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Erosion of Cathode Blocks in 180 kA Prebake Cells

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Abstract

Changes in the top level of cathode blocks due to erosion have been measured in 180 kA prebake cells for three consecutive years in order to determine cathode erosion rates for three different types of cathode blocks and eleven different suppliers. The results of the test program indicate significantly high, linear erosion rates for graphitized blocks with the rate slowing after 1600 days. Cathode blocks containing 30% graphite erode at a significantly lower erosion rate. Erosion depths have been found to vary greatly within cathodes, and significantly higher erosion rates may even occur at different locations under the same anode. These complex erosion patterns indicate that a more complicated, interrelated mechanism is involved rather than the simplistic abrasion mechanism suggested to date.

Experimental

Detailed cathode sidewall and cathode block erosion measurements were made on AP-18 prebake cells at the Reynolds SCRM smelter at Baie Comeau and the ABI smelter at Bécancour, Quebec, Canada.

Measurements were made using a sidewall ledge profile rod attached to a leveling arm and a measuring board shown in Figure 1. This system references the measurements to the top edge of the deckplate. Erosion measurements were made under anodes 1 and 4 on the upstream side and anodes 9 and 12 on the downstream side of the AP-18 cells that have 16 anodes. Also, the tap hole erosion was measured.

Figure 1. Measuring the erosion of cathode blocks in an operating AP-18 cell.

Cathode Blocks

Cathode blocks used in the aluminum industry can be classified into four major categories: (1) anthracitic, (2) semi-graphitic (containing anthracite with graphite additions), (4) graphitic blocks (100% graphite aggregate with pitch binder, baked up to 1200°C, and (3) graphitized blocks, (petroleum coke aggregate with pitch binder heated above 2500°C). The compositions of the eleven different cathode blocks evaluated in this test are shown in Table I.

Graphitized blocks are increasingly being used in aluminum smelters because of their low cathode voltage drop and ability to provide an increase in line amperage and metal production when operating cells at the same high current efficiency.

The major disadvantage of using graphitized blocks is the accelerated erosion leading to collector bar attack, high iron and eventual cathode failure and higher costs.

Plant Results

Total Cell Measurement

One cell with graphitized "A" blocks was stopped after 2000 days of operation and the cathode cavity cleaned to inspect the cathode surface. The entire cathode surface topography was measured and the results are shown in Figure 2. These surface topography measurements indicate an irregular erosion pattern on the cathode surface:

- The highest erosion occurred under the anodes.
- The deeper area of erosion occurred under several anodes near the sidewall.
- Some anodes had deeper erosion than others.
- Almost no erosion in the center of the cell.
- Less erosion was evident at the tap hole.

Individual Measurements Under Anodes and Tap Hole

Cathode erosion measurements are made under the anodes of operating cells by pulling anodes out for measurements. The cathode block erosion has been measured in twelve cells under the same anode locations and tap hole in the same cathodes for the past three years to provide accurate erosion data in order to determine erosion rates.

A comparison of the average erosion rate for each family of cathode blocks measured in the study is presented in Table II and tap hole rates are shown in Table III. An example of erosion profiles measured under the four anodes and tap hole for a cell with graphitized blocks is plotted in Figure 3. A summary of the erosion results is shown in Figure 4 providing the average and maximum block erosion measured under the anodes and the respective regression curves for a specific type of graphitized "A" cathode block up to 2300 days.

Table I
Types of Cathode Blocks Tested

Block Type	(1) Anthracite	(2) Graphite	(3) Petroleum Coke	(4) Graphitized
Graphitized A			100%	Yes
Graphitized B			100%	Yes
Graphitized C			100%	Yes
Graphitized D			100%	Yes
Graphitized E			100%	Yes
Graphitic F		100%		No
Graphitic G		100%		No
Graphitic H		100%		No
Semi-Graphitic I	85%	15%		No
Semi-Graphitic J	70%	30%		No
Semi-Graphitic K	70%	30%		No

