Analysis of Cathode Lining Failure Modes in High Current Density Cells at EGA

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Abstract

High-amperage cells in the Hall-Héroult process often face premature cathode-lining failure. EGA studied the life span of eight different subgroups, namely A, B, C, D, E, F, G, and H. The classification is based on electrical resistivity, flexural strength, crushing strength, and linear thermal expansion coefficient. The cathode minimum life-span across cathode grade subgroups is greater than 500 days. Grades A and B have the minimum life in high amperage cells. Statistical analysis of the premature failure rates for these groups were evaluated at 25 % and 15 % respectively while they were less than 1 % for C, D, E and 0 % for F, G, and H. Premature cathode lining failure is a major source of capital expenditure in high current density technologies. Drawing on the empirical evidence of some prematurely failed cathodes and the literature review, the purpose of this study was to establish the failure mode and effects of formation of deep potholes that shorten the life of these cells and to propose operational practices to minimize occurrences. This analysis is based on 21 theory-laden observations and measurements before and after the cathode failure. Denzin [1] and Patton [2] data sources and theory perspective triangulation were used to draw main themes. The measurements were followed by statistical correlations and interaction plot posteriori to establish the link among variables. Analysis of data indicates convergence on heterogeneous wear and formation of deep-seated potholes as the main failure mode of A and B grades. Possible factors driving heterogeneous wear include (a) thermal expansion, (b) anode spike formation, (c) fretting wear, and (d) high current density. For instance, the thermal expansion was found to be higher in A-group by a factor greater than 2 compared to F or G. Moreover, it was found that A is a high-density isotropic block whereas F is anisotropic.

Keywords: Cathode lining failure, cathode life, potholes, cathode wear, Denzin and Patton triangulation.

1. Introduction

The high erosion rate (with outliers ranging from 8 - 10 cm/year) of graphitized cathodes in high-amperage cells has become a source of financial stress for EGA. In addition to the expenses incurred in rebuilding new cathodes, the short service life and the risk of the liquid aluminium to run out of the cavity are major operational risks for smelters. In many cases, the “W- shaped” wear of graphitized cathodes appears to be the cause of failure (Nobakhtghalati [3], Reny and Wilkening [4]), but not the failure mode leading to deep-seated potholes formation. A review of cathode wear and pothole formation has been published recently [5].

This paper is a twofold-purpose study: (a) it establishes the failure modes and effects analysis (FMEA) of some graphitized cathodes in high-current density aluminium cells, and (b) it suggests the deep-pothole formation prevention to increase cell life. Given the complexity of the deep-seated pothole formation, we used a posteriori observational learning and erosion theories to guide this FMEA.

Erosion, damage, and failure mechanisms of aluminium cathode lining depend largely on the electrochemical dynamics, slurry wear, fretting, thermal dynamics and oxidative wear as failure modes. Some of these failure modes derive from the temperature gradients in the cathode blocks, thermal expansions, and fractures in the body of the blocks. At EGA, cathode blocks premature failure rate was found to vary from grade-to-grade. A and B grades premature failure rates, statistically were evaluated at 26 % and 15 % respectively while they were less than 1 % for C, D, E and 0 % for F, G, and H.

For fractures to occur on the body of the carbon block, high temperature gradients and expansion should develop followed by constraints, potentially in the opposing directions of the expansion as the block is attached rigidly to the side lining. For mechanical erosion to occur at the cathode surface, fluids and solid particles have to slide on the cathode surface continuously and with sufficient kinetic energy. For electrochemical wear to materialize, the cathode surface current density is the major cause.

Many of these cathode failure mechanisms might take place simultaneously (synergistic or chain effects) or asynchronously (isolated effects) during electrolysis. For instance, electrochemical wear may enhance slurry wear by creating deeper erosion zones and increase local current density which enhances the metal circulation. Cathode detachment may cause low resistance, increased current density, and increased electrochemical erosion afterwards.

In an effort to extend the life of the aluminium reduction cells, numerous studies have been used to improve the electrochemical resistance and characteristics of the cathode material. These studies ranged in scope from improved mechanical properties of graphitized petroleum coke cathodes to alternative shapes as well as material such as titanium diboride (TiB_2) for inert wettable cathodes. Yet, these efforts have neither produced significant positive results to be exploited at the industrial level, nor have they addressed the current problems of premature failure of aluminium reduction cells due to heterogeneous erosion in high-current density technologies.

