AL04 - Cathode Cooling Damages Due to Potline Power Interruptions

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Abstract

Prolonged electrical power interruptions often result in the shutdown of aluminum cells in potlines. Cooling cells to ambient temperature causes irreversible and non-repairable damage to the carbon cathode lining due to the formation of numerous, and often deep, cooling cracks on the top surface of cathode blocks and in rammed seams between blocks that ultimately shorten potlife. In this work, ANSYS® 12.0 based 3-dimensional full cell quarter and 3D slice thermal cooling models results provide verification that large tensile stresses are generated in the cathode panel due to the bottom face of the cathode being anchored by steel collector bars while the top of the cathode panel is shrinking during cooling. It was found that after 24 hours of cooling the thermo-mechanical stress generated at the top surface of the cathode panel was greater than 11 MPa which is enough to cause cracks in the cathode panel occurring at around 8 MPa.

Keywords: Modeling, cooling, thermomechanical, cathode cracks.

1. Introduction

Carbon cathode and anodes used in industrial aluminum cells are submitted to thermomechanical stresses at different times in their life, for example while pouring molten cast iron into the cathode block slots to hold steel collector bars in place, heating cells for startup, at immersion of new anodes into molten bath and when cooling pots to ambient once the electrical current is interrupted.

The duration of power outages during a power interruption determines the extent of cooling of the bath, which in turn determines how many pots will be shut down due to frozen cryolitic bath, and therefore the number of pots that will have damaged cathodes. Cooling occurs in all cells in a potline when the electrical power is interrupted. The internal pot Joule (I^2R) heating stops in all pots; however, pots initially continue to dissipate heat at the same rate as during normal operations. Pots cool at different rates due to differences in their size, lining design and operating parameters. Modern cells lose heat at a faster rate compared with older cell technologies due to their use of more thermal conductive cathode construction materials and, therefore, are at a higher risk of shutting down due to power interruptions.

Cooling cells to ambient temperature can cause irreversible and non-repairable damage to the carbon cathode lining. For example, the formation of numerous, often deep, cooling cracks on the surface of cathode blocks and in the rammed seams between blocks has been consistently observed, with a resulting shortened potlife when the cell is restarted.

1.1. Thermal Arrest

A thermal arrest is a significant phenomenon in aluminum cells during long power interruptions because it decelerates the cooling process which slows the increase in electrical resistance of the bath and maintains liquid some cryolitic electrolyte which helps when reenergizing power in the potline once power is restored. In some instances, the thermal arrest delay in cooling has assisted some potlines to continue operating after 6 to 8 hours of power interruption by keeping the cryolitic bath molten longer.

Aluminum electrolysis cells typically operate in the range 955 to 965 °C depending on chemistry and superheat. Solidification of cryolitic bath in cells begins when the bath temperature in cells cools to its freezing point, 940 to 950 °C depending on chemistry. Cryolitic bath typically cools at a rate of 15–20 °C per hour, depending on cell heat losses, until further cooling is temporary halted due to a phase change from liquid to solid with evolution of the latent heat of fusion. This is the energy required for a phase change which keeps the remaining liquid at the freezing temperature until nearly all the liquid has solidified. Cooling the electrolyte in cells below ~850 °C results in the solidification of the totality of the bath.

The length of time for the thermal arrest depends largely on the volume of liquid bath in the cell, heat losses, and chemistry. It is expected that molten cryolite freezes at the outset near the sides and ends of cells which are also the locations of highest heat loss, and finally freezes in the center of the cell.

1.2. Thermal Arrest During a 5-Hour Power Interruption in a 300 kA Potline

A 5-hour power interruption occurred due to a power failure in 2008 in a 300 kA pot line with 160 cells at the Keao Aluminum Company in Zoucheng, China [1]. Bath temperatures were measured hourly; they decreased rapidly from 967 °C to around 920 °C where the cooling halted for about 1 hour at a thermal arrest due to the freezing of molten cryolite as shown in Figure 1.

