

## Impact of Lining Materials Degradation on Reduction Cell Performance

Ali Jasim<sup>1</sup>, Yousef Ahli<sup>2</sup>, Alexander Mukhanov<sup>3</sup> and Sheikha Fatima Almualla<sup>4</sup>

1. Senior Manager - Cell Lining & Environment Control

2. Vice President – Reduction

3. Lead Engineer - R&D

4. Engineer I - Process Control

Emirates Global Aluminium (EGA), Abu Dhabi, UAE C

corresponding author: abanjab@ega.ae

<https://doi.org/10.71659/icsoba2024-al027>

### Abstract

Increase in modern cell amperage and anode size has added a thermochemical stress on sidewall lining materials which could result in accelerated degradation. Variation in cell operating conditions due to routine and non-routine activities will affect degradation rates of side wall lining materials and affect its operating temperature and potentially cell life. In this paper, examples of various impacts of side wall lining material degradation are discussed as part of continuous improvement program. Emirates Global Aluminium (EGA) has adopted advanced cell lining testing to evaluate material suitability for cell operating conditions. The work includes autopsies and side wall inspections. This has contributed to better cell performance.

**Keywords:** Aluminium reduction cells, Cell lining materials, Cell lining degradation, Cell autopsies.

### 1. Introduction

Lining design and construction of modern Hall-Héroult reduction cells have undergone continuous development to cope with current operation mode. The cathode, which is lined with carbon materials, refractories and insulation, is designed to operate with optimum performance and achieve maximum cell life. The quality of cell design and construction, and the control of construction materials are critical to achieve required operating conditions. The focus on increasing amperage has increased thermochemical stress on lining materials, and requires better cell operation. Any deviation from the required operating window may result in reduction of cell efficiency, increased energy consumption and lower cell life.

Sidewall lining, which consists of SiC slabs, carbon materials and mortars or glues, significantly contributes to the cell thermal balance and formation of freeze protection. A deterioration of thermal balance may lead to the loss of freeze and expose the side wall lining materials to molten metal or electrolyte, which will destroy the lining and potentially result in sidewall failure. This paper discusses the importance of selection of optimum lining materials, and structured cavity inspections or autopsies to understand cell failure mode and provide required corrective actions. It also describes the testing of these critical materials for further improvement in Hall-Héroult reduction cell design.

### 2. Silicon Carbide Side Lining

Silicon nitride (Si<sub>3</sub>N<sub>4</sub>)-bonded silicon carbide (SiC) bricks were introduced as side lining material in the early 1990s. These bricks are made by mixing high purity silicon carbide grains and elementary silicon with an organic binder, then pressed or vibrated to shaped blocks with desired dimensions. These blocks are initially dried at 120 °C and then put in a furnace in nitrogen

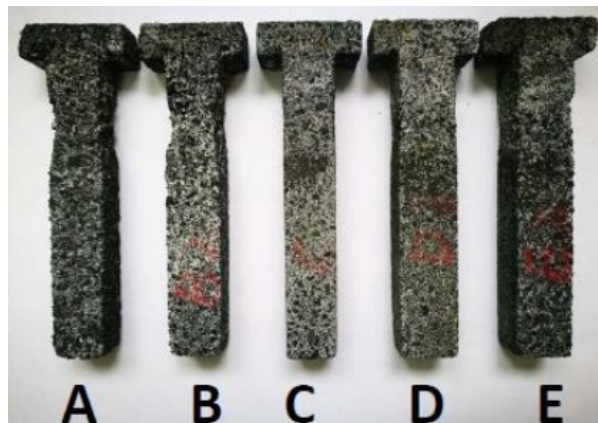
atmosphere where the nitridation process takes place at high temperature, maximum of 1400 °C [1]. It is essential that no oxygen is present during the process to minimise any oxidation reaction [1]. Silicon nitride-bonded SiC bricks are the preferred side-lining material due to their superior resistance to electrolyte attack, high thermal conductivity and high-temperature strength [1-3]. These characteristics are essential to minimise sidewall lining attack by the corrosive electrolyte and to sustain the required thermomechanical strength while operating at high temperature. They also have higher oxidation resistance up to 950 °C, compared to previously used carbon side wall blocks, which could be oxidised at a temperature below 550 °C. The improved properties of SiC bricks can support smelter higher productivity with amperage increase by using thinner sidewall lining bricks and longer anodes.

