CB15 - Improving Prebaked Anodes Electrical Resistivity in Aluminium Bahrain (ALBA)

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Abstract

Carbon anodes are used in electrolysis process for production of aluminum. The quality of anodes has direct impact on aluminium production cost, carbon and energy consumption and environmental emissions. One of the critical properties of anodes is electrical resistivity. Low electrical resistivity anodes help to reduce energy consumption, while high electrical resistivity anodes can lead to squeeze anode-cathode distance (ACD) in electrolytic cells leading to anodes spikes formation. Anode electrical resistivity depends on raw material quality, dry aggregate granulometry, mixing energy and anode forming parameters. The presence of cracks and pores in anodes increases the anode electrical resistivity. Therefore, it is important to know how the pores and cracks form during the anode production so that the necessary actions could be taken This paper shares the experiences of Aluminium Bahrain (ALBA) in reducing electrical resistivity (ER) from 58 - 60 µΩm to below 55 µΩm consistently. This was carried out by conducting various trials to investigate the impact of different anodes production process parameters such as vibration time, counter pressure, vacuum, forming temperature, coke temperature, granulometry, butts % in recipe, fire cycle, heating gradient used during baking to reach to ultimate objectives.

Keywords: Carbon anodes, Quality of anodes, Cracks and pores, Electrical resistivity, Process parameters

1. Introduction

Aluminum Bahrain (ALBA), the world's largest single-site aluminum smelter ex-China with aluminum production of more than 1.6 million tonnes (2022) is known for its technological strength and innovative strategies. ALBA always striving to maximize the productivity and reduce resources consumption such as carbon and energy in-order to reduce impact over environment, to improve safety and to improve overall business.

With meticulous approach, ALBA progressively achieves its potline current creep plan successfully over the past many years.

Potline 6 was commissioned in 2019 based on DX+ Ultra technology with original design to operate at 460 kA. Presently this potline is operating at 478 kA which is more than 4 % of its design in just two years. One of critical elements to operate potlines successfully at higher amperage is anodes quality. ALBA Potline 6 performance was found quite sensitive to anode electrical resistivity probably due to high anodes current density as compared to other potlines.

Potline performance impacted negatively at higher ER close to 60 µΩm. Hence, a team was formed to optimize the process parameters to bring ER from level of 60 to below 55 µΩm.

Anode electrical resistivity depends on raw material quality, dry aggregate granulometry, mixing energy, anode forming parameters and heating rates in Kiln. The presence of cracks and pores in anodes increases the anode electrical resistivity. This paper describes work done by ALBA to reduce ER from 60 µΩm to 55 µΩm by optimizing granulometry and other anode production parameters. This paper also covers brief details of literature survey, and technical papers referred to conduct trials and make process changes to reduce anode electrical resistivity.

ALBA Paste plant 4 commissioned in 2019, catering anodes to Potline 6, it equipped with latest art of technology having Rhodax® crusher for the preparation of dry aggregates (Figure 1) of paste recipe with two fractions grains and fines, IMC$^{®}$ process (Intensive Mixing Cascade) which relates to the preparation of the Paste mixing and cooling in Eirich cooler / mixer (Figure2) and Xelios™ vibrocompactor which relates to anode forming.

In this plant two fraction grain (0.3 - 30 mm) and fine (< 0.03 mm) being used for green anode production. The process of forming grain and fine fractions is shown in Figure 1.

All the dry mix material together feed to the Rhodax® crusher, output of crusher goes to Mogensen screen to classify the material based on particle size. Particles > 50 mm from the Mogensen screen goes to the reject bin, over size fraction (30-50 mm) will go to the recirculation loop of the Rhodax® crusher. Particles + 0.3 - 16 mm goes to the grain silo and < 0.3 mm goes to further grinding to get the fine fraction. Particles < 3 mm passes through the Turbo classifier 1 (TSV1) and then TSV 2, the output of TSV 2 stored in the fine fraction silo and reject will goes to ball mill for further grinding.

