OPERATING PARAMETERS AFFECTING THERMAL SHOCK CRACKING OF ANODES IN THE VALCO SMELTER

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Abstract

Between 1986 and 1989, the Volta Aluminium Smelter experienced thermal shock corner cracking in 1 - 3 percent of anodes in reduction cells. Extensive investigations showed that several operating factors contributed to this problem in varying degrees, including fines and pitching control, anode size, forming method (press or vibrator), and cell operating stability. This paper discusses the investigations and process adjustments made that resulted in significantly reduced thermal shock cracking at VALCO.

Introduction

The Volta Aluminium Company Limited (VALCO) Reduction facility[1] operates a green carbon plant on a typical three fraction aggregate of butts, coarse and fines. Material size ranges are as follows:

Butts :	-1 inch	+ 4 mesh
Coarse:	-4 mesh	+ 20 mesh
Fires :	-20 mesh containing approximately 50 percent -200 mesh	

The aggregate is mixed with solid pitch in steam heated batch mixers and pressed (vibrated only starting in 1990).

Until 1979, a two piece double hung anode was pressed. Each piece was 41.5 inches long by 15.75 inches wide by 22 inches high. Two vibratory formers were installed in 1976 to produce a one-piece anode measuring 41.5 x 31.5 x 22 inches.

Due to unsatisfactory performance of the original vibrators, the press was modified in 1979 to produce a one-piece anode of the same size. The press was operated alongside the vibrators until 1985 when the formers were shut down and the plant operated on 100 percent pressed anodes.

After modifying the press to produce the full size anode, a significant increase in cracking of pressed anodes in the reduction cells was observed. The problem became very apparent when the plant began operating on 100 percent pressed anodes. After extensive investigations, the cracking problem was resolved prior to plant conversion to larger (48 inches x 31.5 inches x 24 inches) vibrated anodes in 1990.

This paper discusses the investigations.

The Problem

Between 1986 and 1989, VALCO experienced an anode thermal shock cracking problem. Large chunks of anodes broke off mainly from the anode corners one to two days after setting in the cells. Figures 1 and 2 show the types of cracks observed. Approximately 80 - 90 percent of all cracks were of the type shown in Figure 1. The problem was cyclical, ranging in severity from 1 - 3 percent (Figure 3). Cracking occurred under all cell conditions, but was more severe in abnormal cells (with electrolyte temperatures above of 980° Cand above).

FIGURE 1

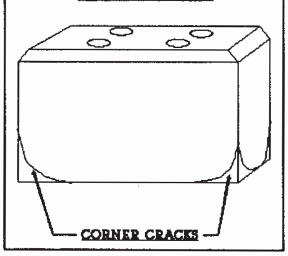
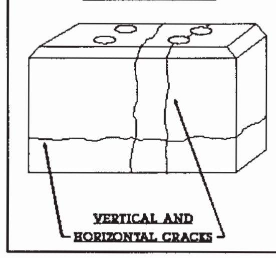


FIGURE 2



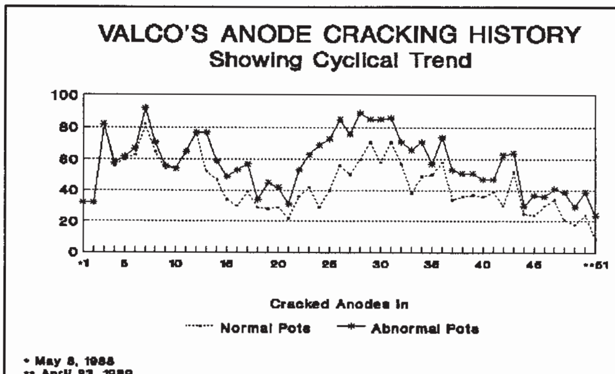


FIGURE 3

A. Tomsett and J. Johnson (Eds.), *Essential Readings in Light Metals*
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INVESTIGATION

Part 1 Investigations began with cataloging all changes that had occurred that could have affected anode quality. The following changes were identified:

- Coke Source Change

  Coke source changed from straight run Type A coke to VALCO's regular Type B coke blend.