EGA has been using SiC bricks in the side wall lining since many years, while testing the bricks from various sources. In one of the tested materials, a noticeably higher degree of degradation of side wall SiC bricks was observed, which resulted in 30-40 % lower cell life in trial pots. Figure 1 shows a highly deteriorated sidewall SiC brick, even though the cell autopsy showed that the sidewall freeze protection against the chemical attack of molten electrolyte was adequate.



**Figure 1. Highly reacted sidewall SiC bricks at lower cell life.**

Due to the abnormal increase in silicon content in the metal of the test cell, the cell was cut out and autopsied before its target cell life. The test cell operation was thermally stable in terms of bath temperature and superheat, comparable to the rest of the potline. Cryolite resistance test was made on the trial cell SiC slab, shown in Figure 2 as sample A. The showed that the trial cell SiC slab had the highest rate of volume reduction and the lowest cryolite resistance. The chemical analysis of these SiC bricks showed the lowest  $\text{Si}_3\text{N}_4$  content of 8.31 % and highest residual Si content of 3.9 %. Thus, it had a very low chemical and mechanical resistance to bath



**Figure 2. Cryolite resistance test for five different sources of SiC slabs.**

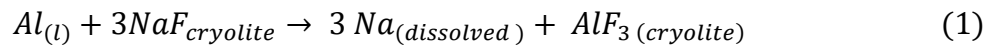
The same tested SiC slab was analysed and observed to have highest free silicone content, and inspection of newly received bricks showed the presence of abnormally high free dust as shown in Figure 3. In the process of SiC bricks production, controlling the microstructure, grain distribution and binder content of material are crucial for good performance. The presence of higher free silicone, higher porosity surface area as a result of poor nitridation process allows faster degradation in electrolytic cells.



Figure 3. High level of free dust observed in tested low quality SiC slab.

### 3. Sodium Attack on Sidewall Lining

Sodium in aluminum will be in equilibrium with the melt species ( $\text{NaF}$  and  $\text{AlF}_3$ ) according to Equation (1) and react further to sodium in carbon Equation (2) [4].



An increase of cathode block sodium expansion could occur while operating at higher current density which could result in higher local stress on cathode blocks and total cell lining structure [5]. The structural changes in cell cathode blocks due to sodium expansion is considered as main contribution of crack formation in the blocks [6]. The penetrated sodium will increase the strength of material initially, but at later stage of cell operation the bending stress would reduce as a result of internal stress [6]. From cathode blocks, sodium penetrates into the side ramming joint and up the SiC slab. The sodium reaction zone is seen in Figure 4; it is the darker triangular zone at the bottom of the slab.

Poor quality SiC blocks are prone to higher microscopic cracking, spalling on the upper part which also coincides with debonding from the potshell, and creation of air gap between the shell and sidewall SiC brick, shown in Figure 4. This may lead to the loss of freeze and high temperatures in the sidelining, leading to higher rate of sodium penetration into lower sidewall, accelerated reaction with refractory bricks (Figure 5), and sodium penetration through the collector bar sealing window to the outside of the potshell. There it creates sodium ooze and attacks the bolted cathode flexible tabs, Figure 6. This increases the bolted contact resistance between the collector bar and copper tab, which is uneven between collector bars, making also the collector bar currents uneven. As a result, the external voltage drop (the voltage drop between the collector bars and the central point on the anode beam on the downstream cell) also increases. At EGA, the overall voltage drop between the metal pad and the downstream anode beam, called the combined drop, is measured at regular intervals for cell control. Figure 7 shows the combined voltage drop vs cell age, and we can see an increase in some cells with age from approximately 1000 days. This identifies the cells with collector bar joints attacked by sodium.