The average temperature of the molten bath in four cells after 4 hours of cooling was 897 °C. The 1-hour thermal arrest slowed the cooling process which halted the decrease in temperature for 1 hour, thus reducing the electrical resistance of the bath and retaining liquid cryolite which greatly aided restoring operations when reenergizing the potline once power was restored.

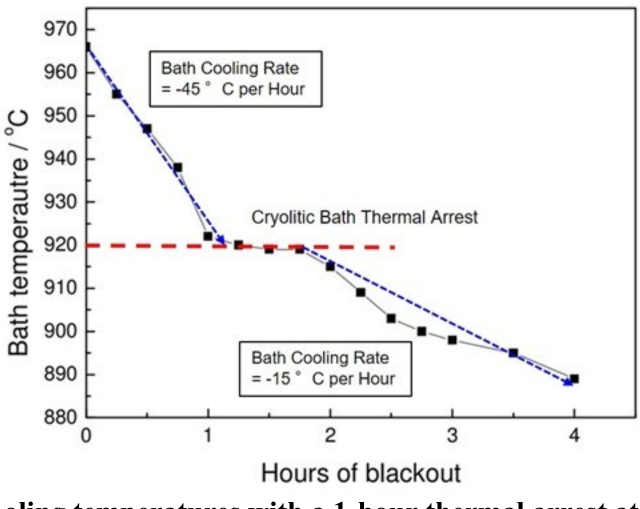

Figure 1. Bath cooling temperatures with a 1-hour thermal arrest at 920 °C during a 5-hour power interruption.

Most of the cells in the potline continued to operate after the potline was reenergized. At that time, cells operated at low amperage, 120 kA. Bath was generated in some cells by operating at 10 V which increased the thermal input and thereby increased the melting of cryolite and solid bath in a few cells. After 2 weeks, the metal purity was greater than 99.7 %, indicating that the

After 20 hours of cooling, the stress exceeds the critical limit of 8 MPa to cause cathode cracks. Hence, the thermo-mechanical stress in aluminum cells with power interruptions less than 10 hours would be insufficient to cause cooling cracks in the cathode panel.

3.4. Cathode Damages

Aluminum cells are damaged due to fracture of cathode blocks when cooled from 960 to 25 °C. Numerous measurements shown in Tables 2 and 3 have verified that the thermo-mechanical flexural stress must be > 8 MPa to cause fracture in all types of cathode blocks except anthracite. Anthracite cathode blocks are no longer used in aluminum smelters due to their high electrical resistance and higher energy consumption. The modeled thermal-mechanical stress due to the expansion at the top of the cathode panel while the bottom of cathode blocks is held stationary by steel collector bars after 20 hours of cooling is > 11 MPa, which is sufficiently high to cause cracks along the length of cathode blocks.

Thus, aluminum cells are not damaged due to cooling only 300 degrees, (e.g., from 960 to 660 °C) when power is interrupted up to 8 hours and the cell continue to operate after the potlines is reenergized because:

- The thermal-mechanical stress, (less than 3 MPa) due to thermal gradients in cathode blocks is insufficient to cause fracture of cathode blocks,
- The thermal shrinkage of the length of the cathode panel, (less than 1 cm) is insufficient to cause fracture of cathode blocks,
- The thermal-mechanical stress due to the expansion at the top of the cathode panel while the bottom of cathode blocks is held stationary by steel collector bars, (less than 3 MPa) is insufficient to cause facture of cathode blocks

The 3D thermal modeling results in this investigation verify that the stress generated in 8 hours, or less, due to cooling as a result of power interruptions is insufficient to cause stress > 8 MPa necessary to cause fractures and cracks in the cathode panel of industrial aluminum cells. Thus, there is no evidence that cathodes are damaged in industrial aluminum electrolysis cells after up to 8 hours of cooling during a power interruption and the cells continued to operate after reenergizing the potline without requiring a shutdown and restart operation.

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