- Pressed vs. Formed Anodes

  Anode block production changed from a combination of formed and pressed anodes to 100 percent pressed anodes.

- Pitch Level in Anode

  Pitch level in the green mix had increased from 15.6 - 15.8 percent to 16.0 percent level.

- Pressing Temperature

  Pressing temperatures had increased from the 118-122° Crange to 127-130° Crange.

- Butt Cleaning

  Butt cleaning conformance had decreased from 90 to 70 percent.

- Anode Baking Temperatures

  Conformance to 1080°C minimum finishing temperatures increased from 70 - 80 percent levels to 100 percent. Average bake temperatures increased from 1100° to 1120° C.

- Butts Screen Analysis

  Butts fraction screen analyses had generally shown smaller butts particle size.

Part 2 In Part 2 of the investigations, conditions were recreated as closely as possible to the original conditions to observe their effect on anode cracking. Other related parameters were also investigated; sample sizes were typically large, ranging from 2,500 - 10,000 anodes in each category. The more interesting results are reported below:

Type A Coke Pressed Anodes

The objective was to investigate the effect of coke source change on anode cracking.

Type A coke pressed anodes in green inventory of the same size, and manufactured with essentially the same anode formulation recipe, were baked and evaluated in the Potrooms for cracking.

Type A anodes showed 4.3 percent cracking versus 2.0 percent for pressed anodes containing Type B coke blend. This difference was significant at 95 percent confidence, confirming that the coke source change probably helped improve, rather than worsen, the anode cracking level.

Type A Coke Vibrated Anodes

The objective was to investigate the cracking tendency of vibrated versus pressed anodes.

Type A coke vibrated anodes in green inventory of the same size and manufactured with essentially the same anode formulation recipe were baked and evaluated in the Potrooms for cracking.

The vibrated, Type A coke anodes showed 1.3 percent cracking versus 4.3 percent for pressed, Type A coke anodes and 1.8 percent for pressed, Type B coke anodes. These differences were significant at 95 percent confidence, thereby establishing the superior resistance of vibrated anodes to thermal shock cracking.

Large Vibrated Anodes Test

As part of the preparation to convert the plant to larger vibrated anodes, a test was conducted using the larger anodes to help develop operating practices. During the test, the anodes were evaluated for thermal shock cracking.

Results showed 0.5 percent cracking on the test anodes versus 1.5 percent for regular pressed anodes. This further confirmed the superior resistance of vibrated anodes to thermal shock cracking.

Reduced Pitch Level in Mix

Results of initial investigative work into VALCO's anode cracking problem done at VALCO, Kaiser's Center for Technology, and R & D Carbon, in Switzerland, and suggestions from refractory experts indicated that excess pitch binder content could result in anode cracking in pots.

To verify this hypothesis, test anodes were produced with mix recipes containing pitch levels of 15.8 percent, 15.6 percent and 15.4 percent, and compared with regular anodes containing 15.9 percent pitch. Anodes were evaluated in the Potrooms for cracking.

Results were as follows:

% Pitch in Mix	% Anode Cracking
15.9	1.5
15.8	1.3
15.6	1.5
15.4	2.8

No significant change in anode cracking level was obtained until pitch level was reduced to 15.4 percent. At this point, a dramatic increase in anode cracking was recorded, as well as high anode airburn replacements.

Pitch content of 15.6 percent appeared to be the lowest level at which anodes with minimal cracking and airburn characteristics could be produced at VALCO.

VALCO's anode cracking problem did not appear to be due to excess pitch, but more likely to insufficient pitch.

Higher Pressing Pressure Anodes

The objective was to determine whether or not increasing anode pressing pressure would reduce anode cracking in cells.

Test anodes were produced with pressing pressure increased from 3000 to 3310 psi, baked and evaluated in the Potrooms for cracking.

Results showed no reduction in anode cracking or increase in densities.

Higher Fines Level Anodes

The objective was to determine whether or not increasing fines fraction level in anode would reduce anode cracking in the cells.

Test anodes were produced with fines fraction level in dry anode aggregate increased from 38 percent to 43 percent. Pitch level was raised from 15.6 to 16.0 percent. Anodes were baked and evaluated in the Potrooms for cracking.