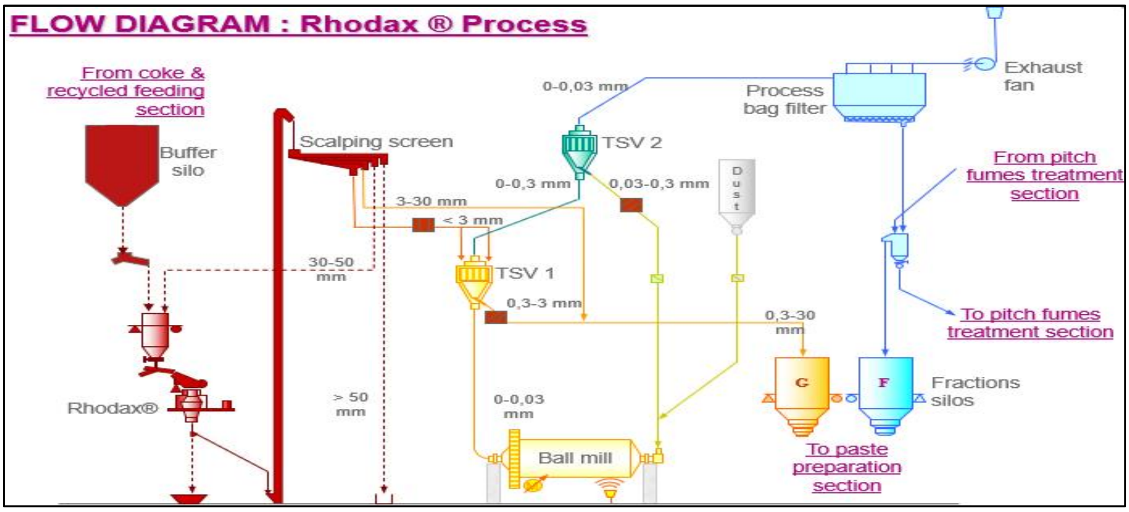

Figure 1. Dry aggregate preparation line.

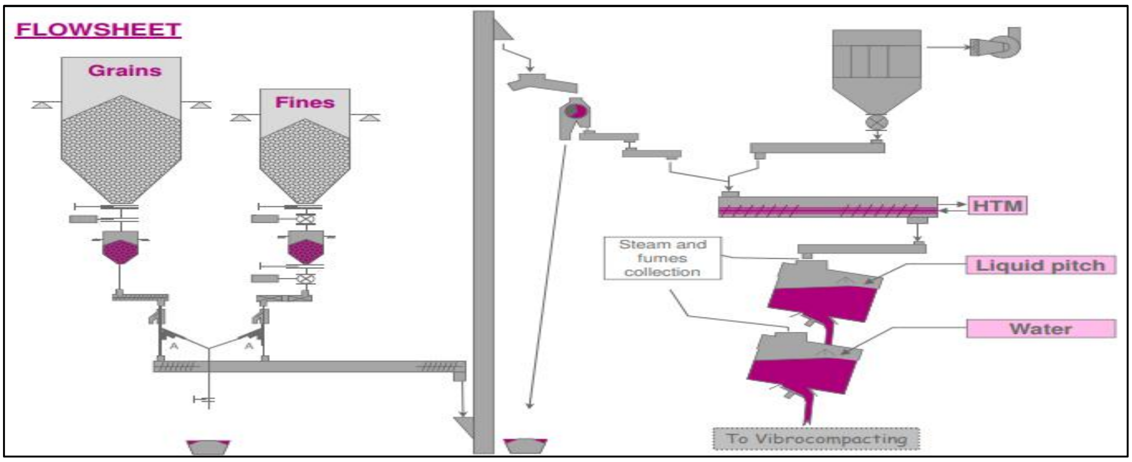

Figure 2. Paste mixing and anode forming line.

2. Anode Performance in ALBA Potline 6

Anode performance in potline depends upon bake anode quality and its consistency. One of the critical properties of anodes is electrical resistivity. Low electrical resistivity anodes help to reduce energy consumption, while high electrical resistivity anodes can lead to squeezing of ACD [1] in electrolytic cells which can result into anodes spikes formation. ALBA Potline 6 experienced deterioration in performance at anode electrical resistivity 60 µΩm.

3. Electrical Resistivity for Pot Line 6 Anodes

Anode core sample are being collected after baking in Kilns. These samples are being analyzed in laboratory for electrical resistivity as per ISO 11713 using equipment RDC150.

Electrical resistivity for Potline 6 anodes increased significantly to 60 µΩm during May 2022 to December 2022. A team consists of carbon & calciner operation, process and maintenance was formed to reduce ER below 55 µΩm. Based on experience, literature survey and technical papers (Reference list attached), a series of trials was carried out to reduce ER. As common observation was cracks in core samples (Figure 4) and low flexural strength (Figure 3). The focus was to optimize process parameters to minimize presence of internal cracks in baked anodes. It is well known that high vibration time, counter pressure, ultra fines in dry aggregate (-32 microns fraction in fines) and high anodes pre-heating rate can cause cracking and high ER in anodes. Initial trials were focused to optimize green anode forming parameters, ultra fines in dry aggregate and pre-heating rate during anode baking.

