

# Advances in the Preparation of Titanium and its Alloys Using Titanium-Containing Compounds as Cathodes for Electrolysis

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## Abstract

Titanium and its alloys have excellent physical and chemical properties, and are widely used in aerospace, biomedical, automotive industry and people's daily life. At present, the titanium preparation process is mainly divided into metal thermal reduction method and molten salt electrolysis method. Among them, the former preparation of titanium process has complex technology, high energy consumption, etc. resulting in high production costs of titanium, limiting the further development and popularization of titanium, molten salt electrolysis method is favored by researchers, through continuous efforts, for the development of titanium industry to provide new ideas and insights. This paper mainly summarizes the preparation process and latest research progress of titanium sources in molten salt at home and abroad in recent years, focuses on electrolytic cathodes, introduces the preparation of titanium and titanium alloys from titanium-containing compounds and titanite-containing blast furnace slag containing ilmenite, and introduces the electrochemical behavior of titanium ions in different systems. The existing problems are analyzed and discussed, and the future titanium preparation process is prospected.

## Keywords

**Titanium Smelting; Molten Salt Electrolysis; Electrochemical Behavior; Cathode.**

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## 1. Introduction

Titanium has the advantages of light weight, high strength and good corrosion resistance, and is a very important strategic metal material after steel and aluminum, and is widely used in aerospace, military, industrial procedures, automobiles, agricultural food, medicine, etc.

With the gradual increase in the application of titanium and alloys, and the production cost of titanium remains high, researchers have improved the production process of titanium and its alloys mainly from the aspects of titanium smelting process and production raw materials. However, the traditional preparation process of titanium alloy is generally metal thermal reduction method, usually prepared under high temperature, high pressure and vacuum conditions through a series of complex processes, the preparation conditions are harsh, the process is long, such as the extraction of TiO<sub>2</sub> from ilmenite and the preparation of TiCl<sub>4</sub> by Kroll method, the process is complex and the energy consumption is high, resulting in titanium and alloys are difficult to commercialize and the price is high. Therefore, how to optimize the production technology of titanium and its alloys, reduce costs, and seek alternative green and short-process methods for preparing titanium and its alloys has been the unremitting goal of researchers and the focus of the industry for many years.

The preparation of metallic titanium by molten salt electrolysis is considered to be the most promising process method, usually using titanium halides or oxides and other titanium-containing compounds in molten salt for electrolysis of titanium. Among them, the representative process of molten salt electrolysis method is FFC process, which was proposed by Professor D.J. Fray of Cambridge University and his collaborators in 2000, which is an electrochemical method for the preparation of metallic titanium by direct reduction of solid  $\text{TiO}_2$ . [1], Since then, the research on titanium metallurgy process has entered a new climax, and a number of promising electrometallurgical processes for preparing titanium metal have been proposed one after another. Looking at the current research and development status of titanium extraction process by molten salt electrolysis, the main raw materials are  $\text{TiCl}_4$ ,  $\text{K}_2\text{TiF}_6$ ,  $\text{TiO}_2$ ,  $\text{CaTiO}_3$ , titanium-containing blast furnace slag, crippled titanium alloy, etc. According to the different titanium sources, the molten salt electrolysis process with more research can be divided into two types: one is the molten salt electrolysis process represented by FFC titanium-containing compounds as cathodes, and the other is the molten salt electrolysis process containing titanium chloride or fluoride as an electrolyte, the research status of molten salt electrolysis process containing titanium-containing compounds as cathodes is introduced respectively, and the electrochemical behavior of titanium ions in chloride or fluoride is summarized, in order to provide a theoretical reference for the preparation of titanium and alloys by molten salt electrolysis.

## 2. Different Titanium-containing Compounds are Electrolytic Cathodes to Prepare Titanium

In recent years, in order to alleviate the shortage of titanium resources, several electrochemical processes for electrolytic preparation of titanium have been invented, such as the FFC-Cambridge process that directly uses  $\text{TiO}_2$  as the cathode for electrolysis; The calcium generated by the cathode was indirectly chemically reduced to the OS process of  $\text{TiO}_2$ ;  $\text{TiO}_2$ -mediated reduction EMR process without direct contact with calcium; SOM process in which oxide ions are transported from the molten salt electrolyte to the anode using a solid electrolyte and titanium ions are reduced. In addition to  $\text{TiO}_2$  as an electrolytic cathode, other titanium-containing compounds such as  $\text{CaTiO}_3$ ,  $\text{K}_2\text{TiF}_6$ , etc. have also been used as more studied electrolytic cathode raw materials, which are introduced below.

