Exploring Refractory Material Degradation in Aluminium Electrolysis Cell

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Abstract

The durability and effectiveness of aluminum electrolysis cells heavily depend on the quality of the refractory materials lining. These materials are crucial for maintaining thermal equilibrium and shielding insulating bricks from extreme temperatures and chemical assaults. This article presents an investigation of the composition changes to evaluate the mechanical and thermal properties of Ordinary Refractory Bricks (ORB) in relation with electrolyte bath contamination at a laboratory scale. Through comprehensive chemical characterization techniques such as Thermogravimetry and differential thermal analysis (TG/DTA) and X-ray Powder Diffraction (XRD), this study quantified the concentration range of contamination experienced by ORB. Subsequently, ORB samples were exposed to electrolytic bath contamination at different temperatures (between 700 °C and 960 °C) for one hour. Both uncontaminated and contaminated samples underwent evaluations of the thermophysical properties. This approach helps to elucidate how thermal properties are affected by contamination, providing valuable insights into enhancing cell performance and longevity. By focusing on the thermal aspects alongside chemical characterization, this study seeks to improve understanding of ORB behavior during its degradation and contribute to advancements in aluminum reduction cell technology.

Keywords: Ordinary refractory bricks, Contamination, Aluminum reduction cells, Thermal properties.

1. Introduction

Due to the long lifespan of aluminum reduction cells, it is impractical to base the selection of refractories exclusively on in-service cell tests or autopsies of tap out cells. Hence, several laboratory-scale tests have been developed. The two main challenges in the laboratory study of the degradation process in ordinary refractory bricks (ORBs) are: 1) understanding the degradation phenomena under specific physical and chemical conditions, and 2) determining the reaction kinetics and rate of degradation. Although significant efforts have been made to understand these phenomena, less work has been done to develop new, more representative degradation tests. A thorough understanding of the chemical reactions occurring within the ORBs, especially concerning the aggressiveness of the electrolyte bath, is vital for extending the lifespan of aluminum reduction cells. This knowledge is essential for reducing environmental impact and improving the economic sustainability of aluminum production.

The ORBs will be directly exposed to the electrolytic bath, the primary source of contamination for cell refractories. By exposing samples to this substance, the test accurately simulates the conditions the refractories will face in their actual operational environment. This allows for a precise assessment of the material's resistance to this specific form of degradation, providing crucial data on its effectiveness in real industrial conditions.

Additionally, degradation tests conducted in the presence of nitrogen gas in the new method offer a holistic approach to evaluating refractories resistance to real operating conditions. This approach allows researchers to assess not only resistance to contaminants but also the structural stability of the material in the absence of significant oxidation. This combination of tests enables a more comprehensive evaluation of refractory performance while ensuring a cost-effective and easy-to-implement approach.

2. State of the Art

Researchers in aluminum production have extensively studied refractory materials used in aluminum reduction cells. Siljan et al. [1] provided a comprehensive review of alumino-silicate refractories, detailing advancements, and their performance in the challenging conditions of aluminum production. In 2001, Pelletier and Allaire [2] proposed a unified approach to thoroughly understand the corrosion mechanisms in potlining refractories. Building on this work, Pelletier and Allaire [3] continued their investigation in 2003, examining the impact of different cathode materials on potlining refractory corrosion. In 2016, Tschöpe et al. [4] pioneered the development of chemical degradation maps, offering a holistic view of sodium attack in refractory linings. Most recently, in 2024, Ben Salem et al. [5] conducted an on-field investigation of cell lining materials, performing a detailed autopsy of a high-amperage cell to identify the probable causes of reduced cell life.

3. Methodology

3.1 Description

Six contamination tests will be conducted on ORBs at varying bath temperatures: 700, 760, 875, 900, 930, and 960 °C. ORBs with dimensions of 50 × 20 mm will be used, placed in a small graphite crucible. The crucible will be filled with electrolytic bath up to 20 mm from the bottom, the ORB will then be immersed and covered with an additional 20 mm of the bath as mentioned in Figure1.

This setup is designed to expose the cylindrical brick sample to a unidirectional flow of the corrosive electrolytic bath. The sample will be directly exposed to the bath’s species. Each test will last for one hour at the specified temperatures.

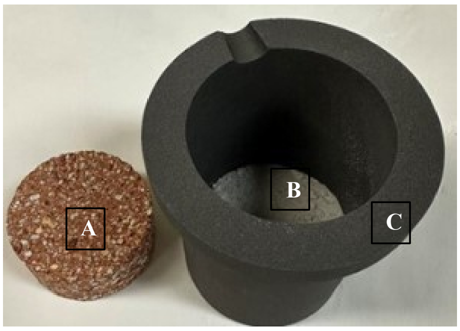

Figure 1. ORB bath assembly: A) ORB, B) bath, C) crucible.

