A Preparation of Ultra-Low-Consumption Anode for Aluminium Electrolysis and Its Production Pilot

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Abstract

The Chinese government has been increasingly stringent in managing carbon emissions from aluminium electrolysis. To reduce these emissions and improve anode utilization efficiency, this study addresses issues such as rapid consumption and severe oxidation in traditional anodes by developing a novel ultra-low-consumption anode preparation technology. By reconstructing the 3D internal structure of the anode and analysing its porosity and pore size distribution, the study innovatively introduces impregnation and filling of coke particles, gap weight gain, and surface anti-oxidation technology, which achieves a dual high-efficiency combination of weight enhancement and oxidation resistance. During the pilot in aluminium electrolysis production, key indicators such as consumption rate and oxidation degree were tracked and monitored. The results demonstrate that the novel ultra-low-consumption anode significantly enhances the oxidation resistance of the anode and increases its density. The consumption rate of the novel anode is markedly reduced, achieving the expected goal of extending the anode cycle by 2 days. This technology offers advantages such as simple operation, low cost, and significant effectiveness, demonstrating promising potential for widespread application.

Keywords: Ultra-low-consumption anode, Anode cycle, Weight enhancement, Oxidation resistance.

1. Research Background and Current Status

China's aluminium electrolysis industry has maintained global leadership since the 21st century. In 2024, its output reached 43.393 million tonnes (according to International Aluminium Institute statistics), accounting for a 59 % of global production. In the first half of 2025, electrolytic aluminium output reached 21.552 million tonnes, with a cumulative growth rate of 6.9 %, demonstrating steady expansion. However, China's current efficiency remains in the range of 90–93 %, while the anode gross consumption stands at 470 kg/t Al. However, the issue of excessive consumption caused by low-quality anodes remains prominent, reducing current efficiency by 0.5–1.2 %. Additionally, anode surface oxidation not only increases CO_2 emissions per tonne of aluminium by 3–5 % but also carries fluorides, contributing to environmental pollution. Currently, the global electrolytic aluminium industry still predominantly uses traditional anodes characterized by high porosity (12–15 %) and high carbon consumption. For China, however, it is imperative to enhance anode performance through technological innovation, such as reducing porosity to below 8 % and lowering carbon consumption to under 450 kg/t Al. This has become a critical focus for breaking through production capacity bottlenecks and supporting the achievement of the "dual-carbon" goals, holding paramount significance for advancing the sustainable and high-quality development of China's electrolytic aluminium industry.

Zhang proposed that the air oxidation resistance of anodes is primarily influenced by the quality of green petroleum coke and the density of prebaked anodes, among other factors. He found that

ensuring minimal volatile content and fine powder in green petroleum coke could enhance the anode's oxidation resistance. However, in actual production processes, numerous uncontrollable factors make it difficult to maintain a stable composition. Therefore, in practice, post-treatment of anodes is often employed, and such treatment has been shown to improve the oxidation resistance of anodes [1]. Durkić and Lee discovered the inhibitory effects of boron and phosphorus on the oxidation reactivity of carbon atoms [2, 3]. Later, Tosta proposed that the suppression of carbon oxidation by boron and phosphorus could also be applied to carbon anodes [4]. Ishak impregnated the anode surface with a boron oxide solution, followed by heating and drying to form a boron oxide protective layer, while Mirtchi sprayed and dried the anode with a boron-containing mixed solution incorporating AlF_3 and other insoluble compounds [5, 6]. All these researchers experimentally demonstrated a reduction in the air reactivity and CO_2 reactivity of the anodes.

Domestic researchers have also conducted research on antioxidant coatings for anodes. Hongquan Gao employed an alumina sol composite coating, which demonstrated effective anti-oxidation performance across the entire operating temperature range of the anode. However, the study only investigated the variation of coating pore size with temperature and did not include cell pilot tests, thus lacking persuasiveness [7]. Ping Lin adopted a composite coating structure combining a transition layer, barrier layer, and sealing layer. SEM analysis showed that the anodic oxidation loss of the anode coating prepared with the optimal formulation was reduced by 70 % compared to the bare sample [8]. Ling Li further incorporated fluoride-resistant materials into the antioxidant coating to mitigate fluorine gas corrosion, though this coating lacks industrial test data support [9]. In recent years, researchers have proposed the application of nano-ceramic-based high-temperature anti-oxidation coatings. Shunhua Li, Boyi Wang, et al. coated the carbon anode surface of a 420 kA electrolytic cell with BY-4 nano-ceramic-based anti-oxidation coating material. The results demonstrated that the nano-coating has good anti-oxidation effects in practical industrial applications, effectively mitigating carbon anode slagging and extending the anode replacement cycle by 1.33 days [10]. The raw materials for the antioxidant coating on the anode consist of aggregates and binders mixed. The aggregates in the coating primarily use alumina powder, which has no impact on the bath or the quality of primary aluminium. As for the binder, there are generally two types: inorganic binders and organic binders. Research shows that under the high-temperature and highly corrosive environment of the electrolytic cell, organic binders undergo pyrolysis or chemical reactions, losing their adhesive properties and causing the coating to peel off extensively, thereby failing to provide protection. Inorganic binders can maintain their bonding performance in the electrolytic environment [11].

The presence of anode pores is the root cause of carbon residue formation. Therefore, from the perspective of reducing anode porosity, the impregnation roasting process has been proposed. Domestic and international studies have shown that the impregnation roasting process can effectively reduce the porosity of carbon materials and increase the bulk density [12]. This process has been widely used in the production of carbon products such as graphite electrodes and C/C composites. However, its application in the production of aluminium carbon anodes remains limited.

Hanxiang Jiang et al. proposed a solution impregnation method, where $AlCl_3$ solution reacts with ammonia water to generate $Al(OH)_3$ that impregnates anode pores. After roasting at 950 °C, Al_2O_3 forms and remains in the anode pores. However, this process has low filling efficiency and high post-impregnation roasting costs [13]. Jinliang Wang et al. proposed an impregnation and roasting process for anodes, where prebaked anodes are placed in a high-pressure impregnation tank and impregnated with coal tar pitch, followed by post-impregnation baking according to a specific temperature curve to produce "one-impregnation two-baking" anodes. This process can effectively improve the physicochemical properties of anodes, but its high cost prevents industrial application in aluminium production [14]. Linyong Wei et al. introduced an anode adsorption

components. This significantly enhanced the anode's oxidation resistance and mechanical strength, effectively mitigating the impact of petroleum coke raw material quality fluctuations on anode performance. The technology simultaneously reduces anode carbon consumption and CO_2 emissions, with tests demonstrating notable decreases in DC power consumption for some electrolytic cells and improved current efficiency.

The ultra-low-consumption anode has an extended service life and reduced replacement frequency, which not only lowers workers' labour intensity but also minimizes operational disturbances in electrolytic cells. Its standardized production model establishes an intelligent process system for the aluminium electrolysis industry, providing technical support for the "dual carbon" goals through reduced energy consumption and carbon emissions. Additionally, the green manufacturing experience gained can be extended to other energy-intensive industries. Currently, this technology has completed industrial validation, enhancing China's international technological competitiveness in the aluminium electrolysis sector and driving the industry toward low-carbon and high-efficiency transformation.

7. References

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