### 2.1 $\text{TiO}_2$ is an Electrolytic Cathode

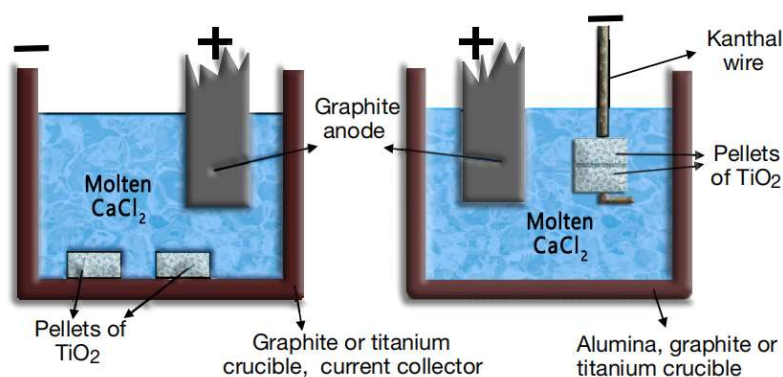
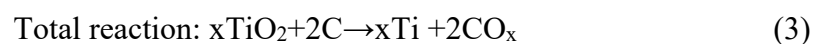
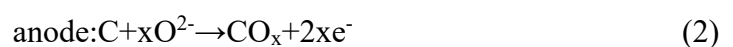
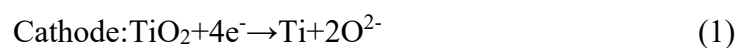
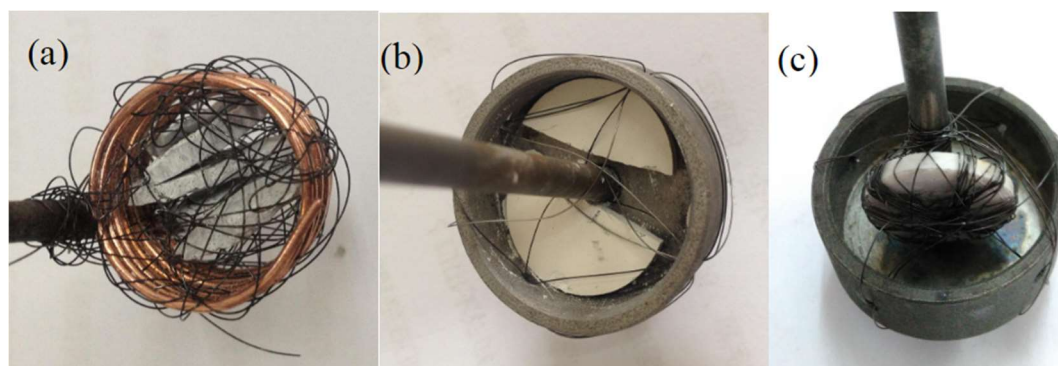


Figure 1. Schematic diagram of FFC process unit [1]

A typical representative of molten salt electrolysis of  $\text{TiO}_2$  as an electrolytic raw material is the FFC process. At the beginning of the FFC process discovery, titanium dioxide powder tablets were pressed and then sintered to prepare cathodes; Graphite as the anode; With  $\text{CaCl}_2$  as the electrolyte, a certain voltage is applied under the protection of an inert atmosphere for electrolysis. The electrode process of the process can be expressed as follows, The principle is shown in the **Figure 1**. Schematic diagram of FFC process unit[1].