Results showed a significant increase in anode cracking at 95 percent confidence level. Airburn replacement and dust in the bath also increased significantly.

These results were probably influenced by inadequate pitch content at the new fines level.

Anode Cracking by Location in Baking Pits

The objective was to determine whether or not excessive temperature gradients in anodes during baking were contributing to anode cracking.

Anodes coming out of the baking pits were identified by location in the pits and evaluated in the Potrooms for cracking.

Results showed no correlation between anode cracking and location in baking pit.

Reduced Anode Baking Temperature

The objective was to recreate the bake temperature levels attained during the period of low anode cracking.

Test anodes were produced with bake temperatures reduced by approximately 20° C. Bake temperature data were as follows:

	Test Anodes	Control Anodes
Average Temperature (° C)	1101	1119
Temperature Range (° C)	1065-1150	1080-1165

Results showed no change in anode cracking level; however, other anode quality parameters deteriorated significantly. Airburn and dust in the bath showed significant increases. Approximately 1.3 percent loss in current efficiency was recorded. Poorly baked anodes would not necessarily crack in cells, but resulted in a serious loss of operating efficiency.

Anode Cracking Versus Cell Condition

The effect of cell operating condition on anode cracking was evaluated. At VALCO, abnormal (warm) pots are defined as pots with electrolyte temperature of 980° Cand above.

Cracked anodes replaced in such cells were compared with crack replacements in normally operating cells for a period of about two years.

On the average, abnormal pots constituted 4.6 percent of all pots operating, but contributed to approximately 20 percent of all cracked anodes replaced.

Part 3 Laboratory Investigations

The objective of this part of the investigation was to identify what physical properties in the anodes were contributing to the thermal shock cracking problem.

Two inch diameter baked anode core samples of various categories of VALCO anodes were taken and contracted to R & D Carbon, in Switzerland, for evaluation[2]. Duplicate samples were sent to Kaiser's Center for Technology in Pleasanton, California, for parallel evaluation.

The categories of anodes were:

X - Anodes used prior to start of cracking problem
W - Cracked anodes removed from pots
C - Anodes used during period of low cracking levels (about 1 percent)

Analyses results from R & D Carbon and Kaiser's CFT were essentially the same. Results of the R & D Carbon evaluation are shown in Table 1.

It is evident that the physical properties normally associated with thermal shock cracking, namely Flexural strength, Thermal Conductivity, Coefficient of Thermal Expansion, Apparent Density and Youngs Modulus were in the normal range. The variability in these properties in the cracked anode group (W) gave cause for concern.

We concluded that the traditional physical anode properties did not explain VALCO's anode cracking problem.

Part 4 Focus on Green Mill Operation

Part 4 of the investigations focused on the Green Mill operations.

Eight critical variables in the Green Mill were identified and closely monitored by the Process Control Department to determine the extent of variability, in addition to existing monitoring activities.

TABLE 1

PROPERTIES OF ANODES	UNITS	C-ANODES		X-ANODES		W-ANODES		TYPE ANODES	
		x	2σ	x	2σ	x	2σ	x	2σ
APP.DENSITY	g/cm^3	1.57	.05	1.58	.04	1.55	.06	1.56	.02
ELECT.RESIST.	μΩm	52	6	53	5	55	10	55	4
FLEX.STRENGTH	10^5 N/m^2	129	45	124	43	109	62	110	30
COMP.STRENGTH	10^5 N/m^2	446	142	492	86	433	158	440	120
REACTIVITY REST	%	86	10	83	15	--	--	83	8
DUST	%	6	10	9	8	--	--	11	5
R CO_2	%	8	2	8	10	--	--	11	5
DENSITY, XYLENE	g/cm^3	2.087	.02	2.086	.04	2.087	.04	2.07	.03
AIR PERM.	nPm	1.5	1.2	1.2	0.8	1.6	1.5	1.0	0.5
THERMAL COND.	W/mK	4.7	1.1	4.0	0.9	3.8	1.3	3.5	0.8
E-MODULUS	10^8 N/m^2	60	8	61	8	50	9	60	8
C.T.E.	$10^{-6}/K$	3.8	0.5	3.5	0.5	3.5	0.3	3.8	0.4

The variables were: Coke Bulk Density, Particle Size Distribution of Butts, Coarse, Fines fractions and Ball Mill Product, Anode Mix Temperature, Anode Pressing Temperature and Green Anode Density.