Table 1. Weight loss and degradation rate of ORBs from 700 to 960 °C.

	Temperature (°C)					
ORBs	700	760	875	900	930	960
Weight loss (g)	0.2	0.4	3.6	5	6.5	7.4
Degradation rate (g/cm^2 h)	0.004	0.008	0.076	0.11	0.14	0.16

The degradation of the ORBs increases with the exposure temperature from 700 to 960 °C for a contamination duration of 1 hour, as shown in Figure 11. Previous tests indicate that after an exposure time of 5 hours, one of the samples was completely dissolved in the bath. Thus, demonstrating the high aggressiveness of the bath.

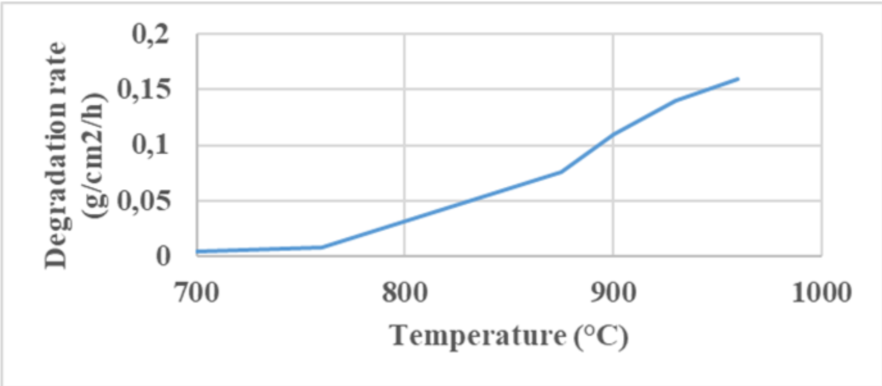

Figure 11. Degradation rate as a function of contamination temperature.

6. Conclusions

The degradation of the ORBs occurs as the bath attacks them. This attack begins at 700 °C and continues up to 960 °C, which closely aligns with the actual temperatures of the refractory layers in the aluminum electrolysis cell (ranging from 666 °C to 935 °C). During contamination, the appearance of bubbles was observed. Our findings suggest that what is observed in autopsies post-mortem is not true ORBs impregnated with bath and vaporized sodium, but rather a mixture of dissolved ORBs within the bath, exhibiting similar layers to those observed in industrial contaminated ORBs. Thus, at the temperature of sodium vaporization, the effect of vaporized sodium opens the cathode pores, allowing the passage of the bath. At lower temperatures, only the bath attacks the ORBs. Its passage occurs through the fissures that have appeared in the cells since their commissioning. Future endeavors will involve examining the mechanical and thermal properties of contaminated ORBs to achieve a more comprehensive understanding of the degradation phenomenon.

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8. References

1. Ole-Jacob Siljan, Christian Schoning and Tor Grande, State-of-the-art alumino-silicate refractories for al electrolysis cells, *JOM*, Vol. 54, (2002), 46–55.

2. Robert Pelletier and Claude Allaire, Corrosion of potlining refractories: a comparison between different cell lining designs using a unified approach, *JOM*, Vol. 53, (2001), 102–115.
3. Robert Pelletier and Claude Allaire, Corrosion in potlining refractories: effect of cathode material interpreted using a unified approach, *JOM*, Vol. 55, (2003), 58–62.
4. Klaus Tschöpe, Jan Rutlin, and Tor Grande, Chemical degradation map for sodium attack in refractory linings, *Essential Readings in Light Metals: Volume 4 Electrode Technology for Aluminum Production*, (2016), 978–983.
5. Mohamed Hassen Ben Salem, Gervais Soucy, Daniel Marceau, Antoine Godefroy, and Sébastien Charest Study of the degradation of ordinary refractory bricks in an aluminum reduction cell, *Light Metals* 2024, 664-670.
6. François Allard, *Étude des mécanismes de formation et du comportement des dépôts au pourtour de cellules d'électrolyse d'aluminium*, Master Thesis, Université de Sherbrooke, 2014.
7. Alexander V. Proshkin et al., Properties of refractory materials for primary aluminum production electrolyzers, *Refractories and Industrial Ceramics*, Vol. 49, No. 2, (2008), 84–89.