Chen GZ et al. [2] used titanium crucible as pseudo-reference electrode, graphite rod as counter electrode, molybdenum wire carbon rod and titanium rod as working electrodes, respectively, according to the three pairs of current peaks on the cyclic voltammetry curve of  $\text{TiO}_2$ -coated titanium electrode, it was proposed that the  $\text{TiO}_2$  reduction process was divided into three steps:  $\text{TiO}_2 \rightarrow \text{Ti}_2\text{O}_3 \rightarrow \text{TiO} \rightarrow \text{Ti}$ ; Wang Shulan [3] of Northeastern University et al. used thermally dried analytical grade molten  $\text{CaCl}_2$  as electrolyte. The graphite crucible was used as the electroreduction cell and as the pseudo-reference electrode. Using the graphite rod as the counterelectrode, the molybdenum wire is connected to the potentiostat outside the reactor, and the reduction is carried out in two steps by cyclic voltammetry, timing current and electrochemical impedance spectroscopy, namely  $\text{TiO}_2 \rightarrow \text{TiO} \rightarrow \text{Ti}$ ; Pritish Kar et al. [4] established a model for calculating the diffusion coefficient and compared the linear sweeping voltammetry obtained by the model with the experimental results of Dring et al. It is believed that the reduction is carried out in four steps, namely  $\text{TiO}_2 \rightarrow \text{Ti}_3\text{O}_5 \rightarrow \text{Ti}_2\text{O}_3 \rightarrow \text{TiO} \rightarrow \text{Ti}$ , and the transformation of  $\text{Ti}_3\text{O}_5$  and  $\text{Ti}_2\text{O}_3$  in the reaction is carried out almost simultaneously. Li Zequan et al. [5] studied the deoxygenation process of  $\text{TiO}_2$  electrolytic reduction by using  $\text{TiO}_2$  electrode as working electrode, graphite anode auxiliary electrode, and graphite crucible as reference electrode by cyclic voltammetry and chronocurrent method, and believed that  $\text{TiO}_2$  electrolysis underwent two reduction processes:  $\text{TiO}_2 \rightarrow \text{TiO}$  and  $\text{TiO} \rightarrow \text{Ti}$ .

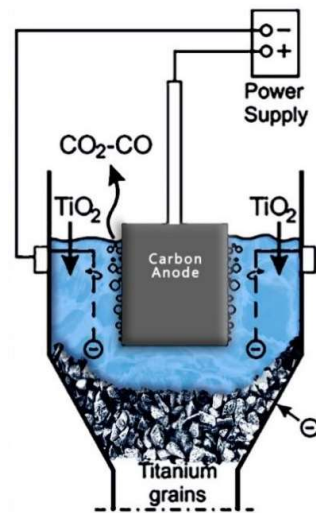


**Figure 2.** Lu Jiao is used as a copper basket, molybdenum basket and titanium basket for cathode carrier [8]

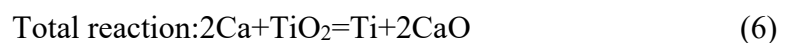
Based on the principle of FFC's Cambridge method, Chinese scholar Liao Xianjie et al. [6] prepared metallic titanium by electrolysis of  $\text{TiO}_2$  in a 1073K  $\text{NaCl-CaCl}_2$  molten salt. The electrochemical reduction involved in the reaction is divided into 4 steps:  $\text{TiO}_2 \rightarrow \text{Ti}_3\text{O}_5$ ,  $\text{Ti}_3\text{O}_5 \rightarrow \text{Ti}_2\text{O}_3$ ,  $\text{CaTi}_2\text{O}_4 \rightarrow \text{TiO}$ ,  $\text{TiO} \rightarrow \text{Ti}$ , [7] in which  $\text{CaTiO}_3$  spontaneously decomposes after the formation of metallic titanium. This method avoids the chlorination process, reduces production costs, speeds up the production cycle, and reduces energy consumption. However, in the actual production process, the anode material falls off with the reaction, so that the prepared metal titanium is not pure enough. Lu Jiao [8] based on the FFC Cambridge method,  $\text{TiO}$  powder was mixed into the pure  $\text{TiO}_2$  powder, and the cathode was obtained by mixing, pressing and sintering, and copper basket, molybdenum basket and titanium basket were used as cathode carriers (as shown in **Figure 2**. Lu Jiao is used as a copper basket, molybdenum basket and titanium basket for cathode carrier ), and graphite rods were used as anodes. First, the empty molybdenum rod and carbon rod are placed in  $\text{CaCl}_2$  molten salt at 900 °C, and pre-electrolyzed for 2h under the condition of electrolysis voltage of 3.2V; then the

molybdenum rod is taken out, the prepared cathode is placed into molten salt, and metal titanium can be obtained by electrolysis at 3.2V under Ar protection conditions for a certain time. The incorporation of TiO improves the conductivity of the cathode sheet, shortens the electrolysis process, and is conducive to electrolytic reduction. When the amount of TiO is about 9%, electrolytic reduction has the best effect. Practice has proved that this method is simple and environmentally friendly, generating pollution-free carbon dioxide.