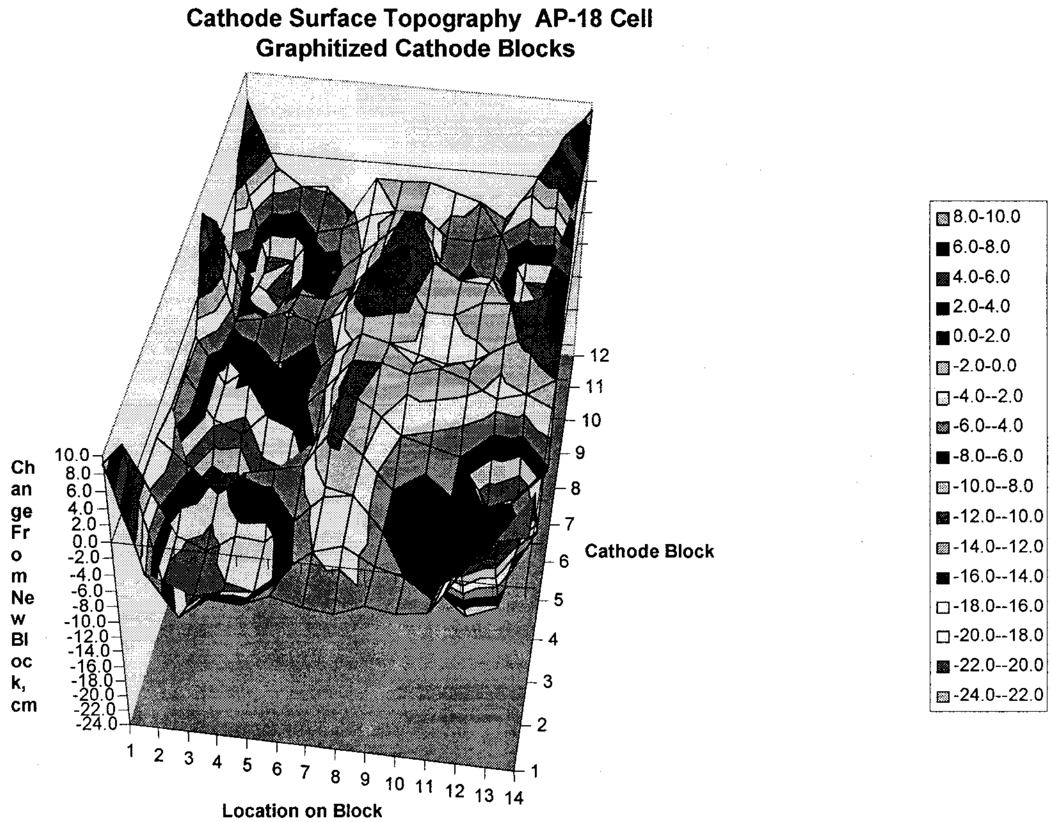

Figure 2. The measured cathode surface topography of a cell with graphitized blocks.

The equation for the non-linear average erosion for graphitized "A" cathode blocks is:

$$Y = -2 \times 10^{-6} (X^2) + 0.0081(X)$$

Where,
Y = average block erosion, cm
X = age, days

The cathode block erosion data demonstrates the following points:

- The maximum erosion area occurs directly under the anodes.
- The cathode block is generally more eroded than the ram carbon seams.
- The erosion rate under the anodes for the five graphitized blocks (A to E) are all similar, showing an average erosion of 2 to 3 cm per year for the first four years.
- The data confirms a leveling off of the erosion rate after 1600 to 1800 days.
- Typical maximum erosion rates for the three 100% graphitic blocks (F to H) are all very similar with an average erosion rate of 1.2 to 1.8 cm/year for the first four years.
- All of the different cathode blocks with 15-30% graphite aggregate (I to J) have a significantly lower erosion rate under the anode, about 0.9 to 2.2 cm per year for the first four years.
- The data indicates that initially higher erosion rate occurs at the tap hole, but that it tends to stabilize after several years and is generally similar to the erosion of the block under the anodes thereafter. The tap hole erosion rates may also be plant specific.

Table II.
Average Block Erosion Rate Under Anodes

Block Type	Plant A cm/yr	Plant B cm/yr
Graphitized A	2.7	3.3
Graphitized B		2.3
Graphitized C		2.7
Graphitized D	2.7	
Graphitized E		3.0
Graphitic F	1.2	1.8
Graphitic G	1.7	
Graphitic H	1.7	
Semi-Graphitic I	0.8	
Semi-Graphitic J	0.9	1.0
Semi-Graphitic K	2.2	

Table III.
Block Erosion Rates At The Tap Hole

Block Type	Plant A Avg. Erosion cm/yr	Plant B Avg. Erosion cm/yr
Graphitized "A"	2.8	2.5
Graphitic "F"	1.8	1.9
70-85% Anthracite "J"	0.9	1.0

Metal Pad Velocity Measurements

Metal velocities were measured in four cells using an iron rod dissolution method. Average and maximum measured metal velocity values are summarized in Table IV. Both the direction and magnitude of velocities are similar for all the cells.