**Figure 4. Air gap formed between SiC slab and steel shell.**



**Figure 5. Reacted refractory brick at base of SiC on the shell side.**



Figure 6. Collector bar attack by Sodium ooze.

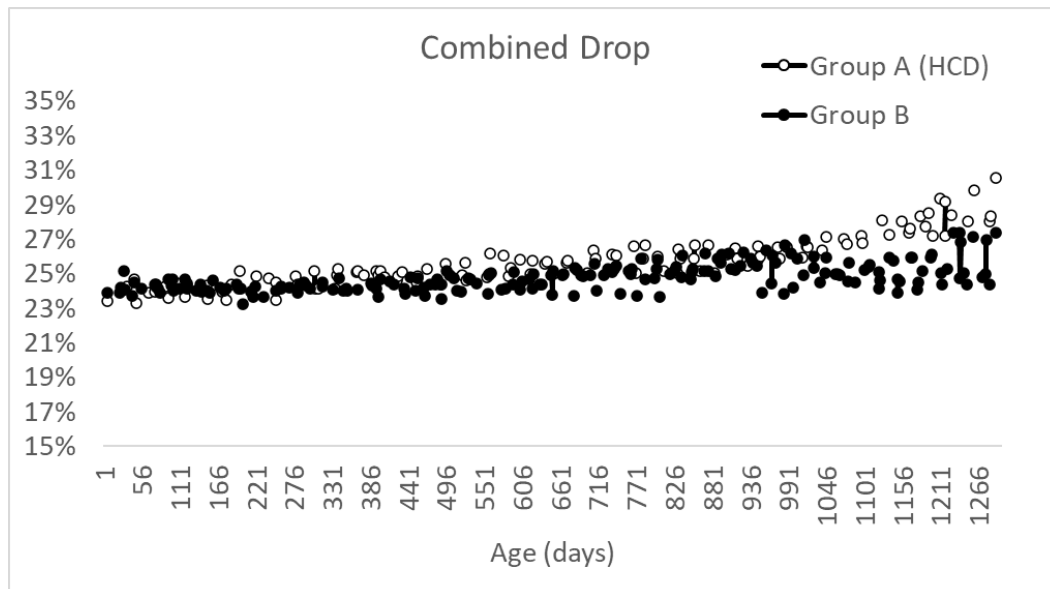


Figure 7. Increase in combined drop of cells whose cathode copper joint was attacked by sodium.

The uneven current distribution in the collector bars could result in increases variability of cathode erosion with deeper erosion in cathode blocks which carry more current. This could decrease cell life.

#### 4. Air Gap Between SiC and Potshell

Major thermal and electrical changes occur with cathode age, affecting electrical resistivity and thermal conductivity of materials [8], to which cell operation has to adapt. In poor quality SiC blocks or poor construction of the sidewall, an air gap between the SiC and potshell can form. This has a great impact on sidewall heat loss. Modelling shows that with an air gap, which adds insulation to the sidewall, the heat loss through the sidewall decreases by 20–30 kW. This makes the freeze thinner, and may expose the sidewall lining material to molten metal or bath. However, the impact on side wall shell temperature will be different since lower sidewall heat transfer will result in lower shell temperature as indicated in Figure 9.