Ono et al. [9] proposed the calcium thermal reduction mechanism OS process, which carried out the calcium thermal reduction reaction and the reaction of recovering the reducing agent in the same reaction cell. The reaction cell uses graphite as the anode, pure titanium or stainless steel as the cathode, and CaO and CaCl<sub>2</sub> to form the reaction medium. TiO<sub>2</sub> powder is added from the upper part of the reaction tank, reduced to metal titanium by Ca near the cathode, and an appropriate amount of deoxidized Ti is rapidly agglomerated and deposited to form sponge particles, which are deposited at the bottom of the electrolytic cell. CaO in molten salt is ionized into Ca<sup>2+</sup> and O<sup>2-</sup>, and directionally migrated to the cathode and anode under the action of electric field, respectively, under the condition of electrolytic system, Ca<sup>2+</sup> is electrons at the cathode to generate Ca, and reacts with TiO<sub>2</sub> to generate CaO dissolved in molten salt; O<sup>2-</sup> loses electrons at the anode to form oxygen and reacts with the graphite anode to form CO or CO<sub>2</sub>. The by-product CaO obtained by the reduction reaction is decomposed into metal Ca in the electrochemical region, The electrode process of this process can be expressed as follows, and the principle is shown in the **Figure 3**. Schematic diagram of OS process device[10].



**Figure 3.** Schematic diagram of OS process device[10]



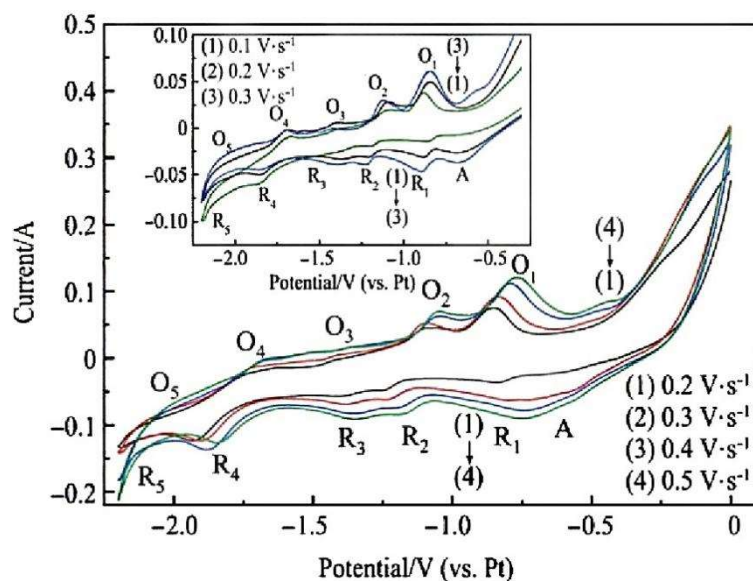
The OS process reduces production costs, realizes the recycling of calcium metal, saves resources and energy, and realizes continuous production. But there are also great defects, the produced titanium powder contains calcium impurities, resulting in the low purity of the prepared metal titanium, in order to achieve industrial production, further improvement is needed.

Liu Meifeng et al. [11] analyzed the direct electrochemical reduction products of  $\text{TiO}_2$  and performed electrolysis at a decomposition voltage lower than  $\text{CaO}$ , which was oxygen ionization. Electrolysis at a decomposition voltage higher than  $\text{CaO}$  is a combination of oxygen ionization and calcium thermal reduction. The presence of calcium impurities  $\text{CaTiO}_3$  and  $\text{CaO}$  directly affects the preparation of titanium powder in OS process, and Wan Heli et al. [12] studied the behavior of  $\text{CaTiO}_3$  in the process of calcium thermal reduction of  $\text{TiO}_2$  from the aspects of thermodynamic analysis, additive  $\text{CaCl}_2$ , reaction time and temperature, and pointed out that  $\text{CaTiO}_3$  was inevitably produced in the process of calcium thermal reduction of  $\text{TiO}_2$  to prepare titanium powder, mainly due to the generation of  $\text{CaTiO}_3$  in the reduction process and the addition of additive  $\text{CaCl}_2$ .  $\text{CaO}$  generated by  $\text{CaCl}_2$  hydrolysis is sintered with  $\text{TiO}_2$  at high temperature to form  $\text{CaTiO}_3$ . When the mass ratio of  $\text{CaCl}_2$  to  $\text{TiO}_2$  is 1:4, the reaction temperature is 1273K, and the reaction time is 6h, the single-phase unit cell is finally obtained as a hexagonal unit cell structure titanium powder, the powder has an irregular shape, the particle size is 8~15 $\mu\text{m}$ , and its average purity reaches 99.55% for EDS analysis. Guo Shenghui et al. [13] used three different feeding processes to electrolytically reduce  $\text{TiO}_2$  in the  $\text{CaCl}_2$  molten salt system to obtain titanium on the cathode. Electron probe and X diffraction analysis showed that the titanium content of the cathode product reached 94.646%, 80.632% and 99.784%[14], respectively. Microscopic analysis showed that the titanium obtained on the cathode was sponge or granular.