Table IV
Metal Velocity

Cell	Average Velocity cm/sec	Maximum Velocity cm/sec
7074	3.4	5.6
7094	2.6	5.0
7069	5.1	7.5
8102	3.2	8.1

These metal velocities indicate a low metal flow in the cell at the cathode surface due to the excellent magnetic compensation in the bus bar and about 25 cm metal pad depth. The metal velocities are significantly lower than older prebake cell designs. The low metal velocities indicate that metal flow by itself is not the major contributor to cathode erosion in these modern cells.

Erosion Mechanism

It is generally believed that the carbon cathode wear is caused by the combined processes of physical abrasion and chemical corrosion. Liao and Øye [1, 2] indicated that laboratory experiments show the wear mechanism is probably through solid carbide formation with carbide dissolution as the slowest step. Simple abrasion and chemical corrosion would predict that the erosion in cathode blocks was:

- linear over the cathode lifetime.
- smooth and uniform over the total cathode surface.

Extensive plant measurements in this study indicated that cathode erosion can not be explained only by a simplistic abrasion and/or chemical corrosion wear mechanism. For example it was found that:

- Erosion rates are linear only during the first 1600-1800 days; they are nonlinear over the lifetime of the cells.
- The maximum cathode erosion area is located under the anodes near the end of the cathode blocks.
- The erosion is deeper under some anodes compared to others in the same cell.
- The wear pattern in this area is not smooth, but rather has a rough, pitted appearance.
- The cathode block is eroded faster than the ram carbon joints between blocks.
- Variable wear rates were found to exist at the tap hole for different cells and plants.

Lombard et. al. [3] presented maximum wear data for cells up to 60 months of operation that demonstrated a nonlinear behavior for cells with graphitized block no. 1.