After several months of monitoring, the problem was evident. The particle size distribution of aggregate materials, especially the fines, was much more variable than indicated by the Green Mill sampleman's analysis (Figures 4 and 5).

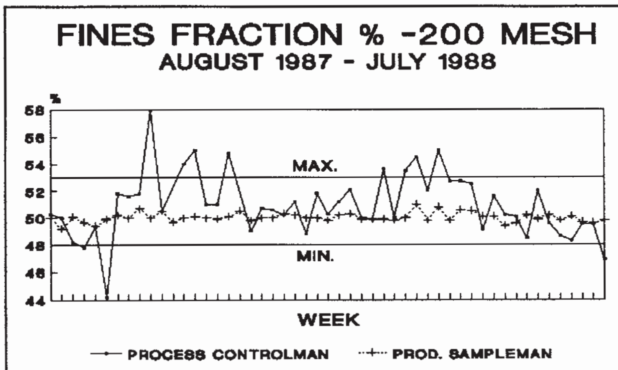

FIGURE 4

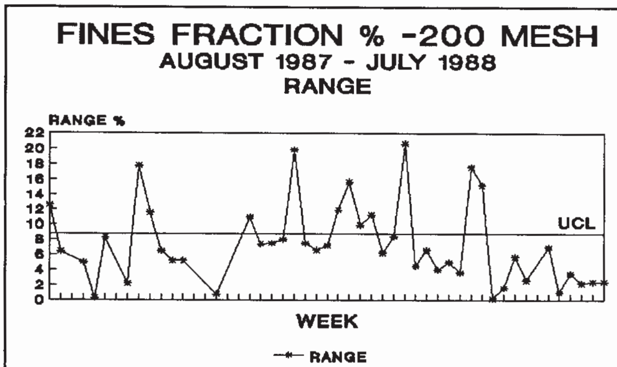

FIGURE 5

Causes of the variability included the following:

- The ball mill feed control system was drifting.
- Addition of nuisance dust (from baking and rodding operations) to ball mill feed was poorly controlled.
- The Green Mill sampleman's screening equipment was obsolete.

- The sampleman's screening techniques needed improvement.

As a result of these problems, ball mill feed adjustments (or lack of it) were being decided, based on erroneous data which in turn affected anode quality adversely.

Corrective Actions

- The ball mill feed systems were rehabilitated.
- Addition of nuisance dust to ball mill feed was regulated to a steady state.
- The sampleman's equipment was overhauled.
- Samplemen were retrained in the theory and practice of material sampling and screening techniques.
- Fines material was drawn from all fines fraction storage bins simultaneously during anode production to improve blending.
- The fines weigh scale feed system was modified to minimize weighing errors.

Implementation of corrective actions was essentially completed by January, 1989.

Results

The effect of the corrective actions on the fines fraction particle size distribution can be seen in Figures 6 and 7. The following results were achieved.