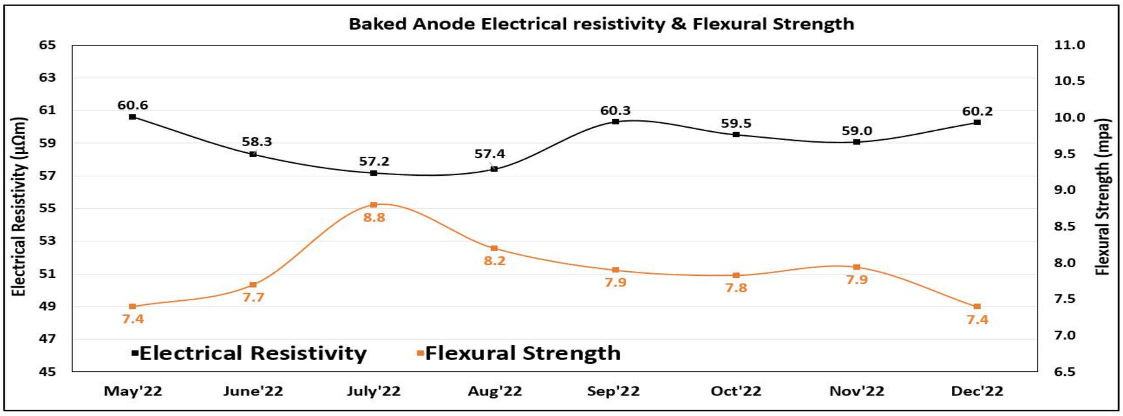

Figure 3. Baked anode electrical resistivity and flexural strength.

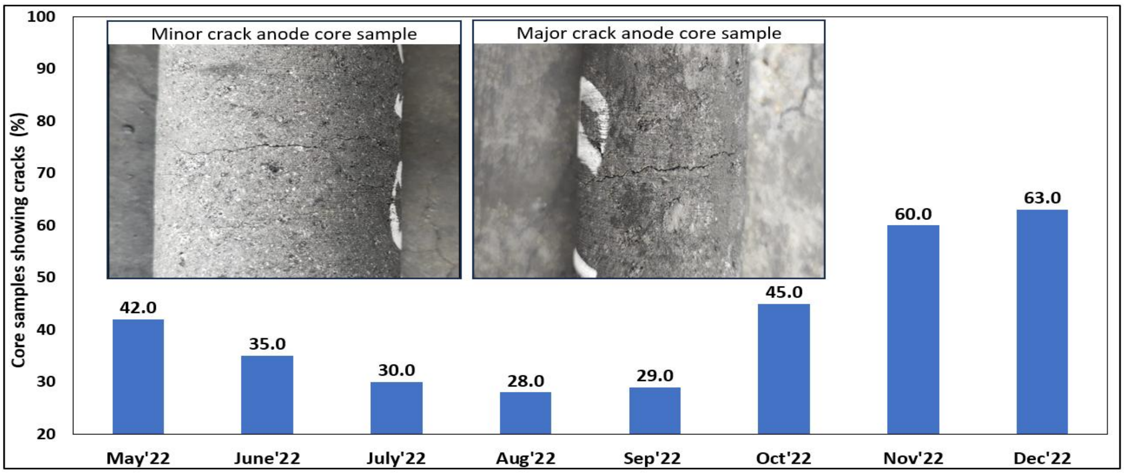

Figure 4. Core samples showing cracks (Visual inspection).

4. Optimization of Process Parameters

The critical parameters were identified which can affect the electrical resistivity of baked anodes and listed below:

- Anodes Heating Rate During Baking.
- Vibrocompaction Time.
- Counter Pressure.
- Vacuum.
- Granulometry.

One change at a time was applied keeping other parameters fixed to evaluate the impact on electrical resistivity.

4.1 Anodes Heating Rate During Baking

Majority of time anode heat up rates during baking were lower than 14 °C/h, irrespective of fire cycle. That is the reason no significant difference was observed in ER at 24 h and 28 h fire cycle as shown in Figure 5. There were no visible vertical cracks in core samples or baked anodes observed, most of the cracks were internal and horizontal in direction, indicating high ER issue was more related to paste plant process.

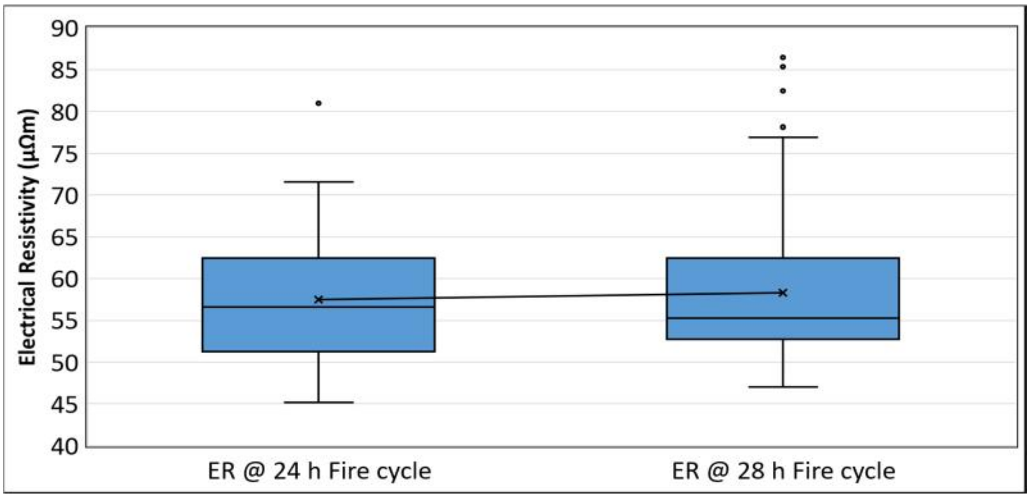

Figure 5. Baked anode electrical resistivity vs fire cycle.