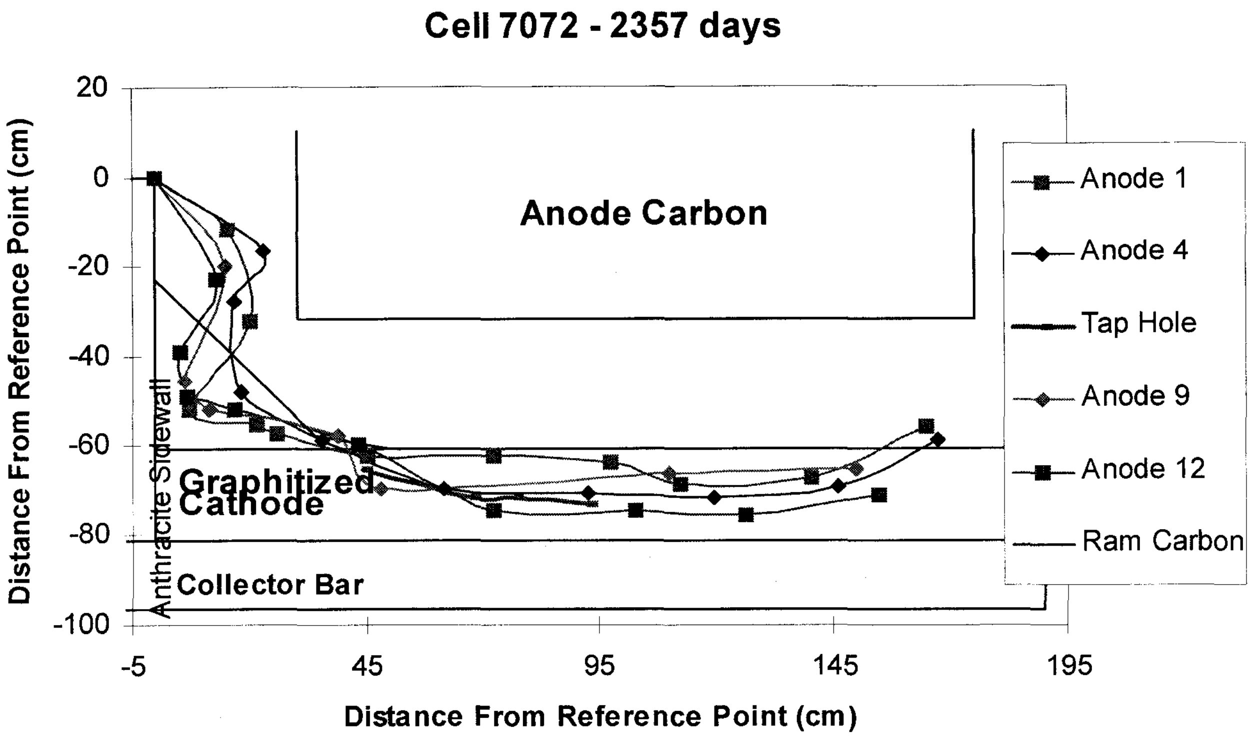

Figure 3. Measured cathode erosion profile for graphitized cathode blocks located under the anode and the tap hole.

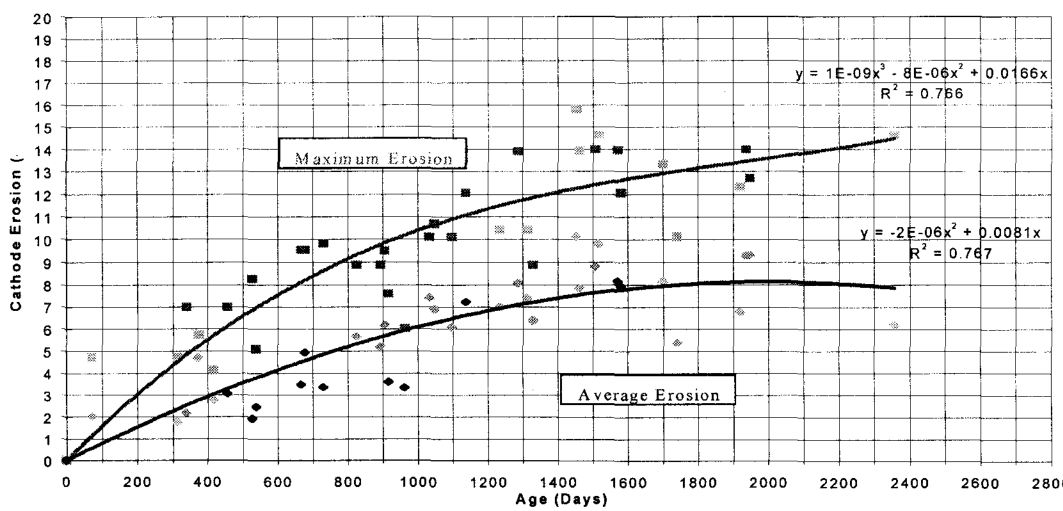

Figure 4. Cathode erosion results for Graphized "A" Cathode Blocks.

Block Erosion at the Tap Hole

Tap hole erosion in cathode blocks has been shown to be due to high localized metal velocities induced by the metal turbulence during metal tapping [4]. Tap hole erosion rates may vary greatly at various plants due to the differences in tapping equipment and practices, specifically the air pressure, siphon location, etc.

Proposed Mechanism for Erosion Under Anodes

- A small depression due to erosion occurs first as the soft graphite block near the sidewall is removed on the cathode surface due to the higher cathode current density in the metal pad at this location.
- Once a pit occurs, an even higher current density occurs in the pit due to the lower electrical resistance than found elsewhere on the cathode surface.
- The higher current flow generates a high, intense localized metal turbulence in the pitted area.
- The higher metal velocity removes not only the carbide film that is formed, but small chunks of solid cathode material due to the metal vortex action inside the cathode "rat hole."
- However, it is not known why the erosion tends to level off after 1600 to 1800 days.

Conclusions

Cathode erosion measurements made at the same locations in the same cathodes for the past three years and in other cells indicate that:

- The cathode erosion rate under the anodes for graphitized blocks are all similar, showing an average erosion of 2 to 3 cm per year for the first four years; a leveling out of erosion then appears to occur in the 1600 to 1800 day range.
- All of the different cathode blocks with 30% graphite aggregate have a significantly lower erosion rate under the anode, about 1 cm per year for the first four years.
- A higher initial erosion rate is measured in the tap hole, but after several years it is generally similar to that of the erosion rate of the block measured under the anodes.
- An erosion mechanism based on high localized electrical current and metal turbulence is proposed to explain the irregular erosion pattern, particularly in the area under the anodes, for graphitized cathode blocks.

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