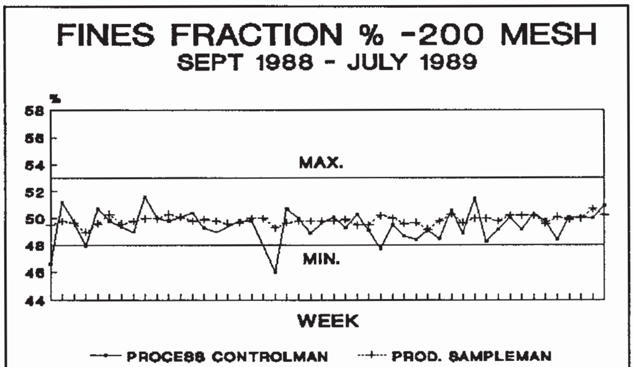

FIGURE 6

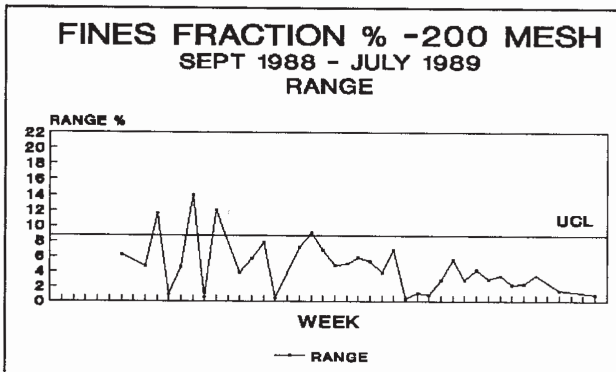

FIGURE 7

- Good agreement was attained between Process Control Department and the Samplemen in the fines screen analyses (Figure 6).
- There was significant reduction in variability of fines particle size distribution (Figure 7).
- Anode cracking declined steadily to relatively insignificant levels (Figure 8).

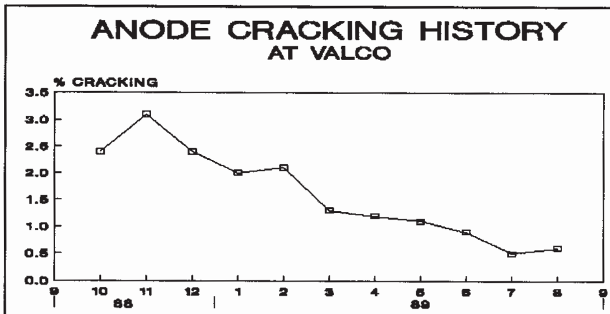

FIGURE 8

Anode formulations typically contain about 30 percent fines. The surface area of this fines represents about 95 percent of the total surface of the dry aggregate[3].

Wide variations in fines particle size distribution therefore results in large changes in surface area requiring comparable changes in pitching. Since these variations were not previously recognized and controlled at VALCO, serious fluctuations in anode quality occurred that subsequently led to excessive cracking.

Re-evaluation of Anode Physical Properties

After implementation of corrective actions, baked anode core samples were taken again when cracking levels were very low (July, 1989) and sent to Kaiser's Technology Center at Mead, Washington, for re-evaluation of physical properties and to identify any physical properties that might have been causing the cracking problem.

The results are shown compared with the previous R & D Carbon analyses in Table 2.

TABLE 2

PROPERTIES OF ANODES	UNITS	C-ANODES		X-ANODES		W-ANODES		LTS-ANODES		TYPE ANODES	
		x	2σ	x	2σ	x	2σ	x	2σ	x	2σ
APP.DENSITY	g/cm^3	1.57	.05	1.58	.04	1.55	.06	1.54	.03	1.56	.02
ELECT.RESIST.	$\mu\Omega m$	52	6	53	5	55	10	55	4	55	4
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COMP.STRENGTH	10^5 N/m^2	446	142	492	86	433	158	--	--	440	120
REACTIVITY REST	%	86	10	83	15	--	--	--	--	83	8
DUST	%	6	10	9	8	--	--	--	--	6	4
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THERMAL COND.	W/mK	4.7	1.1	4.0	0.9	3.8	1.3	2.6	0.5	3.5	0.8
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C.T.E.	$10^{-6}/K$	3.8	0.5	3.5	0.5	3.5	0.3	2.5	0.2	3.8	0.4

Again, apart from a lower coefficient of thermal expansion on the low thermal shock anodes, not much can be inferred from the data.

Conclusion

From the investigation of VALCO's anode cracking problem, the following conclusions were made:

* VALCO's anode cracking problem was caused by changes in pitch demand due to large variations in the fines surface area.

* Anode cracking was most likely caused by insufficient rather than excess pitch in the anode.

* With any given set of raw materials and anode formulation, pressed anodes are more susceptible to thermal shock cracking than vibrated anodes.

* Cell operating stability affects thermal shock cracking of anodes. The more stable the operations, the less tendency to crack anodes.

* Traditional anode properties do not appear to correlate well with thermal shock cracking. However, Kaiser has developed testing equipment to directly measure the thermal shock propensity of anodes.

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