4.2 Vibrocompaction Time

Trial batches of green anodes produced at vibration time of 50 s, 55 s and 60 s. Anodes were baked and core sample results shown that the mean value of Electrical resistivity was lower at 50 s vibration time as compared to 55 s and 60 s vibration time as shown in Figure 6. There was not any significant impact observed on anode density during the trial.

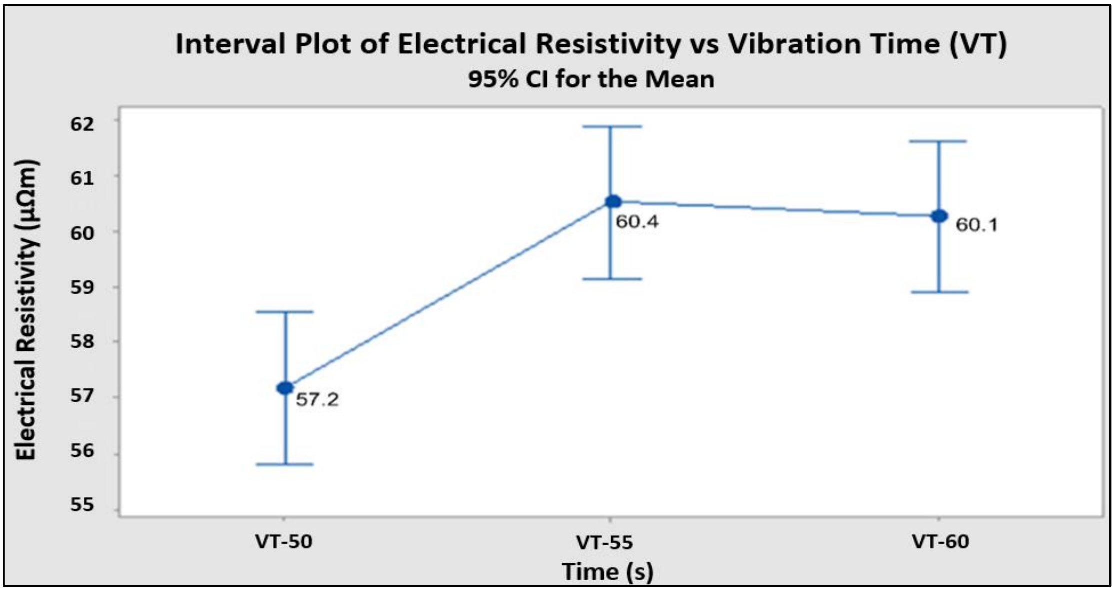

Figure 6. Baked anode electrical resistivity vs vibration time.

4.3 Counter Pressure

During green anode forming two forces are acting, one is the compaction pressure from the top which known as counter pressure and other one is the vibration forces which is generated through eccentric mass provided in the vibro table.

As high counter pressure can cause internal cracks, trial batch of anodes was produced by reducing counter counter pressure from 0.22 to 0.16 MPa (2.2 to 1.6 bar), but no impact was observed as shown in Figure 7.

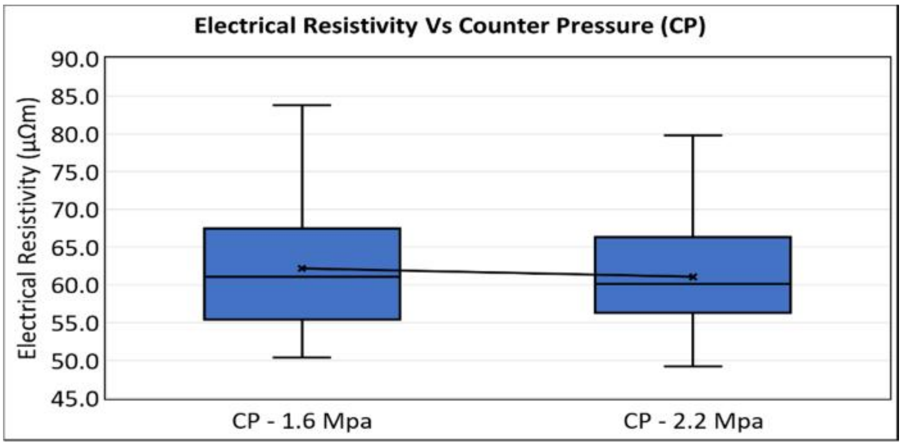

Figure 7. Baked anode electrical resistivity vs counter pressure.

4.4 Impact of Vacuum on Electrical Resistivity

Emirates Global Aluminium achieved good results in ER by switching off vacuum. [3]

Trial batches of green anodes produced by varying vacuum pressure from less than -20 kPa (-200 mbar) to greater than -25 kPa (-250 mbar). Anodes were baked and core sample results shown increase in Electrical resistivity as shown in Figure 8.