## 2.2 $\text{K}_2\text{TiF}_6$ Acts as an Electrolytic Cathode

Due to the small solubility of  $\text{TiCl}_4$  in chloride molten salt systems,  $\text{K}_2\text{TiF}_6$  is often used as the titanium source. CHEN GUANG-SEN et al. [15] The mechanism of electrochemical reduction of  $\text{Ti}^{4+}$  ions by 1wt% $\text{K}_2\text{TiF}_6$  in an isomolar  $\text{KCl-NaCl}$  molten salt at 973K was  $\text{Ti}^{4+} + e^- = \text{Ti}^{3+}$ ,  $\text{Ti}^{3+} + e^- = \text{Ti}^{2+}$ ,  $\text{Ti}^{2+} + 2e^- = \text{Ti}$  (pt alloy),  $\text{Ti}^{2+} + 2e^- = \text{Ti}$  (pure).

Tian Yabin et al. [16] using tungsten wire as the working electrode, tungsten rod as auxiliary electrode, platinum wire as the reference electrode of the three-electrode system believes that at 1073K at 42.62%  $\text{NaCl-54.38\% KCl-3\% K}_2\text{TiF}_6$ , the electrochemical reduction of  $\text{Ti}^{4+}$  in molten salt on the tungsten electrode is a four-step reaction process, each step of the reaction transfers one electron, and the electrode reaction is controlled by diffusion, the electrode reaction equation is:  $\text{Ti}^{4+} + e^- \rightarrow \text{Ti}^{3+}$ ,  $\text{Ti}^{3+} + e^- \rightarrow \text{Ti}^{2+}$ ,  $\text{Ti}^{2+} + e^- \rightarrow \text{Ti}^+$ ,  $\text{Ti}^+ + e^- \rightarrow \text{Ti}$  and agreed with CHEN GUANG-SEN.



**Figure 4.** 42.62%  $\text{NaCl-54.38\% KCl-3\% K}_2\text{TiF}_6$  at 1073 K (0.192mol·L<sup>-1</sup>) Cyclic voltammety curve of molten salt at different scanning rates (working electrode area  $S=0.322 \text{ cm}^2$ )[14]

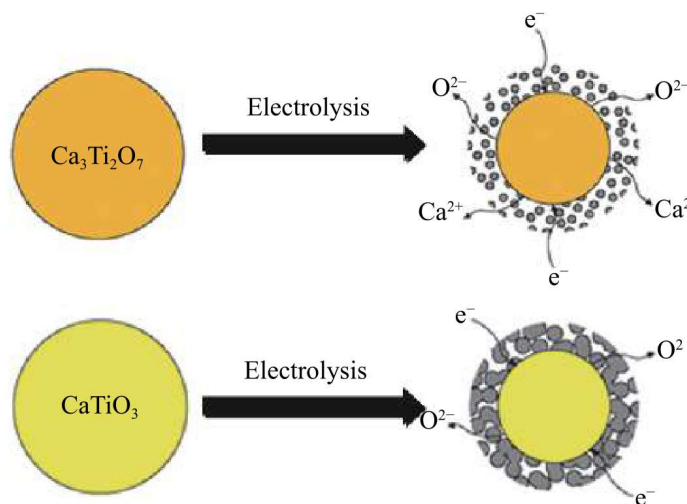


The addition of titanium sources is mainly fluoride, oxide or chloride of titanium, of which  $K_2TiF_6$ . As a common titanium source additive, it has been paid attention to by many researchers, but  $K_2TiF_6$ . Electrolysis as a titanium source will generate fluorine gas at the anode in the process of depositing titanium, causing pollution to the environment, if  $K_2TiF_6$  is used as a molten salt electrolyte, adding titanium dioxide as a titanium source will effectively improve this shortcoming[17].

### 2.3 $CaTiO_3$ Acts as an Electrolytic Cathode

Jiang Kai [18] of Wuhan University and others proposed for the first time to directly electrolyze  $CaTiO_3$  as a precursor to prepare metal Ti, and the experimental results showed that direct electrolysis of  $CaTiO_3$  could improve the electrolysis efficiency. Subsequently, Ru Liyue [19] of Chongqing University and others systematically studied the difference between direct electrolysis of TiO and  $CaTiO_3$  theoretically and experimentally in their dissertations, and obtained similar results. Chen Konghao et al. [20] pointed out that the current efficiency of direct electrolysis of  $CaTiO_3/C$  is higher than that of  $TiO_2/C$ , mainly because when electrolysis of  $TiO_2/C$ , the electrochemical reaction  $xTiO_2 + Ca^{2+} + 2e^- = CaTiO_3 + Ti_{x-1}O_{2x-3}$  forms  $CaTiO_3$ , which reduces the current efficiency; But neither is current efficient; Under low voltage,  $CaTiO_3$  is mainly decomposed into TiO first, and when the voltage is higher, it can provide greater driving force, and  $CaTiO_3$  can be directly decomposed into  $Ti_2O$ [20].

