. So this technologies improvement will be the direction for the titanium sponge enterprises in China for the next few years.

For the ingot and mill products, the Chinese titanium manufacturers are paying much more attention on the facilities reconstruction during the past few years. Take an example for Baoti Group, as one of the important facilities, a set of 2400 KW EBCHR furnace and precision roll milling machine with 20 rollers have been equipped, and make the high quality titanium rectangle ingot and strip produced. Meanwhile, in order to improve the quality of titanium wires and bars, a set of high speed rolling machine has also been reconstructed.

Moreover, for titanium industry in China, a new area named Western Titanium Valley of China (WTVC) is forming, which includes Shaanxi Province (Located Baoti Group Co., Ltd, Northwest Institute for Nonferrous Metal Research and Northwestern Polytechnical University), Ningxia Province (Ningxia Orient Tantalum Industry Co., Ltd), Guizhou Province (Zunyi Titanium Plant). That means in WTVC, the Chinese main titanium industry and research institutions are located, and the output of ingot and mill production in this area occupies more than 50% of China, and takes the important position of Chinese titanium industry and research.

3. Research and Development Activities

3. 1 Support System of the Government

As one of the important structure materials, the
titanium related research and development activities have been greatly supported not only from the center government but also from the local government. For the center government, the supporting system mainly includes Major Project of China National Program for Fundation Research and Development ("973" program in short), National High Technology Research and Development Program ("863" program in short), National Natural Science Fundament Program (NNSF), National Science and Technology Supporting Plan, etc. In the past few years, totally more than 10 billion RMB have been supported by the center and local government.

3.2 New Alloy Development

New alloy development is still active during the past 4 years. Table 1 shows some newly developed or underdevelopment titanium alloys in China at the end of 2010. TC21 alloy (Ti-6Al-2Zr-2Sn-3Mo-1Cr-2Nb) is one of the developed new alloys and has been taken successful application in the aerospace industry. Figure 9 shows the typical properties and microstructure as well as the component.

![Figure 9](image_url)

**Figure 9.** Typical properties, microstructure and manufactured component of TC21 alloy. Parts photo supplied by Dr. Zhihou ZHU

T2448 alloy is another successfully developed new Bio-titanium alloy with the nameley chemical composition of Ti-24Nb-4Zr-7, 9Sn. The Young’s modulus can be reached to 20GPa, and the biomechanical compatibility is excellent. Meanwhile, the tensile strength reached more than 1700MPa after heat treatment for the formed nano-size precipitation. The alloy has been successfully applied in medicine treatment as the implant.

3.3 Component Manufacture Technologies

Cost saving is still the main point for the researchers. Some Chinese scientists pay much more attentions on the near net shape forming technologies of titanium components such as Isothermal Forging and Laser Direct Manufacture. Prof. Yang from Northwest Polytechnical University developed one of the isothermal technologies named Isothermal Local Loading Forming (ILLF), which has the highlights of advanced force-saving forming technology, integrated control of inhomogeneous deformation and microstructure evolution for precision shape-forming and high performance of the parts, optimization and robust control by through-process mutiscal model. By using this technology, titanium bulkhead has been manufactured for aerospace application, and shown in Figure 10. Based on the technology of laser forming, Prof. Wang tries to develop it to manufacture the large complex parts for aerospace application and named it as Laser Direct Manufacture (LDM). Figure 11 demonstrates the scheme diagram of LDF technology. By using this technology, the manufacture of large complicated parts becomes easier, the cost of the parts is extremely cut down in material preparation, manufacture process as well as the manufacture time; the fly-to buy ratio is also improved remarkably; meanwhile, the flexibility designable becomes possible. Wang focuses their main attention on trying to solve the key barriers of the laser forming
technologies including: a) dispersing the thermal-stress formed during the process and avoiding the split of the manufactured parts; b) controlling the solidification process to form designed solidification microstructure including the grain size, morphology as well as crystal orientation; c) selecting the proper parameters to avoid the internal defects formation; d) applying a special heat treatment to gain the microstructure with an excellent compositive performance. Figure 12 shows the microstructure formed after laser direct manufacture and heat treatment as well as the corresponding fatigue and da/dn properties. Besides the detailed research work on process, the manufactured parts of titanium have been applied on the Chinese commercial aircraft C919, and Figure 13 shows some parts manufactured by LDM. By now, the size of the largest parts that can be made by LDM is about 4000mm (L) * 3000mm (W) * 2000mm (H). So, the technology should be the best method to manufacture the large complicated component for aerospace application if the performance can meet the needs and the quality can be stably controlled.

Figure 11. Scheme diagram of Laser Direct Manufacture technology (LDM) \(^{(13)}\)

Figure 10. Partial views of titanium bulkhead and the typical formed microstructure manufactured by using IILF technology developed by Yang \(^{(10)}\)

Figure 12. The formed microstructure after laser direct manufacture (a) and heat treatment (b) as well as the fatigue property (c) and da/dn property (d) \(^{(15)}\)
3.4 Grain Refinement

Improving the mechanical properties of titanium alloy through grain refinement still attracts the researcher’s attention. The Equal Channel Angular Pressing (ECAP) is thought as one method to refine grain size. ECAP has been used for CPTi at room temperature by Zhao\(^5\), the results show that the grain size can be reached to 0.2\(\mu\)m by 6~8 times passes and the corresponding tensile strength is more than 780MPa. The grain size of as-received material is more than 23\(\mu\)m and the corresponding tensile strength is only about 400MPa. Figure 14 shows the microstructure of as-received material and after ECAP.

![Microstructure of as-received material before and after ECAP](image)

**Figure 14.** Microstructure of as-received material (a) and after ECAP (b) of CP-Ti\(^5\)

Besides those research works, Chinese researchers also paid their attentions on the modeling and computer simulation for alloy design and deformation process\(^2,7\), titanium surface modification for biomedical application\(^3\), new technologies for TiAl alloy casting\(^3\), titanium based composites reinforced with particle\(^8\) and so on, and gained remarkable progress.

4. Summary

During the past four years after Kyoto conference, Chinese titanium industry keeps increasing in capacity and output of sponge, ingot and mill production with a reasonable rate, and the enterprises mainly focus their attention on the technology improve and facility reconstruction. Those activities will make the quality of titanium productions in China improved. In the next 2 to 5 years, the capacity of sponge titanium will be more than 140,000 metric tons and 160,000 metric tons respectively due to 3 new manufacture lines setup and original manufacture enlargement, and meanwhile the capacity of ingot will be more than 110,000 metric tons and 130,000 metric tons respectively for the new EB and PAM furnace equipped. So at the end of 2015, the output of mill products will be very huge, and this situation will be a great challenge for Chinese titanium industry—where is the direction for those titanium mill products? Concerning this, the titanium application research work should be emphasized and try to find the new application area. For the research activities, the fundamental research should be the key for innovation of manufacture process and lowering the cost of titanium. In order to make great progress for this point, the cooperation among the manufacturer, university and research institute could be enhanced. The cost saving technologies, near net shaping technologies as well as some new application technologies will be the research direction for the Chinese researchers in the next 5 to 10 years. Meanwhile the international cooperation should also be important during the research activities.

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