In attempting to establish the cathode-lining FMEA, the one question that comes to mind is what creates deep-seated potholes (see Figure 1) at the back wall in the cathode blocks? Many researchers have endeavored to identify the possible causes of such excessive and heterogeneous abrasion. For instance, Perruchoud et al. [6] studied the coke selection criteria for abrasion resistant graphitized cathodes. They found that the excess abrasion was related to the use of low sulfur anode grade petroleum coke, which leads to a soft cathode after graphitization. They found that the selection of isotropic calcined cokes from appropriate soft pitches could allow decreasing the abrasion rate. The authors also found that dedicated coal tar pitch feedstocks used in optimized delayed coking in combination with shaft kiln calcinations have the potential to cause the “W-shaped” wear of graphitized cathodes that was found to be responsible for the cell short service life.

After collector bar casting, the measurements of the total resistance should be conducted (Figure 22). The technical team should establish acceptable limits beyond which disassembling and recasting should be considered. Next, the assembled blocks should be grouped by resistivity similarity (repeatability) at 95 % confidence interval. Blocks for which the total resistivity difference exceeds 5 – 10 % should not be associated (see Figure 23). Next, as we found that most deep-seated pothole formation and premature failures occur at the ends or close to end blocks, install blocks with higher resistivity where high erosion rate was observed.

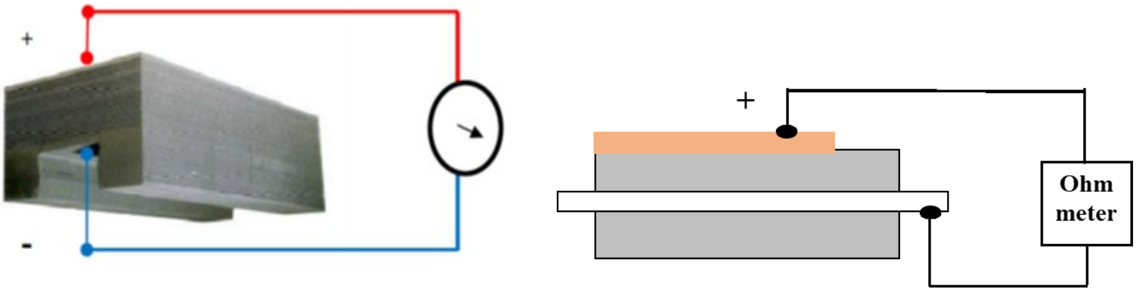

Figure 22. Measurements of the cathode block resistivity (left) and of the resistance of the assembly carbon block-collector bar (right).

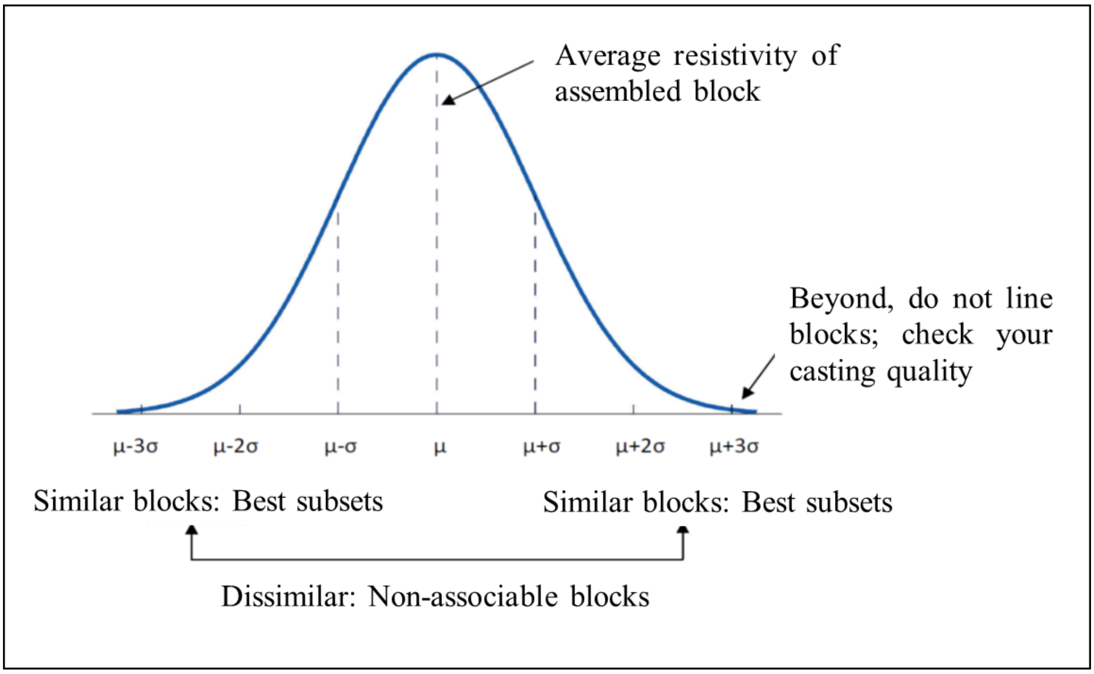

Figure 23. Measurements of cast block resistivity and lining strategy.

8. References

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