Dong Wang et al. [21] accelerated the electroreduction of high-valence titanium in  $CaCl_2$  with  $Ca_3Ti_2O_7$ . The stability of  $CaTiO_3$  and  $Ca_3Ti_2O_7$  in  $CaCl_2$  melt solution was studied, and the reduction rates of  $CaTiO_3$  and  $Ca_3Ti_2O_7$  were compared at 3.2V constant voltage electrolysis for 30 min at  $900^\circ C$ . The results show that the electroreduction difficulty of  $Ca_3Ti_2O_7$  and  $CaTiO_3$  is basically the same. Because during the electrodeoxidation of  $Ca_3Ti_2O_7$ , more "diffusion channels" are generated in the cathode because  $Ca^{2+}$  is released from the  $Ca_3Ti_2O_7$  precursor during the electrodeoxidation process. By adding  $TiO_2$  in-line during electrolysis, which is converted to titanate in situ, excess CaO can be efficiently absorbed. Therefore, the complete reduction of  $CaTiO_3$  takes 12h, while  $Ca_3Ti_2O_7$  only needs half the electrolysis time when using  $Ca_3Ti_2O_7$  as raw material, which provides a new method for efficient and sustainable electrolytic reduction of titanate by improving the Ca/Ti ratio.



**Figure 5.** Comparison of  $CaTiO_3$  and  $Ca_3Ti_2O_7$  diffusion channels during electrolysis[21]

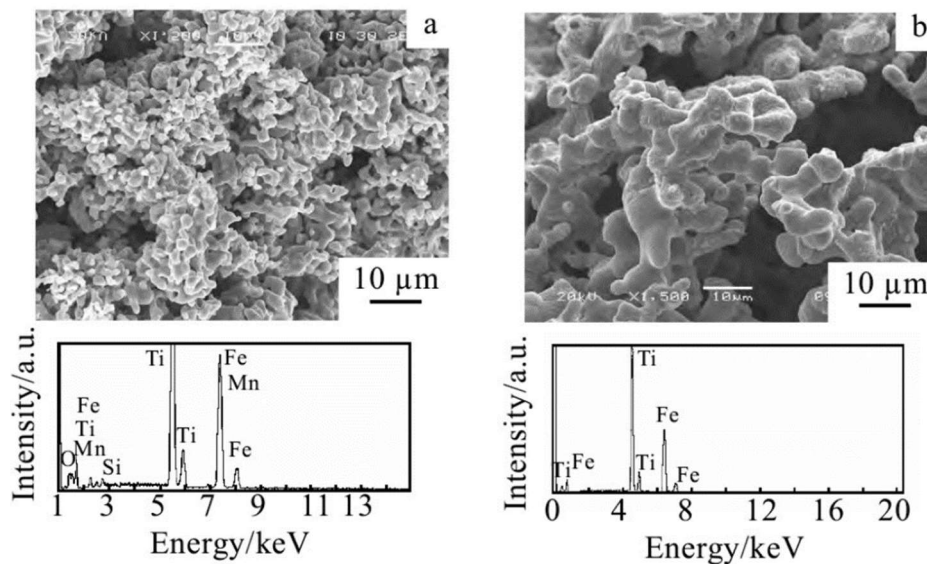
### 3. Titanium and Alloys are Prepared from Ilmenite and Titanium-containing Blast Furnace Slag as Cathode Raw Materials

Most of the titanium resources exist in the form of ilmenite, vanadium titanium magnetite and other composite ores, of which about 45% of the titanium elements in the vanadium titanium magnetite after blast furnace smelting enter the blast furnace slag, although the titanium-containing blast furnace

slag contains about 22% of  $\text{TiO}_2$ , but due to titanium dispersion distribution, fine particles and other reasons are difficult to be directly used, most of them are discarded, explore reasonable utilization methods can avoid a lot of waste of resources and environmental pollution. The development and utilization of ilmenite and its high titanium slag resources after iron removal has an inestimable effect on the development of a country's titanium industry and even the sustainable development of the national economy.