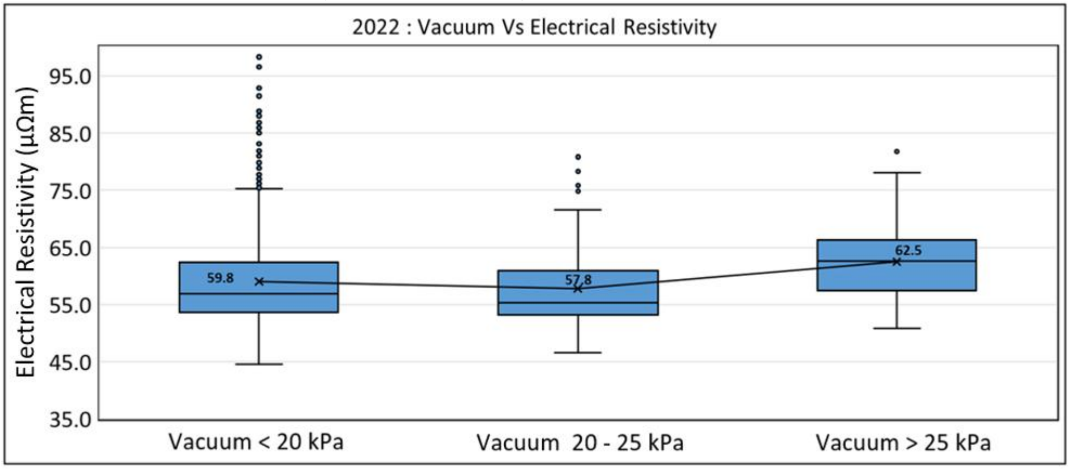

Figure 8. Vacuum vs baked anode electrical resistivity.

In addition to above trials ultra fines in dry aggregate were optimized, mixing and cooling energy improved, coke preheater temperature increased and forming temperature was also reduced to achieve target electrical resistivity.

Even with all above trials and optimization, ER remained at high level of 59-60 µΩm. (Table1)

Table 1. Results of paste plant process optimization.

Process Parameters	**Units**	**Before Optimization**	**After Optimization**
Vibration Time	s	60	50
Counter Pressure	MPa	0.2	0.15
Vacuum	kPa	> 25	< 20
Coke temperature	°C	170	180
Forming Temperature	°C	165	165
Mixing + Cooling Energy	kWh/t	10.4	10.4
Ultra Fines in Dry Aggregate (-32 microns)	%	14	13.5 - 14.5
Fines in Recipe	%	22	21
Pitch	%	13.2	13.2
Results			
Micro cracks in core samples	%	19	18
Flexural Strength	MPa	8	8
Electrical Resistivity	**µΩm**	**60**	**59 - 60**

ER continued to be high even with optimization of forming parameters. Hence, ALBA decided to introduce changes in granulometry to improve ER.

4.5 Impact of Granulometry on Electrical Resistivity: -

In depth analysis of each fraction of Paste plant 4 dry aggregate was done. Statistical analysis showed strong correlation between +16 mm particle size in dry aggregate and baked anode ER similar observations have been reported [4]

+16mm in dry aggregate shown variation from 1 % to 7%. Best ER was achieved when +16mm in dry aggregate was < 2 % as shown in Figure 9. So, it was decided to take actions to reduce the +16 mm particle size in dry aggregate to minimum level. Similar observations have been reported [5].

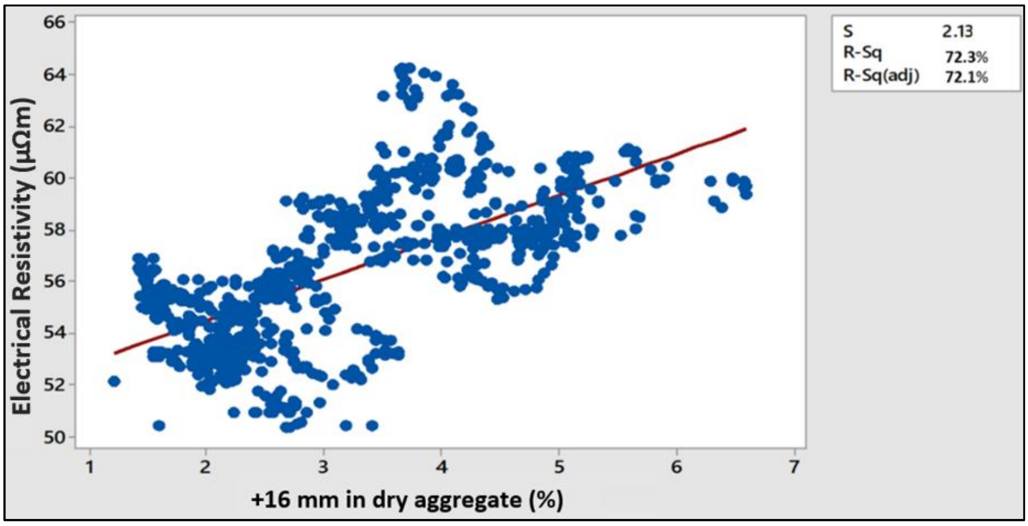

Figure 9. Baked anode electrical resistivity vs +16 mm particle size in dry aggregate.