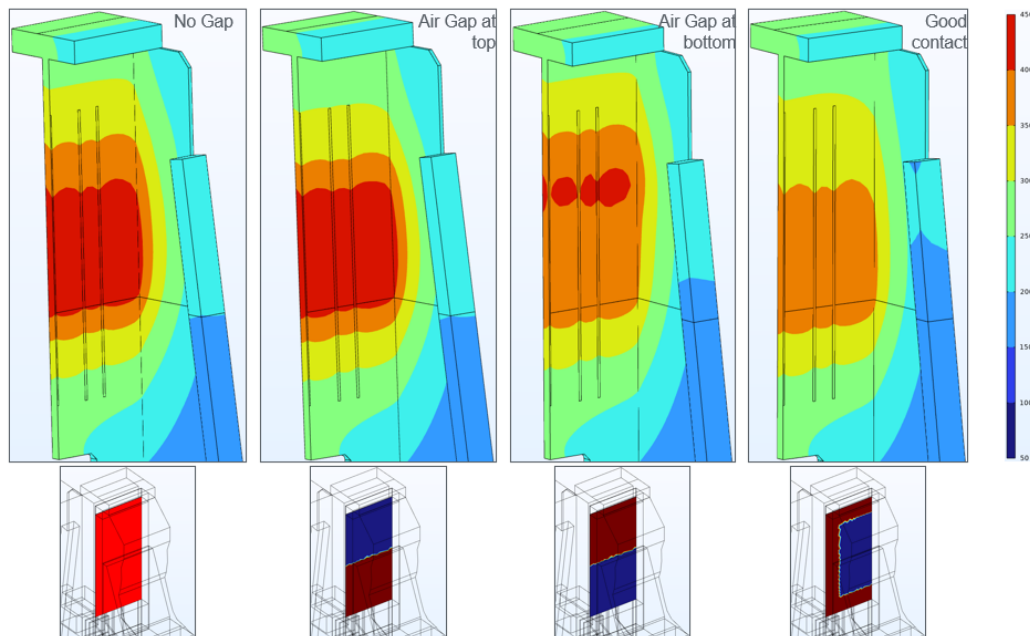


Figure 9. Impact of an air gap on the sidewall shell temperature.

## 5. Conclusions

Optimum design and selection of Hall-Héroult cell lining material are important for cell performance. Cell operating parameters must adapt to lining material changes with age to achieve long cell life. Selection and testing of lining material should be designed to avoid undesired impact on cell performance and early failures. The study has showed the negative impact of an airgap between the SiC slab and steel shell; it in hinders the formation of protective sidewall ledge which could result in increasing shell temperature and increasing the risk of sidewall failure. Moreover, a thin ledge increases the temperature in the lower sidewall and increases the rate of sodium penetration to the collector bar window and outside the potshell where it attacks bolted copper tabs and increases the bolted joint resistance and cell external resistance. Thus, careful consideration of cell design and material selection is essential for good cell performance.

## 6. References

1. Egil Skybakmoen, Quality Evaluation of Nitride-Bonded SiC Sidelineing Materials: Historical Trends 1997–2022 Including Results and Development of Test Methods, *Light Metals* 2022, 921-928.
2. Rudolph P. Pawlek, SiC in electrolysis pots: An update, *Light Metals* 2016, 515-517.
3. Alton T. Tabereaux and A. Fickel, Evaluation of silicon carbide bricks, *Light Metals*, 1994, 483–491.
4. Jørund Gimmestad Hop, *Sodium expansion and creep of cathode carbon*, PhD thesis. Norwegian University of Science and Technology, 2003.
5. Arne Petter Ratvik, Anne Støre, Asbjørn Solheim, Trygve Foosnæs, The effect of current density on cathode expansion during startup, *Light Metals* 2008, 973–975.
6. S.R. Brandtzaeg, Barry J. Welch, Mechanical changes in cathode carbon during startup, *Light Metals* 1989, 169–174.
7. Zhang Wang, Egyl Skybakmoen, Thor Grande, Spent Si<sub>3</sub>N<sub>4</sub> Bonded SiC Sidelineing Materials in Aluminium Electrolysis Cells, *Light Metals* 2009, 353-358.
8. Morten Sørli, Hermann Gran and Harald A. Øye, Property changes of cathode lining material during cell operation, *Light Metals* 1985, 497–506.