### 3.1 Ilmenite as an Electrolytic Cathode

Xu-Yang Liu et al. [22] prepared Fe-Ti alloy by electrolysis of ilmenite concentrate cathode in  $\text{CaCl}_2$  molten salt, which proved that calcium chloride hydrolysis reaction to generate  $\text{CaTiO}_3$  in the electrochemical reduction of ilmenite concentrate in calcium chloride, and the formation and decomposition of  $\text{CaTiO}_3$  intermediate products is an inevitable process. At the same time, the addition of  $\text{CaCO}_3$  during the sintering process can promote the generation of Ti in the cathode and improve the current efficiency. Du Jihong et al. [23] prepared TiFe alloy by electrolysis of ilmenite in  $\text{CaCl}_2$  molten salt, and believed that the reduction of ilmenite underwent the alloying process from preferential generation of Fe to gradual formation of TiFe and TiFe, and intermediate products included  $\text{CaTiO}_3$ ,  $\text{Fe}_2\text{TiO}_4$  and TiO. The first alloy formed by the reaction is  $\text{TiFe}_2$  alloy, which is finally converted into TiFe alloy through the mutual diffusion of Ti and  $\text{TiFe}_2$ , indicating that diffusion is the control step of the reaction[24]. Under the same electrolytic conditions, ilmenite is more difficult to electrolyze than mixed oxide. This is due to the large size of ilmenite particles, its impurities are solidly soluble into iron titanate, deoxidation is more difficult, electrolysis efficiency is lower, and through the analysis of electrolysis efficiency[25], it is believed that the reduction of titanium oxide is  $\text{Ti}^{4+} \rightarrow \text{Ti}^{3+} \rightarrow \text{Ti}^{2+} \rightarrow \text{Ti}^+ \rightarrow \text{Ti}$  step by step.



**Figure 6.** Morphology and composition analysis of ilmenite after 14 h and mixed oxide electrolysis for 8 h

Qi Cancan et al. [26] performed thermodynamic calculations on the possible reactions of ilmenite electrochemical reduction processes. Based on the FFC method, ilmenite was used as the cathode and electrolyzed in  $\text{LiCl-KCl}$  and  $\text{LiCl-KCl-CaCl}_2$  molten salts to obtain  $\text{Fe}_2\text{Ti}$  and FeTi alloys respectively.

Cui Peng et al. [27] in the  $\text{LiCl-KCl}$  molten salt system, it was confirmed that the iron in ilmenite was first reduced and a small amount of  $\text{Fe}_3\text{Si}$  alloy was formed under different electrolysis times, cell voltages and electrolytic temperatures. In the process of electrodeoxidation of molten salt, the phase

of titanium is  $\text{Li}_2\text{TiO}_3$ ,  $\text{LiTiO}_2$  and  $\text{TiO}$ , and the deoxidative reduction of  $\text{TiO}$  is considered to be a reaction restriction step in the electrolysis of ilmenite molten salt to generate metallic titanium and its alloy.

### 3.2 High Titanium Slag as an Electrolytic Cathode

Xing Wei et al. [28] prepared ferroalloys with high titanium content by direct electrolysis of high titanium slag by molten salt electrodeoxidation method in  $900^\circ\text{C}$   $\text{CaCl}_2\text{-NaCl}$  eutectic molten salt system, but at the same time, a small amount of intermediate products  $\text{CaTiO}_3$  and impurities such as Mg, Si, and Al remained in the product. It is pointed out that the electrolysis of high titanium slag treated by alkali melting and acid leaching can obtain products with metallic titanium as the main phase.