In Paste plant Rhodax® crusher technology butts and coke are crushed together and classified through Mogensen screen (Figure 1). Grain size distribution (GSD) governed by input of butts & coke sizes, Rhodax speed, Rhodax crusher gap and Mogensen screen mesh size. Rhodax speed and gap were fixed to achieve maximum crushing power. Following actions decided to reduce +16mm particle size in dry aggregate: -

1. Replacement of worn out Rhodax liners.
2. Reduce butt's particle size by improving crushing efficiency.
3. Reduce Mogensen (Scalping) screen cut size from 30mm to 18mm.

With first two actions the +16 mm particle size in dry aggregate reduced from 6-7% to 3-4 % but not reached to desired level. Then finally Mogensen screen cut size changed from 30 mm to 18 mm. With this change in mesh recirculation of oversize material to Rhodax® crusher increased tremendously. To manage the recirculation material, butts in recipe was reduced from 30 % to 20 %. Dry aggregate samples collected to analyze the GSD and observed that +16mm particle size in dry aggregate reduced from 3 % to 0 %. Overall GSD also shifted towards finer side. +10 mm in dry aggregate dropped from 11 % to 9 % and the -10 mm to +4.75 mm reduced from 16 % to 14 % [6]. The crushed coarse particles distributed uniformly to fractions below 4.75 mm to + 0.3 mm. as shown in Figure 10.

The green anodes produced with improved dry aggregate granulometry were baked and anode core samples were collected. No cracks observed in core samples. These core samples were analyzed which showed increase in the flexural strength from 8.0 to 10.0 MPa. So, corresponding ER reduced significantly from 60 µΩm to 55 µΩm. as shown in Figure 11.

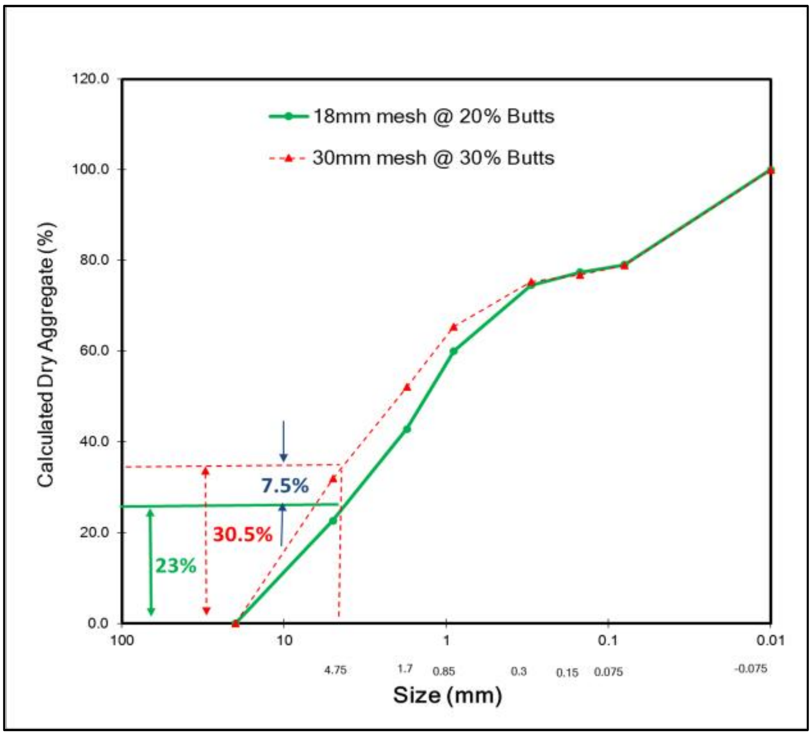

Figure 10. Dry aggregate curve.

