Carbon Cathode Wear in Aluminium Electrolysis Cells

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Introduction

Wear of the carbon cathodes used in the aluminium electrolysis cells has been a very important topic the last few decades due to the introduction of high amperages, more graphitized cathode blocks and more acidic baths. Investigations of spent potlinings have shown that the cathode wear is categorised by a so-called W or WW wear pattern, while locally the wear is characterized by pitting especially at locations with the highest wear. The aluminium industry has over the years conducted autopsies of spent potlinings to understand amongst other things, the possible mechanism(s) leading to carbon cathode wear in aluminium electrolysis cells.

The present paper reports on autopsy findings from six different spent potlinings. Topography of the spent pot linings was characterized by interferometry, while samples collected from the autopsies were characterized by X-ray computed tomography, X-ray diffraction and microscopy. A model based on partly solidification of the bath film at the carbon surface due to the formation of aluminium carbide is presented. Finally, Finite Element Method (FEM) simulations was used to demonstrate the differences in current density at the cathode surface due to partly solidification of the bath caused by the reaction.

Experimental

Six spent potlinings with different grades of carbon cathode blocks (graphitic and graphitized) at three smelters with different amperage regimes and technology were investigated. Details of the pots investigated as well as the macro wear patterns are summarized in table 1.

Table 1 Summary of wear patterns and details of the pots investigated during the autopsy studies

Pot	**Arrangement/ Technology**	**Amperage(kA)/ Cathode Current density (A/cm^2)**	**Potage (days)**	**Carbon Cathode Block type**	**Wear Pattern**	**Comments**
1	Side by Side / Prebaked	313 / 0.8	2461	Graphitized and Impregnated	WW	Planned Shutdown
2	End to End / Prebaked	175 / 0.8	1028	Graphitic (100% Graphite)	W	Tapout
3	End to End / Prebaked	175 / 0.8	3154	Graphitic (100% Graphite)	W	Planned Shutdown
4	End to End / Prebaked	175 / 0.8	2849	Graphitic (100% Graphite)	W	Planned Shutdown
5	Side by Side / Prebaked	313 / 0.8	1731	Graphitized and High Density	WW	Tapout
6	Søderberg	128 / 0.6	2732	Amorphic (30% Graphite)	Even	Planned Shutdown

The investigations involved visual observations, manual and 3D measurements of wear profiles, sample collections as well as laboratory analysis of the autopsy samples collected. Laboratory analysis involved microstructure analysis using optical and scanning electron microscopy as well as computed tomography (CT scanning). Phase composition of solid bath samples were also analysed using X-ray diffraction. FEM simulation using COMSOL Multiphysics® was performed to verify the proposed wear mechanism.

Results and Discussions

Five of the spent potlinings investigated revealed wear patterns similar to what have been reported from other autopsies. The highest wear was observed on the side ends of the spent potlinings while the centre canal had the least wear. The sixth spent potlining, a Søderberg pot, however, showed a relatively even wear across the cathode blocks. Pitting on the surface of the cathodes was observed for all the six spent potlinings, however, for the prebaked spent potlinings a high degree of pitting was observed at the locations with the highest wear than the locations with low wear. CT scanning images revealed a similar wear pattern for both the aggregate and binder suggesting a possible chemical or electrochemical wear mechanism. Optical and scanning electron microscopy revealed the phases present at the carbon-bath interface to be Al_4C_3, Al_2O_3, Na_3AlF_6 and Al. Figure 1 displays the two diffractograms showing the different phases present in the two bath collected from the cathode surface and on top of metal pad.

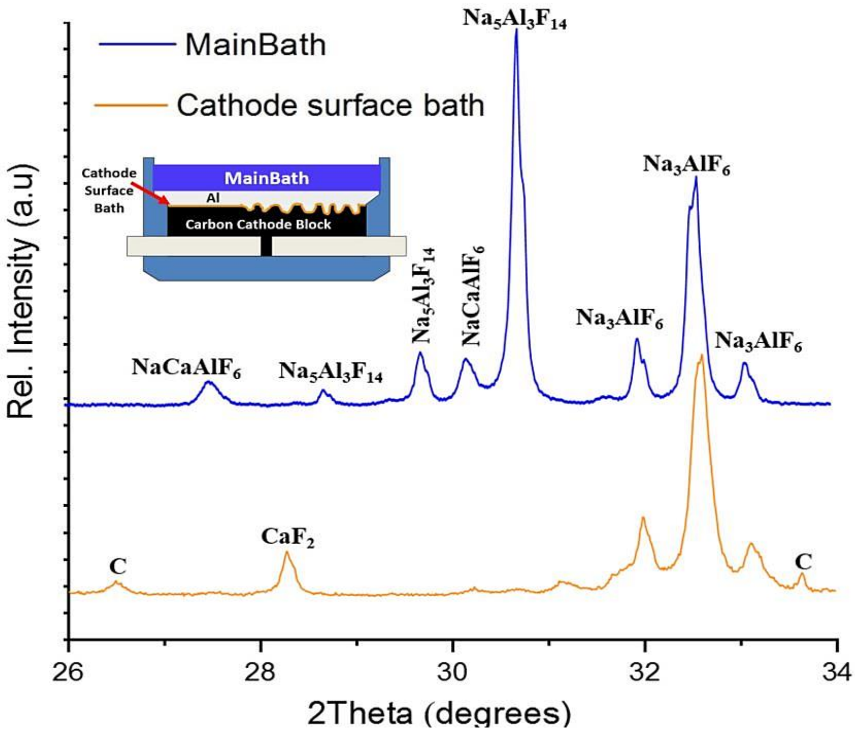

Fig. 1 X-ray diffraction patterns of bath samples collected from the bath on top of the metal pad and on top of the cathode surface. Insert: sketch of an electrolysis cell showing locations of the solid bath samples.

The phases present in the bath from the cathode surface suggests a relatively low acidic bath as compared to the main bath. Reduced acidity of the bath on the cathode surface might be due to electrochemical reactions occurring on the cathode surface. Reaction 1 might lead to depletion of AlF_3 content in the bath on the cathode surface.

$$3C(s) + 4AlF_3(diss) + 12Na(C) = 12NaF(l) + Al_4C_3(s) \qquad (1)$$

Apart from reduced aluminium carbide formation and dissolution due to AlF_3 depletion, reduced acidity might cause a local solidification of the bath on the carbon surface due to the relatively high liquidus temperature of a basic bath. Results from the FEM simulation demonstrated that the solid bath would significantly reduce the local cathode current density. Given that cathode wear is electrochemical in nature, this might suggest a locally slowdown or stop of the wear process.

Conclusion

A mechanism involving an initiation and termination step in the cathode wear process has been proposed based on the autopsy findings. The observation of both aggregate and binder components of carbon being worn out relatively uniformly suggests pitting as occurring by a chemical or electrochemical mechanism.

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