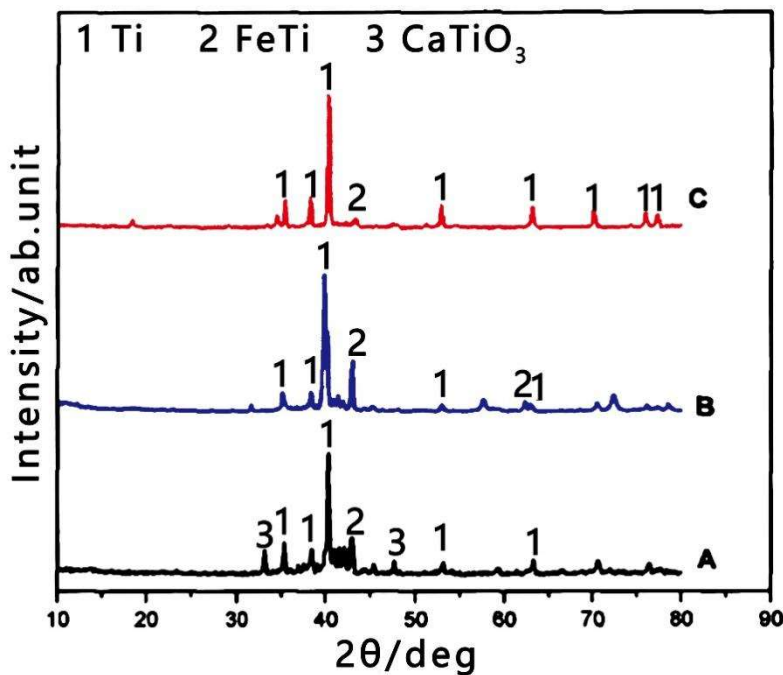


Figure 7. XRD comparison chart of samples obtained by electrolysis of high titanium slag treated by different methods[23]

Dai Wei et al.[29] used FFC process to prepare a titanic iron alloy by electrochemical reduction of high titanium slag as a cathode in calcium chloride molten salt, pointing out that the reduction process of high titanium slag can be divided into three stages: high titanium slag is directly calcified by titanic acid under the action of current at the beginning of the reaction;  $\text{CaTiO}_3$  is electrolytically reduced for a period of time to generate  $\text{TiO}$ .  $\text{TiO}$  in contact with Fe reacts to form  $\text{TiFe}$ , and  $\text{TiO}$  that does not come into contact with Fe is converted into  $\text{Ti}_2\text{O}$  with a higher degree of reduction. It is proposed that  $\text{CaO}$  be added to  $\text{CaCl}_2$  molten salt to promote the electrolytic reduction of high titanium slag cathode by changing the reaction path.

Guan Wenhao et al. [30] used FFC process to use a mixture of high titanium slag ( $\text{TiO}_2$  content of 76.9wt%) and  $\text{SiO}_2$  as raw materials, and used equal molar  $\text{CaCl}_2\text{-NaCl}$  molten salt as electrolyte to prepare  $\text{Ti}_5\text{Si}_3$  alloy under the condition of electrolytic reduction of  $\text{TiO}_2/\text{SiO}_2$  composite cathode at  $900^\circ\text{C}$ , tank voltage of 3.2V, and electrolysis time of 4~20h. At the beginning of the reaction, the rate of electrolytic reduction reaction is fast, but with the passage of reaction time, there are inevitably intermediate products  $\text{CaTiO}_3$  and  $\text{CaSiO}_3$ ; generated, resulting in a gradual slowdown in the reaction rate. The reduction of intermediate products  $\text{CaTiO}_3$  and  $\text{CaSiO}_3$  is a limiting link in the electrolytic reduction process. At the same time, the electrolytic reduction rate is also affected by the slot voltage.



## 4. Conclusion and Outlook

The high production cost of titanium metal is one of the main factors restricting its application and promotion. Its metallurgical process needs to be continuously developed and improved to replace traditional processes in a low-cost way. In the past few decades, several new molten salt electrochemical methods have been studied to reduce titanium dioxide or other titanium-containing raw materials for cathodic reduction. FFC and SOM production processes can be continuous, energy-efficient and environmentally friendly, and are advancing larger scale work and market industrial-scale quantities. By using  $\text{CaTiO}_3$  and  $\text{K}_2\text{TiF}_6$  as electrolytic cathodes, the ways to improve the current efficiency were explored, and the control conditions, intermediate products and reduction steps of titanium ion electrochemical reduction were explored. It shows that the feasibility of preparing titanium and titanium alloys by electrolytic reduction is very high and recognized by researchers, and in future research work, new processes of sustained, efficient, green and environmentally friendly titanium industry can be explored by changing the titanium source, changing the molten salt system, and adding precursors.

The attempts to prepare titanium alloys by using ilmenite and high titanium slag as cathodic electrolysis were collected, and the limiting factors affecting the efficient utilization of titanium resources such as ilmenite and titanium-containing blast furnace slag, as well as their electrolytic products, were discussed. In the next work, it is hoped that the utilization of titanium-containing resources can be systematically studied, and the regularity of reaction process and production efficiency under different process conditions of different titanium resources can be summarized. If you want to achieve industrial production with a more environmentally friendly and efficient new process, further research and improvement are needed.

## Acknowledgments

The authors acknowledge the Hebei Natural Science Foundation of China (Grant No. E2020209097) and Science and technology project of Tangshan City (21130229C).

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