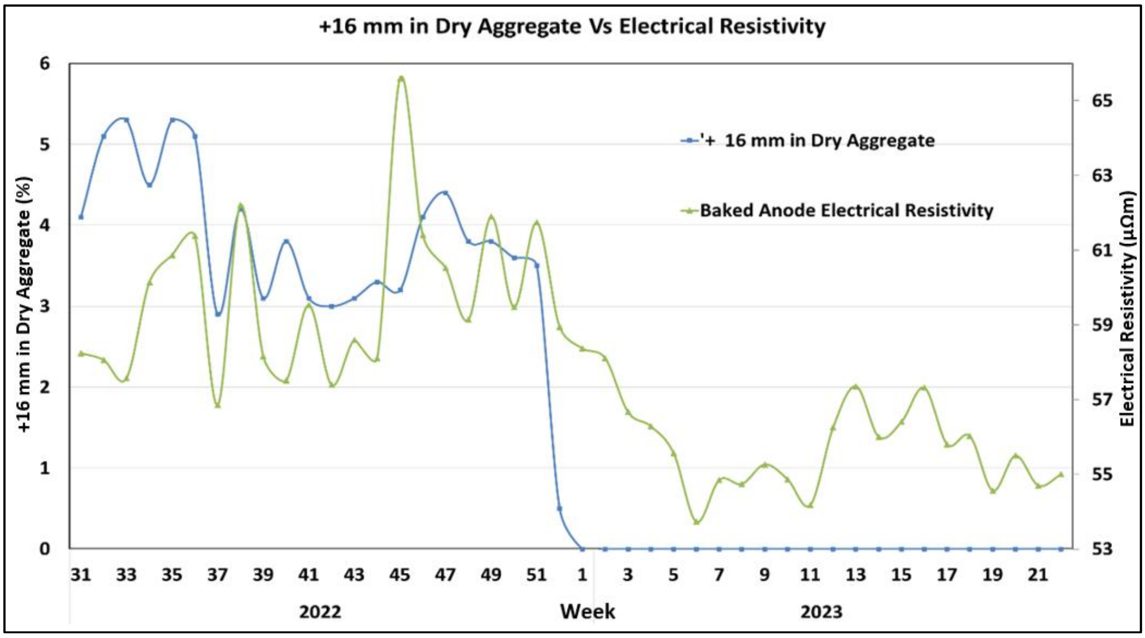

Figure 11. +16mm in dry aggregate vs electrical resistivity.

4.6 Calcined Petroleum Coke Quality

The variations in both real density and L_C of calcined coke plays important role in anodes baked properties [7]. Hence, during the trial period, the variation was reduced to minimum possibles at calciner as shown in Figure 12 with following actions.

- More control on calcination level by frequent measurement of coke real density, L_C and action on fuel injection.
- Consistency in green coke blending.

- The coke stored in separate silo based on its quality.

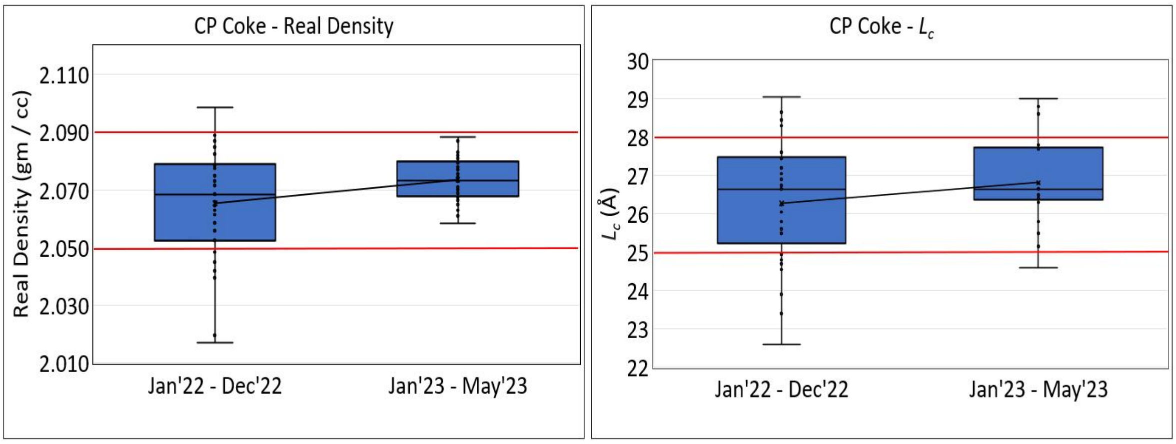

Figure 12. CP coke real density and L_C.

5. Results and Discussion

Electrical resistivity reduced significantly after change in granulometry. Initial focus was on vibration time, counter pressure settings, coke preheating temperature, forming temperature, mixing energy, cooling energy, vacuum settings and ultrafine in dry aggregate, etc., to reduce internal cracks in anodes. Despite rigorous optimization work done in Paste Plant and Kilns no significant change was observed in core sample cracks, baked anode flexural strength and electrical resistivity.

Crushing coke and butts more in Rhodax® crusher and reduced coarser particles size resulted in reduction in core sample cracks (Figure 14), increased flexural strength and baked anode electrical resistivity as shown in Figure 13.

Butts in recipe sacrificed to sustain Rhodax® crusher operation smoothly at reduced mesh size. Electrical Resistivity was reduced from 60 to 55 µΩm by more crushing of butts and coke and reduction in coarser particles in dry aggregate. (Table 2).

By eliminating the +16mm particles, the number of particles in +4.75mm to -16mm increases. therefore, the anode matrix become more uniform and it has reduced propagation of internal cracks as well as it has improved the segregation of the baked anodes.

Table 2. Results of Paste Plant process optimization.

