

The Structure of the Aluminium Smelting Cell Ledge

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Abstract

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In aluminium smelting cells, ledges form on the cell walls. Modern cell design and control cause a suitable ledge profile to form and maintained in order to protect the cell walls from the corrosive liquids, and ensure efficient current distribution and cell heat balance. During cell operation, significant ledge freezing and melting does occur following heat balance changes due to batch operations. In the laboratory scale, a ledge formation mechanism has been studied. It shows a linkage between the rate and directional nature of ledge growth, and its structure, as affected through a superheat change. An open ledge structure can dominate the ledge material growth or melt it out quickly when the superheat either decreases or increases, respectively. This paper begins the investigation of industrial ledge samples, in terms of structure and composition primarily, to identify if this ledge formation mechanism exists in the industrial cell.

Keywords: Aluminium smelting, industrial ledge, structure.

1. Background

Cell wall integrity is critical for maintaining the cell heat balance and a safe operation of an aluminium reduction cell. In terms of integrity, we include the lining materials, such as SiC and refractory bricks etc., and the side ledge that is frozen on the walls. The ledge should be maintained in a profile which allows sufficient heat transfer through side wall (not too thick), and also protect the lining materials from the corrosive liquids (not too thin). Although the side ledge is submerged in molten liquids and is therefore not visible during the daily operation, the ledge profile can be measured as required to ensure the sufficient protection of the walls and good thermal balance of the cell. Not only the ledge and its profile that is formed on the walls is critical, the part of the ledge that extends on the cathode surface (ledge toe) has a significant impact on the current distribution if the ledge toe extends beneath the anode shadow, making the current flow path from the anode to cathode to be non-vertical since the frozen ledge is an insulating material.

Studies on ledges date from 1980s and the industrial ledge dynamic behaviours have been studied (ledge thickness and ledge profile) and discussed by many researchers in terms of heat transfer and ledge composition [1-3]. In principle, the ledge material has been traditionally considered as pure cryolite precipitating from the molten bath as the primary phase and is frozen to the walls as the temperature there drops below the bath liquidus temperature. A thin dynamic boundary layer should be formed at the ledge/bath interface in theory, where the temperature is close to bath liquidus point.

Of course in the industrial ledge, bath components such as AlF_3 , CaF_2 and alumina are present in the boundary layer, and have also been found [2, 3] in the ledge itself. And recent research has

shown that ledge formation and the bath components within the ledge material have a strong impact on the ledge structure and thermal properties[4-6]. Laboratory ledge materials were used in most of these studies to shed light on its structure.

It is likely that the ledge from industrial cells is more complex in terms of composition and micro-structure, especially it is formed during transient events such as anode effect and normal cell operations such as anode setting etc. Hence, ledge formation is likely to be more complex as well. The key issue therefore is whether the structure of industrial ledge contains regions of open crystalline layers where the residual liquid is high in chiolite and alumina phases, which are inherently low melting.

In this paper, cold ledge materials sampled from a cut-out cell has been studied with a view to understand the variance of its composition and microstructure, where are compared with results from ledge formed under laboratory conditions.

2. Methodology

2.1. Investigation of the Laboratory Ledge Material

In our previous study, laboratory ledge materials were studied to understand the ledge structure and growth mechanism [6-9]. The ledge investigated in the laboratory scale showed that the bath modifiers (AlF_3 , CaF_2 and alumina etc.) form different phases and morphologies when observed in the ledge among the usually dominant cryolite phase.

FigureFigure 1 show typical structures observed in the laboratory ledge. At a slow cooling rate, the first phase precipitated is the cryolite solid solution, forming a thin layer of columnar crystals at the wall surface and insulating the wall due to its much lower thermal conductivity compared with the graphite. Ca-cryolite (less than 1 %, and undetectable by XRD) precipitates out of the cryolite solid solution at a temperature below 700 °C. When new crystals continue to grow on this initial ledge layer, the lower thermal driving force for solidification causes a slower growth rate of the cryolite solid solution; thus, liquid (molten bath in the lab cell) gets a chance to be trapped among these dendritic crystals. The entrapped liquid becomes more concentrated in modifiers as the cryolitic crystals surrounding it grow in size, leaving very high ex- AlF_3 content in the entrapped liquid, whose liquidus point decreases and is much lower than the bath liquidus point.

In the portion of ledge where the actual temperature is above the liquidus point of the entrapped liquid, the entrapped liquid will stay molten and an open structure is formed, as shown in Figure 1 (c) and (c-1). In the previous work, this open structure actually has resulted in a low dimensional stability of the ledge layer when thermal balance is disturbed, i.e. a small superheat increase causes very rapid disintegration of the bulk of the ledge layer. These observations and mechanism have been investigated using the laboratory ledge. But considering the simplified thermal conditions and short-term aging of the ledge (about 1.5 hours) in the lab furnace, the industrial ledge is expected to behave differently, and some preliminary results will be reported in this paper.

5. Future plan:

This work has provided us with a first insight into industrial ledge structure. The next step is to develop a systematic method to investigate industrial ledge more thoroughly at different locations and under different cell conditions.

Based on the compositional and structural findings, future work will involve examining the thermochemical properties of the ledge materials as well as the structure, and their impacts on the cell wall heat balance.

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