Process Parameters	**Units**	**Before Optimization**	**After Optimization**
+16mm in Dry Aggregate	%	3.5	0
+10mm in Dry Aggregate	%	11	9
-10mm to +4.75mm in Dry Aggregate	%	16	14
Cumulative of '+4.75 mm in Dry Aggregate	%	30.5	23
Butts in Recipe	%	30	20
Results			
% of core samples cracks	%	19	0
Flexural Strength	MPa	8	9.7
Electrical Resistivity	µΩ m	60	55

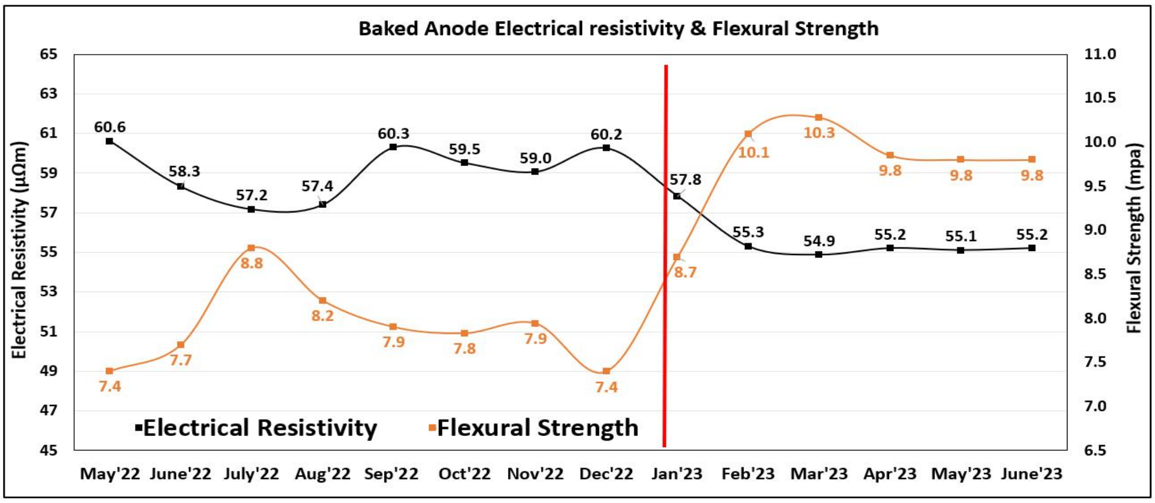

Figure 13. Baked anode electrical resistivity and flexural strength.

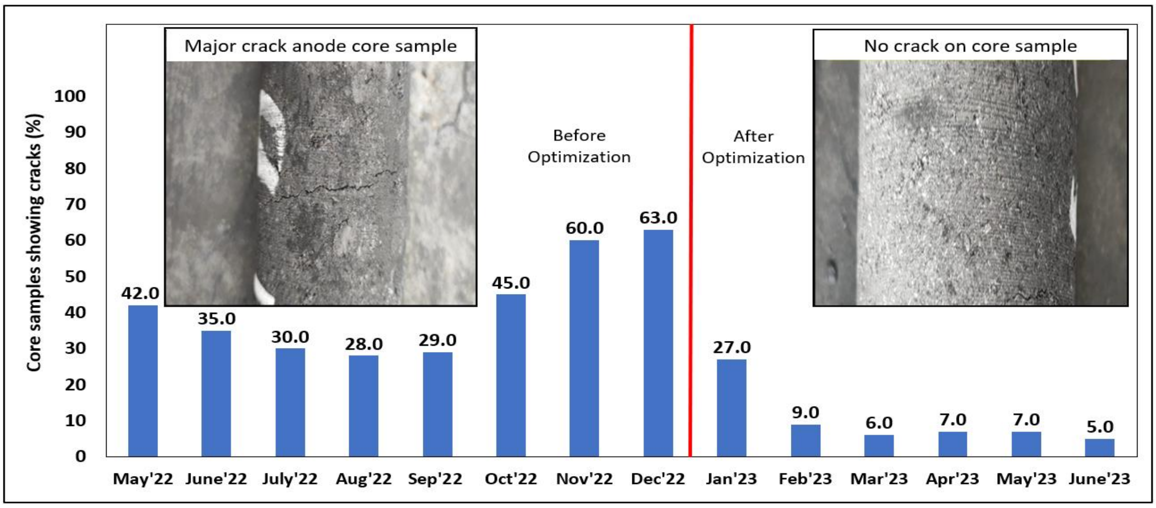

Figure 14. Core samples showing cracks.

6. Conclusions

Potline 6 performance is sensitive to baked anode electrical resistivity. Potline 6 performance started to deteriorate at electrical resistivity close to 60 µΩm. Higher baked anode electrical resistivity was bottlenecked to increase Potline 6 current beyond 475 kA.

Initial process parameters optimization was carried out in paste plant did not show significant improvements in baked anode electrical resistivity. Electrical resistivity shows significant improvement once coarse particles in dry aggregate reduced by changing in Mogensen mesh size and optimizing butts in recipe to cope with recirculation of oversize of Rhodax® crusher. The following changes were introduced.

- +16 mm was reduced from 4 % to 0 %
- -16 mm to +10 mm from 11 % to 9 %
- -10 mm to +4.75 mm from 16 % to 14 %
- Cumulative of +4.75 mm reduced from 30.5 % to 23 %

Baked anode electrical resistivity improved from 60 to 55 µΩm reflected in Potline 6 performance as anode spikes formation in pots reduced significantly.

7. References

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